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SUBMITTAL OF PRELIMINARY DESIGN PACKAGE (30%) FOR THE ON-SITE DISPOSAL FACILITY - NOTE: CONTAINS DESIGN CRITERIA, DESIGN CALCULATIONS (VOLS 1-3), TECHNICAL SPECIFICATIONS AND DESIGN DRAWINGS - 5 BINDERS AND SET OF DRAWINGS

12/20/95

DOE-0344-96
DOE-FN EPAS
~~2500~~ 2324
DESIGN

Department of Energy
Fernald Environmental Management Project
P. O. Box 398705
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DEC 20 1995
DOE-0344-96

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Region V - SRF-5J
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Mr. Tom Schneider, Project Manager
Ohio Environmental Protection Agency
401 East 5th Street
Dayton, OH 45402-2911

Dear Mr. Saric and Mr. Schneider:

SUBMITTAL OF PRELIMINARY DESIGN PACKAGE (30%) FOR THE ON-SITE DISPOSAL FACILITY

The Department of Energy, Fernald Area Office (DOE-FN) is pleased to submit the enclosed Preliminary Design Package (30%) for the On-Site Disposal Facility. This package includes: Design Criteria, Design Calculations (Volumes 1, 2 and 3), Technical Specifications and Design Drawings.

If you have any questions or comments, please contact Mr. Rod Warner at (513) 648-3156.

Sincerely,

for Susan M Peterman
Johnny Reising
Fernald Remedial Action
Project Manager

FN:Jalovec

Enclosure: As Stated

Recycled and Recyclable

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DESIGN CRITERIA PACKAGE

ON-SITE DISPOSAL FACILITY

REVISION B
DECEMBER 1995

United States Department of Energy
Fernald Environmental Management Project
Fernald, Ohio

prepared by

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Fernald Environmental Restoration Management Corporation
Subcontract 95PS005028

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PRELIMINARY DESIGN CRITERIA PACKAGE ON-SITE DISPOSAL FACILITY

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DECEMBER 1995
REVISION B

United States Department of Energy

Fernald Environmental Management Project
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DESIGN CRITERIA PACKAGE
ON-SITE DISPOSAL FACILITY
FERNALD ENVIRONMENTAL MANAGEMENT PROJECT

ISSUED FOR USE

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ACRONYM LIST

ACI	American Concrete Institute
ALARA	As Low As Reasonably Achievable
ALR	Action Leakage Rate
ANSI	American National Standards Index
ARAR	Applicable or Relevant and Appropriate Requirement
AASHTO	American Association of State Highway and Transportation Officials
ASCE	American Society of Civil Engineers
ASTM	American Society of Testing and Materials
AWWT	Advanced Wastewater Treatment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFC	Certified for Construction
CFR	Code of Federal Regulations
CSI	Construction Specifications Institute
CQA	Construction Quality Assurance
DCP	Design Criteria Package
DOE	United States Department of Energy
E&S	Erosion and Sediment
FEMP	Fernald Environmental Management Project
FERMCO	Fernald Environmental Restoration Management Corporation
GCL	Geosynthetic Clay Liner
LCS	Leachate Collection System
LDS	Leak Detection System
LTS	Leachate Transmission System
NEC	National Electrical Code
O&M	Operations and Maintenance
OAC	Ohio Administrative Code
ODOT	Ohio Department of Transportation
OEPA	Ohio Environmental Protection Agency
OSDF	On-Site Disposal Facility
OU2	Operable Unit 2
OU5	Operable Unit 5
RCRA	Resource Conservation and Recovery Act
RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of Decision
SCS	Soil Conservation Service
SDR	Standard Dimension Ratio
SDRI	Sealed Double-Ring Infiltrometer
UMTRA	Uranium Mill Tailings Remedial Action
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
WAC	Waste Acceptance Criteria

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APPENDIX C: ARARs FOR OPERABLE UNIT 2
APPENDIX D: ARARs FOR OPERABLE UNIT 5
APPENDIX E: FERMCO BASELINE OSDF COST ESTIMATE
APPENDIX F: IMPACTED MATERIAL VOLUMES AND SCHEDULE FOR OSDF DISPOSAL

SECTION 1

1. GENERAL DESCRIPTION

1.1 Purpose and Organization

1.1.1 Purpose

This Design Criteria Package (DCP) identifies functional requirements and associated performance requirements that will be used as the basis for design of the Fernald Environmental Management Project (FEMP) On-Site Disposal Facility (OSDF). The conceptual design of the OSDF was developed as an alternative in the Operable Unit 2 (OU2) feasibility study and identified as the selected remedial alternative in the OU2 Record of Decision (ROD) [U.S. Department of Energy (DOE), 1995c].

On-site disposal of impacted material is also the preferred alternative for Operable Unit 3 and Operable Unit 5 at the FEMP. The final Records of Decision for these operable units are anticipated in July 1996 and December 1995, respectively. DOE intends to build only one On-Site Disposal Facility; therefore, the disposal facility will be designed to accommodate all or any portion of the total volume of impacted material resulting from the remediation of Operable Units 2, 3, and 5. The total volume from these operable units is estimated to be 2.5 million cubic yards (1.9 million cubic meters) bank/unbulked.

The construction, filling, and closure of the OSDF is scheduled to occur over a period of approximately seven years, as described in the Accelerated Remediation Plan [$276 million case]. However, due to the potential for variations in funding (which would lead to variations in the pace of remedial action activities), the OSDF must be designed to be constructed, filled, and closed in phases for up to 25 years, with the possibility of closure on an interim basis should it be required.

The design approach for the OSDF, as well as the other portions of the operable unit selected remedy, are presented in the document, "*Final Remedial Design Work Plan for Remedial Actions at Operable Unit 2*" [DOE, 1995d]. The design will be implemented in the following three phases:

- *Phase 1:* design of an impacted material haul road from the south field and inactive and active fly ash pile areas to the OSDF:

- *Phase 2:* design of the OSDF; and

- *Phase 3:* design of the excavation and restoration of the waste unit areas.

This DCP addresses design activities associated with Phase 2 of the *Final Remedial Design Work Plan for Remedial Actions at Operable Unit 2*. The DCP provides criteria for the design of each element of the OSDF that is located within the OSDF battery limit. The elements in the OSDF battery limit include the OSDF structure, soil liner test pads, perimeter drainage swales, roads, berms, temporary and permanent surface-water management and erosion control features, and temporary construction features such as soil stockpile areas, impacted material staging areas, personnel and equipment decontamination facilities, and other features. Other design packages consistent with the integrated approach to FEMP remediation will be prepared for features of the OSDF that are to be located beyond the battery limit, such as the forcemain from the leachate transmission lift station manhole to the Advanced Wastewater Treatment (AWWT) facility. "Design interfaces" exist for those locations where a design component crosses the battery limit.

1.1.2 Organization

This DCP is organized as follows.

- The remainder of Section 1 presents additional information on the project scope and design.

- In Section 2, specific design criteria for each component of the OSDF are presented.

- In Section 3, the design deliverables are identified and brief descriptions of the contents of the deliverables are described.

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1.2 Project Scope

1.2.1 Introduction

The purpose of this section of the DCP is to briefly describe the major design steps for the OSDF elements described in Section 1.1 above. These steps include, but are not limited to: finalization of this DCP; preparation of preliminary (30%), intermediate (60%), pre-final (90%), and final (100%) design packages; preparation of a certified-for-construction (CFC) package; development and implementation of a soil liner test pad program; development and implementation of a geomembrane liner compatibility study; and interface activities.

1.2.2 Design Steps

The major design steps for the OSDF project are summarized below.

- *Preparation of Design Criteria Package.* This DCP identifies the criteria that will be used to design the OSDF.

- *Development and Implementation of Soil Liner Test Pad Program.* The soil liner test pad program will be used to evaluate the performance of candidate materials and construction methods for the clay components of the liner and final cover systems of the OSDF.

- *Development and Implementation of Geomembrane Liner Compatibility Study.* The geomembrane liner compatibility study will be used to evaluate the durability characteristics of the geomembrane materials that will be used in the liner and final cover systems of the OSDF.

- *Preparation of Preliminary Design Package.* The preliminary design package will be prepared in a manner that addresses the design criteria identified in this DCP and that illustrates the concepts of the design for review by DOE, USEPA, and OEPA.

- *Preparation of Intermediate Design Package.* The intermediate design package will contain the same elements as the preliminary design package, plus: (i) revisions based on USEPA, and OEPA comments on the preliminary design; (ii) revisions based on the results of the value engineering session; and (iii) notes added to the preliminary design drawings that are necessary to describe the proposed plan for construction of the OSDF.

- *Preparation of Pre-Final Design Package.* The pre-final design package will contain the same elements as the intermediate design package, plus: (i) revisions based on DOE, USEPA, and OEPA comments on the detailed design; (ii) all drawings and calculations essentially complete; and (iii) pre-final design construction cost estimate.

- *Preparation of Final Design Package.* The final design package will include the elements of the pre-final design package, plus: (i) revisions based on DOE, USEPA, and OEPA comments on the pre-final design; and (ii) final design cost estimate.

- *Preparation of CFC Design Package.* The CFC design package will include the elements of the final design package as well as revisions to the drawings based on comments on the final design package, engineer's certification of the drawings, and certified specifications that are suitable for construction purposes.

- *Interface Activities.* Design interface activities will relate to:
  - transmission of leachate;
  - stormwater management;
  - waste availability and transport;
  - stakeholder communication and input;
  - utility support involvement; and
  - environmental and health and safety monitoring.

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1.2.3 Schedule for Design and Support Activities

The schedule for design of the OSDF is presented in the *Final Remedial Design Work Plan for Remedial Actions at Operable Unit 2*. Key milestones and dates are as follows:

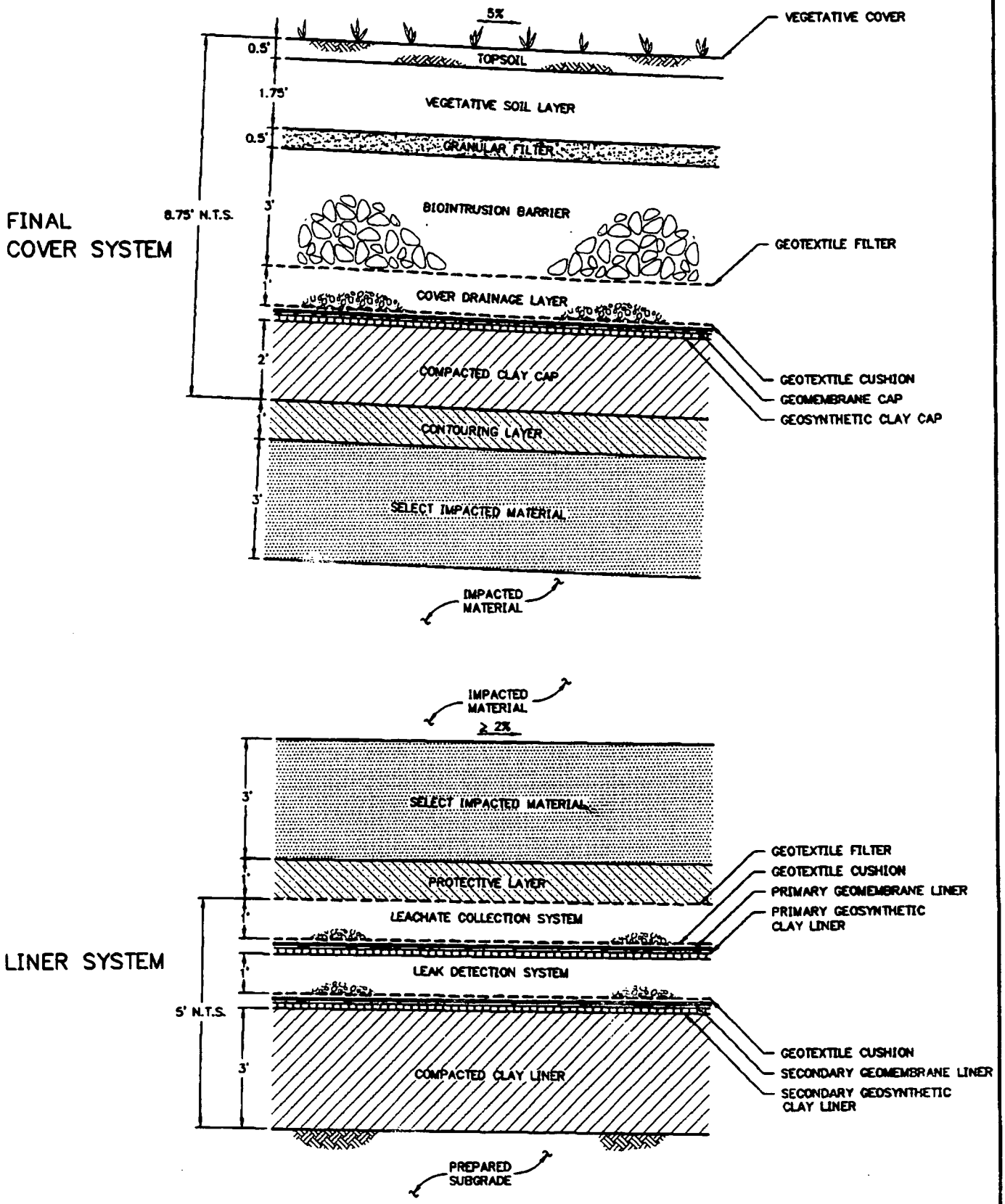
- Submit OSDF Preliminary Design Package to USEPA: 21 December 1995;
- Submit OSDF Pre-Final Design Package to USEPA: 28 June 1995; and
- Submit OSDF Final Design Package/CFC to USEPA: 14 October 1996.

1.3 Primary Components of the OSDF

The primary components of the OSDF, as identified in the *Detailed Facility Description/Functional Requirements* (presented in Appendix A of this document), are the liner system, final cover system, leachate management system, surface-water management system, support elements, utilities, and temporary support facilities.

- *Liner and Final Cover Systems.* The liner and final cover systems will be constructed using both soil and geosynthetic components. The conceptual design of the liner and final cover systems are presented in Appendix B. The preliminary designs for these systems, as currently developed, are shown in Figure 1-1. As shown in this figure, the liner system will consist of a double-composite liner that will have a leachate collection system (LCS) above the primary liner and a leakage detection system between the primary and secondary liners. The final cover system will include a composite cap overlain by the following layers: drainage layer; biointrusion barrier; granular filter layer; vegetative soil layer; and topsoil. The liner system and final cover system designs will be prepared considering material borrow requirements, seasonal (i.e., winter) closure, interim (i.e., multi-year) closure, and site preparation requirements.

PRELIMINARY LINER AND COVER SYSTEM DESIGN
ON-SITE DISPOSAL FACILTY



GEOSYNTEC CONSULTANTS
ATLANTA, GEORGIA

FIGURE NO.	1-1
PROJECT NO.	GE3900-11
DOCUMENT NO.	F9530004.CDO
FILE NO.	F95a001.DWG

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- *Leachate Management System.* The leachate management system will be designed to collect leachate generated by the OSDF and convey it to the AWWT facility. Components of the leachate management system within the battery limit will include: double-walled gravity drain pipes from each OSDF cell, detection and collection manholes, double-walled gravity transmission pipe, permanent valve manhole, permanent lift station, temporary valve manhole, temporary lift station, and temporary forcemain.

- *Surface-Water Management System.* The surface-water management system will be designed to manage surface water under both short-term (i.e., during construction and impacted material placement) and long-term (i.e., after closure) conditions. The design will address perimeter drainage, management of stormwater during construction, management of stormwater in the OSDF, and management of stormwater after final closure of the OSDF.

- *Support Elements and Utilities.* Both permanent and temporary support elements will be designed for the OSDF. Permanent support elements include a perimeter access corridor and a facility access road. Temporary support elements include construction security fencing, administrative support trailers, decontamination facilities for both personnel and equipment, one or more impacted material staging areas, equipment maintenance facilities, and construction materials staging areas. Required utilities include electrical, natural gas, water, telephone, and wastewater lines for the administrative support areas, and water and power for other specified areas. The administrative support trailers must also be provided with parking, security fencing, and all-weather ingress and egress.

1.4 Design Interfaces

There are a number of issues and activities at the FEMP site that will be impacted by the design, construction, filling, and closure of the OSDF. The identified design interfaces are:

- the capacity and treatment capability of the AWWT facility and the piping tie-in by forcemain from the OSDF permanent lift station to the AWWT facility;

- tie-in of required new utilities at the battery limit, including:
  - power;
  - water;
  - security system wiring;
  - wastewater; and
  - telephone;

- relocation of existing utilities within the battery limit;

- design and construction of access road haul roads and relocation of the north entrance road;

- remediation of the FEMP operable units; and

- architectural landscape design for enhanced community acceptance of the OSDF.

1.5 Sources of Information

1.5.1 Information Categories

Information from a variety of sources should be used to design the OSDF. These sources include:

- FEMP site-specific investigations, studies, and plans developed pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended;

- DOE/USEPA orders, standards, and guidance;

- FEMP site-specific pre-design investigations and studies; and
- general technical literature.

1.5.2 CERCLA-Related Documents

The CERCLA-related documents relevant to design of the OSDF are:

- *Final Remedial Investigation Report for Operable Unit 2* [DOE, 1995a];
- *Final Feasibility Study Report for Operable Unit 2* [DOE, 1995b];
- *Final Record of Decision for Remedial Actions at Operable Unit 2* [DOE, 1995c];
- *Final Remedial Design Work Plan for Remedial Actions at Operable Unit 2* [DOE, 1995d];
- *Final Feasibility Study Report for Operable Unit 5* [DOE, 1995e]; and
- *Draft Record of Decision for Remedial Actions at Operable Unit 5* [DOE, 1995f].

Select portions of the *Final Record of Decision for Remedial Actions at Operable Unit 2* are included in Appendix B of this document. The OU2 Record of Decision also contains the Applicable or Relevant and Appropriate Requirements (ARARs) for OU2. These ARARs are presented in Appendix C. The ARARs for OU5, which are contained in the *Draft Record of Decision for Remedial Actions at Operable Unit 5*, are presented in Appendix D.

1.5.3 DOE/USEPA Orders/Standards/Guidance

The primary DOE and USEPA orders, standards, and guidance relevant to the design of the OSDF are:

- *Project Management System* [DOE, 1992];
- *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities* [DOE, 1994]; and
- *Guidance on EPA Oversight of Remedial Designs and Remedial Actions Performed by Potentially Responsible Parties* [USEPA, 1990].

1.5.4 Site-Specific Design Documents

The primary site-specific predesign studies and investigations are:

- "*Predesign Investigation and Site Selection Report for the On-Site Disposal Facility*" [DOE, 1995g]. This report contains data and information on subsurface conditions with the portion of the FEMP property (east of the former production area) having favorable hydrogeology for siting the OSDF.
- "*Conceptual Design, Report for the Engineered Waste Management Facility*" [Parsons, 1992]. This report presents a conceptual design for the engineered waste management facility (now referred to as the OSDF). The report contains criteria for the layout, design, construction, and operation of the OSDF.
- "*100- and 500-Year Flood Plain Determination Sitewide*" [Parsons, 1993]. This report establishes the floodplain boundaries of Paddy's Run within the FEMP property as a result of the 100- and 500-year rainfall events.

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- "*On-Site Disposal Cell Pre-Design Activities Engineering Report, Operable Unit 2*" [Parson, 1994]. This report presents results of a subsurface investigation in the currently-proposed area at the southeast corner of the FEMP property that will be developed for soil borrow to be used in OSDF (which, at the time of the report, was a candidate location for the OSDF).

- "*2,000-Year Flood and Probable Maximum Flood Sitewide Flood Plain Determination*" [Parsons, 1995a]. This report establishes the 2,000-year and probable maximum precipitation events and the corresponding sitewide floodplain boundaries.

- "*Geotechnical Investigation Report, On-Site Disposal Facility*" [Parsons, 1995b]. This report contains geotechnical data for the subsurface soils in the OSDF area, including data compiled from previous investigations performed at the FEMP.

- "*Disposal Facility Pre-Design Geotechnical Investigation, Soil Investigation Data Report, CERCLA/RCRA Unit 2*" [Science Applications International, 1995]. This report presents geotechnical data for the subsurface soils in the OSDF area. The report contains data that is subsequently summarized and presented by Parsons [1995b].

1.5.5 General Technical Information

In addition to the project-specific information described above, a significant body of general technical information (e.g., textbooks, technical manuals, computer software) will be used in preparation of the OSDF design. This information is referenced where cited throughout this DCP.

1.6 Project Deliverables

The design of the OSDF will be documented in the project deliverables, including calculations, drawings, specifications, and reports. The DCP identifies the contents of these deliverables and establishes the criteria to be considered in preparing each deliverable. Preliminary lists of calculations, drawings, and specifications are presented in Tables 1-1, 1-2, and 1-3, respectively. Reports that will be prepared as part of the design process for the OSDF include:

- design criteria package (DCP);
- geomembrane liner compatibility study work plan and report;
- soil liner test pad work plan and report;
- construction quality assurance (CQA) plan;
- impacted material placement plan;
- stormwater management and erosion control plan;
- borrow area management and restoration plan;
- OSDF construction cost estimate;
- value engineering report; and
- responses to DOE, OEPA, and USEPA comments on project deliverables.

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1.7 Revision of this DCP

Compilation, review, and acceptance of this DCP precedes preparation of the other design deliverables. It is anticipated that, as design and review proceed, better approaches, details, etc. will be identified. As a result, this DCP will be modified to reflect these changes. Because this DCP will be a control document after it has been approved, changes to the DCP will be documented in an appendix.

TABLE 1-1

PRELIMINARY LIST OF CALCULATIONS
On-Site Disposal Facility
Fernald Environmental Management Project

1. SETTLEMENT
   - 1.1 Foundation Settlement
   - 1.2 Impacted Material Settlement

2. SLOPE STABILITY
   - 2.1 Foundation
   - 2.2 Liner System
   - 2.3 Interim Impacted Material Configuration
   - 2.4 Final Impacted Material Configuration
   - 2.5 Cover System
   - 2.6 Perimeter Berm
   - 2.7 Borrow Area Cut Slopes

3. SEISMIC STABILITY
   - 3.1 Seismic Hazard Assessment
   - 3.2 Seismic Site Response Analysis
   - 3.3 Seismic Performance Evaluation

4. HYDROSTATIC UPLIFT
   - 4.1 Hydrostatic Uplift

5. LEACHATE GENERATION RATE
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Section 13020 - Construction-Phase Leachate Management
Section 13030 - Seasonal and Interim Cell Closure
Section 13040 - Control of Fugitive Emissions

DIVISION 15: MECHANICAL

Section 15000 - Mechanical

DIVISION 16: ELECTRICAL

Section 16000 - Electrical

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SECTION 2

2. DESIGN CRITERIA

2.1 OSDF Location

2.1.1 Functional Requirements

The functional requirements for the location of the OSDF are as follows.

- The location should result in safe construction (to include impacted material placement) and long-term performance of the OSDF.
- The location should result in protection of human health and the environment and cost-effective development of the OSDF.
- The location should comply with ARARs.
- The location should minimize interference with remediation and decommissioning activities in the former production area.

The OSDF should be located entirely within the FEMP property in the area of most favorable hydrogeology. The general area identified as such is located east of the former production area, rectangular in shape, with approximate dimensions of 800 ft by 4,300 ft (240 m by 1,310 m). This area is shown in Figure 1 of Appendix A.

2.1.2 Location Criteria

The OU2 ARARs (Appendix C) provide siting criteria for the OSDF derived primarily from the Ohio Administrative Code (OAC) 3745-27-07 and -20. These criteria require that a disposal facility not be located within the following areas:

- within 300 ft (90 m) of the property boundary to the limit of waste placement;
- within 1,000 ft (300 m) of an existing domicile, existing water supply well, or developed spring;
- within 15 ft (4.5 m) of the elevation of the uppermost aquifer;
- within a regulatory floodplain; or
- within 200 ft (60 m) of a stream, lake, or natural wetland.

In addition, the OU5 ARARs (Appendix D) require that a disposal facility not be located within 200 ft (60 m) of a fault that has undergone displacement during the Holocene Epoch.

Other criteria that should be considered in locating the OSDF on the FEMP property are given below.

- The centerline of the relocated north entrance road (designed by others) will be offset approximately 150 ft (45 m) from the property line on the eastern side of the site. The toe of the east access corridor slope for the OSDF should not interfere with the ditch or shoulder of the relocated north access road (design consideration).
- The limit of the toe of cover of the OSDF on the western side of the site must be located to provide sufficient area for impacted material removal traffic between the toe of the west access corridor slope and the eastern fence line (northeast corner) of the process area (design consideration).
- The OSDF should be sited such that a perimeter access corridor and perimeter drainage swale can be constructed around the OSDF and within the battery limit (design consideration).

2.2 OSDF Layout

2.2.1 Functional Requirements

The OSDF will be a new feature of the FEMP property and must resist degradation during its design life due to wind, precipitation, temperature, runoff, runon, erosion, and other natural influences. A primary functional requirement is therefore to appropriately layout OSDF as a natural, stable, geomorphologic landform resistant to the natural influences present in an around the FEMP property.

In addition, the layout of the OSDF must be such that the features of the design (e.g., liner system, final cover system, perimeter drainage swale) function as an integrated unit that completely isolate impacted material from the surrounding environment and that result in a constructable, maintainable, and cost effective facility.

Lastly, the OSDF should be laid out so that it can be progressively developed in phases, utilizing contiguous cells that can be constructed, filled, and closed on a flexible schedule consistent with the final schedule for remediation of the FEMP operable units. The design of the OSDF must be flexible to accommodate an active life ranging from seven to 25 years.

2.2.2 Layout Criteria

2.2.2.1 Horizontal Limits

- The length and width of the OSDF must satisfy the location criteria identified in Section 2.1 of this DCP.

- The horizontal layout should be adequate to provide a disposal capacity sufficient for 2.5 million cubic yards (1.9 million cubic meters) bank/ unbulked impacted material (functional requirement). The OSDF should provide sufficient capacity for anticipated bulking of impacted material as a

result of excavation, transport, and placement. The OSDF should also provide sufficient capacity to accommodate seasonal (winter) cover soil. Consideration should also be given to providing a "contingency" disposal capacity to be used in the event that the volume of impacted material requiring disposal increases as a result of remediation-phase confirmatory sampling and to provide additional capacity for potential partial closure activities.

- For cost effectiveness, the OSDF should be regularly shaped, to the extent possible, with as few changes in geometry as possible and with smooth transitions between changes in geometry (design consideration).

2.2.2.2 Final Height and Slope Limits

- The maximum height of the OSDF from the top of the final cover system to existing grade (measured at the crest of the facility) must not exceed 65 ft (20 m) (functional requirement).

- The final cover system slopes must be between five percent and twenty-five percent (ARAR: OAC 3745-27-08(C)(15)(f)(ii)). The slopes should be flat enough to satisfy slope stability factor of safety criteria and erosion control criteria. Within these constraints, slopes should be as steep as possible to achieve a cost effective design (design consideration).

- The transitions between topslope and sideslope areas of the final cover system should be gradual to prevent erosion caused by transitional flow of surface-water runoff (design consideration).

2.2.2.3 Foundation Grade and Slope Limits

- The bottom of the OSDF (i.e., bottom of the liner system) should overlie at least 12 ft (3.6 m) of undisturbed gray clay (functional requirement).

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- The distance between the bottom of the OSDF liner system and the Great Miami Aquifer should be at least 15 ft (4.5 m) (ARAR: OAC 3745-27-07(H)(2)(e)).

- The OSDF liner system should be founded in native brown clay to the extent feasible. Construction of the liner system on fill should be minimized (functional requirement).

- The OSDF should be laid out such that the top of the protective layer for the liner system is at or near existing grade (functional requirement). However, based on geometric considerations, founding of the liner system below existing grade in the northern portion of the OSDF is permitted (design consideration).

- The leachate collection system must be constructed with a slope of at least 2 percent. The leachate collection system pipe drain must be constructed with a minimum slope of 0.5 percent (ARAR: OAC 3745-27-08(C)(1) and (4)).

- The OSDF should be laid out such that leachate transmission system manholes are not too deep, preferably not more than 12 to 15 ft (3.6 to 4.6 m). The double-walled gravity leachate transmission pipe should be located in brown clay, not gray clay, to the extent reasonably achievable (design consideration).

2.2.2.4 Perimeter Features

- The OSDF should be laid out having an access corridor around its entire perimeter. The access corridor berm must prevent runon from upgradient areas during all design storm events.

- The OSDF access corridor should include an access road with a minimum width of 15 ft (4.5 m). The road is to provide access for OSDF maintenance and monitoring vehicles during the post-closure period (design consideration).

- The OSDF should be laid out having a perimeter drainage swale. The swale should the designed to accommodate surface-water runoff from the OSDF final cover system slopes during all design storm events.

2.2.3 Calculations

Calculations required to establish the location and layout of the OSDF are as follows:

- OSDF required volume;
- OSDF capacity verification; and
- OSDF cost estimates.

2.2.4 References

FEMP property data and information required to locate and layout the OSDF should be obtained from the references cited in Section 1.5 of this DCP.

2.3 OSDF Performance

2.3.1 Design Life

The function of the OSDF is to isolate impacted material from the environment throughout the facility design life (i.e., for 1,000 years, to the extent reasonable, and in any case for 200 years) (ARAR: 40 CFR § 192.02(a)). The OSDF design must be developed to achieve this design life goal. Requirements to achieve the goal fall into five categories, defined as follows:

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- *hydrologic control* - provide resistance to hydrologic impacts, including infiltration through the cover system and damage by surface-water runon or runoff;

- *ground-water protection* - provide a high level of leachate containment and collection capability to prevent OSDF-related impacts to ground water;

- *geotechnical stability* - ensure stability of the OSDF throughout construction, filling, and closure, and then through the post-closure period, including impacts associated with potential long recurrence-interval earthquake events;

- *erosion resistance* - minimize erosion of the OSDF area to assure minimal erosional impacts throughout the design life; and

- *biointrusion control* - prevent intrusion by plant roots and burrowing animals.

The requirements described above should be achieved in the OSDF design in the manner indicated in Table 2-1. Also, as shown in this DCP, the requirements should be achieved by:

- using natural (i.e., geologic), durable construction materials wherever possible (e.g., clay liners, gravel drainage layers, etc.);

- selecting the most durable geosynthetic construction materials available;

- providing synergistic (e.g., adjacent geomembrane, GCL, and compacted clay liner and final cover system components) and redundant (e.g., dual leachate collection system drain pipes) design components; and

- designing a final facility geometry that replicates natural geomorphologic landforms.

TABLE 2-1

FUNCTIONAL REQUIREMENT - DESIGN FEATURE MATRIX ON-SITE DISPOSAL FACILITY

	FUNCTIONAL REQUIREMENT				
	Hydrologic Control	**Ground-Water Protection**	**Geotechnical Stability**	**Erosional Stability**	**Biointrusion Control**
DESIGN FEATURE	· Low-permeability cover to minimize infiltration into the OSDF · Site graded to route clean runoff from the OSDF and to prevent runon to the OSDF under 2,000-year storm event · Facility sited out of 2,000-year floodplain · Runoff from impacted areas collected and treated	· Liner and final cover systems completely encapsulate impacted material · Geomembrane liner and cap present through at least the initial and steady-state periods · Compacted clay liner and cap remains functional through very long-term period · Leachate collection system remains functional through at least the initial and steady-state periods · Geochemical attenuation provided by at least 3 ft of compacted clay liner, in-situ native brown clay, and at least 12 ft of in-situ native gray clay	· OSDF located on stable glacial till foundation · OSDF slopes designed to be very stable · OSDF designed to be resistant to deformation under 2,400 year design seismic event · Impacted material placed and compacted in stable configuration · Construction materials selected to enhance stability (e.g., textured geomembrane)	· Geomorphically stable OSDF layout · Smooth transition of cover top slope to side slope · Rounded OSDF final cover system corners · Final cover system designed for erosion resistance under design storm conditions · Flat cover slopes to minimize runoff velocity · Biointrusion barrier beneath entire cover and perimeter drainage swale blocks potential depth of erosion or gullying	· Biointrusion barrier to impede plant root and animal intrusion · Primarily above-ground facility facilitates visual monitoring and maintenance · Continuing maintenance through the initial and steady-state period · Access to site limited and institutional controls can be implemented if necessary

The design of OSDF must be considered within a temporal framework. Over the OSDF design life (up to 1,000 years), the properties of some of the materials of construction, particularly the geosynthetics, may change. In addition, over time, and in the absence of external inputs, the impacted material will cease to generate leachate. To describe the behavior of the OSDF over time, three primary periods of behavior may be defined.

- *Initial Period.* The initial period is defined as the period from initial construction until steady-state conditions prevail ("steady-state" refers to the time when leachate ceases to be generated by the facility, or continues to be generated, but at a very low, steady-state rate). Throughout the initial period, the geosynthetic components of the OSDF may be expected to be fully functional. The duration of the initial period may be on the order of 10 to 20 years after closure.

- *Steady-State Period.* The period of steady-state conditions may start at 10 to 20 years after closure of the OSDF and should last for at least 200 years, and up to 1,000 years to the extent reasonably achievable. It may be conservatively assumed that, at the end of this period, the critical geosynthetic components of the liner system are no longer fully functional.

- *Very Long-Term Period.* The very long-term period is defined as the period during which the performance of the OSDF has stabilized to its permanent state. During this period, natural earth components of the liner and final cover systems continue to function.

The design criteria presented in this DCP are intended to meet the design life goals of the OSDF under the assumptions of the "behavior periods" identified above. Table 2-1 shows how, for each of the project functional requirements, this DCP establishes criteria to achieve a design that will provide for the required performance. Also, the calculations that will be performed for the OSDF design packages (which are identified on Table 1-1) are intended to demonstrate the manner in which the OSDF design can achieve the design life criteria.

2.3.2 Geotechnical Stability and Settlement

2.3.2.1 Static Slope Stability

A. Criteria

Static slope stability analyses should be performed for the following conditions at a minimum (design consideration):

- OSDF Foundation
  - interim impacted-material configuration
  - final OSDF configuration
- OSDF Liner System and Impacted Materials
  - short-term (i.e., end-of-construction) liner system on side slope
  - interim impacted-material configuration
  - long-term (i.e., final OSDF configuration) condition
- OSDF Interim Cover System
  - short-term condition on interim slope
  - long-term condition on interim slope
- OSDF Final Cover System
  - short-term condition on final side slope
  - long-term condition on final side slope
- Perimeter Berm
  - short-term condition
  - long-term condition

- Borrow Area Cut Slopes
    - long-term condition

Minimum acceptable factors of safety for the above analysis conditions shall be developed considering the criticality of the OSDF, the consequences of failure, and guidance provided by:

- UMTRA Technical Approach Document [DOE, 1989];
- NAVFAC Design Manual [U.S. Navy, 1971]; and
- Duncan [1992].

Minimum acceptable factors of safety for static conditions should be at least those from the UMTRA Technical Approach Document. Minimum acceptable factors of safety from that document are listed below.

Condition	Minimum Acceptable Factor for Safety
Stability during construction	1.3
End of construction stability	1.3
Long-term stability	1.5
Long-term with flood stability (including rapid drawdown)	1.2

B. Calculations

For each condition defined in (A) of this section, the engineer should define the critical conditions for stability and perform an analysis to confirm that the calculated factors of safety for the critical conditions are larger than the minimum acceptable values. In performing the analyses, the engineer should follow guidance provided in Holtz and Kovacs [1981], Duncan et al. [1987], and Kulhawy and Mayne [1990], for

example, in choosing between total-stress and effective-stress analysis approaches and in choosing between unconsolidated-undrained (UU), consolidated-undrained (CU), and consolidated-drained (CD) shear strength parameters. In establishing shear strength parameters for geosynthetic interfaces, the engineer should consider not only the above factors, but also the differences between peak and large-displacement shear strength values. Proven approaches should be used that are consistent with the requirements of DOE and USEPA standards and guidelines. Acceptable approaches are described below.

- *OSDF Foundation.* For the OSDF foundation stability condition, use two-dimensional limit equilibrium analysis methods; for example, use Bishop's simplified method [Bishop, 1955] for circular potential slip surfaces and Janbu's simplified method [Janbu, 1973], Spencer's method [Spencer, 1973], or the Morgenstern and Price [1965] method for noncircular potential slip surfaces. Use the computer program XSTABL [Sharma, 1991;1992], UTEXAS3 [Wright, 1991], or other widely-accepted and validated program.

- *OSDF Liner System.*

  - For the short-term liner system on side slope, use the two-dimensional limit equilibrium method of Giroud et al. [1995a], or other comparable method. If seepage forces are potentially significant, use the approach in Giroud et al. [1995b], or other suitable method.

  - For interim and final waste mass configurations, use the techniques listed under OSDF foundations above.

- *OSDF Cover System.* For the interim and final cover systems, use the 2-D limit equilibrium methods of Giroud et al. [1995a,b] listed above under OSDF liner system, or other suitable method.

- *Perimeter Berm.* For short-term and long-term analyses, use the methods listed above under OSDF foundation, or other suitable method.

- *Borrow Area Cut Slopes.* For long-term analyses, use the methods listed above under OSDF foundation, or other suitable method.

2.3.2.2 Seismic Slope Stability

A. Criteria

A seismic hazard assessment should be performed to evaluate potential seismically-induced peak horizontal accelerations of the OSDF foundation, liner system, and final cover system. The seismic hazard assessment should be based on the conservative assumption that the OSDF will be a Performance Category 2 facility as defined in DOE Order 5480.28 (i.e., also equivalent to Performance Grade 3 in DOE Order 5480.28). The OSDF foundation, liner system, and final cover system should be designed to comply with the more stringent of the criteria and guidance given below (design consideration).

- DOE-STD-1020-94. This DOE standard requires that Performance Category 2 facilities be designed for a peak ground surface acceleration having an annual probability of occurrence of 1×10^{-3}.

- USEPA/600/R-95/051. This USEPA guidance document requires that new municipal solid waste disposal facilities be designed to resist the peak bedrock acceleration of a seismic event having a probability of occurrence of no greater than 10% in 250 years.

The minimum peak ground surface acceleration at the FEMP satisfying the DOE-STD-1020-44 requirement is 0.13 g, where "g" is the gravitational acceleration at the surface of the earth (32.2 ft/s^2 (9.8 m/s^2)). This acceleration value is obtained from Table C-5a of the DOE-STD-1020-94. The peak bedrock acceleration at the FEMP site, according to USEPA/600/R-95/051, is 0.16 g.

The maximum acceptable permanent seismic deformation for all analysis conditions is 6 to 12 in. (0.15 to 0.3 m) based on Seed and Bonaparte [1992], and Anderson and

Kavazanjian [1995]. For most conditions, a smaller acceptable permanent seismic deformation should be defined by the engineer based on the potential adverse consequences of excessive movement of OSDF components.

B. Calculations

Site Response Analysis

Site response analyses should be performed to evaluate peak horizontal accelerations of the OSDF foundation, liner system, and final cover system. Site response analyses should be performed using established one-dimensional or two-dimensional computer models such as SHAKE [Schnabel et al., 1972], as updated by Idriss and Sun [1992] for one-dimensional analyses, and QUAD4M [Hudson et al., 1994] for two-dimensional analyses. The selection of impacted-material parameters for seismic analyses should fully consider the existing site stratigraphy and subsurface conditions. The nature of the impacted materials that will be disposed in the OSDF (i.e., primarily soil, but also flyash, sludge, and building debris) should also be carefully considered in establishing these parameters.

The site response analyses will also require selection of representative earthquake magnitudes and strong motion acceleration-time histories. Guidelines that should be used to establish these inputs to the site response analyses include:

- *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities* [DOE, 1994];
- *RCRA Subtitle D (258) Design Guidance for Municipal Waste Landfill Facilities* [USEPA, 1995];
- *UMTRA Technical Approach Document* [DOE, 1989]; and
- *Pre-Design Investigation and Site Selection Report for the On-Site Disposal Facility* [DOE, 1995g].

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The site response analyses should be used to obtain the peak average acceleration of the OSDF for evaluating stability of the OSDF liner system and foundation. The analyses should also be used to obtain the peak horizontal acceleration of the final cover system (at the level of the critical cover system interface for the evaluation of seismic performance of that component of the OSDF).

Pseudo-Static Stability Analysis

Pseudo-static stability analyses should then be performed using the acceleration values identified above. The evaluation should establish whether the pseudo-static factor of safety for the critical case for each stability condition is larger than 1.0. This minimum acceptable pseudo-static factor of safety is consistent with the *UMTRA Technical Approach Document* [DOE, 1989] and other engineering guidance. The stability conditions for which pseudo-static analyses should be performed are as follows:

- OSDF Foundation
  - interim impacted-material configuration
  - final OSDF configuration
- OSDF Liner System and Impacted Materials
  - interim impacted-material configuration
  - final OSDF configuration
- OSDF Final Cover System
  - long-term condition on final side slope
- OSDF Perimeter berm
  - long-term conditions

Deformation Analysis

If any of the above analyses result in a factor of safety less than 1.0, seismic deformation analyses shall be performed to establish whether calculated deformations are within acceptable limits. If the calculated deformations are acceptable, then the adequacy of the design with respect to the specific design criteria should be considered acceptable. Deformation analyses should be performed using a Newmark [1965] sliding block approach, as coded in the computer program Y-SLIP [Yan, 1991], or other suitable method. In performing these analyses, large-displacement shear strengths should be assumed for liner and cover system geosynthetic interfaces.

The maximum acceptable permanent seismic deformation for all analysis conditions is 1.0 ft (0.3 m). For most stability conditions, a smaller acceptable deformation should be defined by the engineer based on the potential adverse consequences of excessive movement of OSDF components. Guidance on selecting limiting deformation values for liner and cover systems can be found in USEPA/600/R-95/051, Seed and Bonaparte [1992], and Anderson and Kavazanjian [1995].

2.3.2.3 Foundation Settlement

A. Criteria

- The settlement of the foundation should not cause grade reversal of the leachate collection layer or ponding of leachate on the liner system.

- Geomembrane and geosynthetic clay liner materials and their seams, as well as leachate collection and leak detection piping, should be able to withstand stresses and deformations resulting from settlement of adjacent materials without exceeding allowable tensile strains and elongations (design consideration).

- The post-settlement slopes of the leachate collection system should be no less than needed to convey leachate from the OSDF to the leachate transmission

system gravity line (design consideration). The post-settlement slopes of the leachate transmission gravity line should be no less than needed to effectively convey leachate by gravity to the temporary or permanent lift stations (design consideration).

B. Calculations

Calculations should be performed to evaluate the settlement of the foundation beneath the OSDF. The calculations should be performed as described below.

- The geotechnical characteristics (i.e., consolidation properties, unit weights, moisture characteristics, etc.) of the foundation materials and impacted materials should be evaluated using the site-specific data identified in Section 1.5 of this DCP. Correlations between soil index and compressibility properties can be obtained from Duncan and Chang [1970], Holtz and Kovacs [1981], Kulhawy and Mayne [1990], or other suitable references.

- The depth of influence should be estimated for the stress that will be applied to the foundation soils by the OSDF. The depth of influence may be estimated based on methods presented by Perloff et al. [1967], Poulos and Davis [1974], or others, and should consider the effects of varying heights of fill at different locations within the OSDF.

- The settlement of each layer of the foundation should be calculated based on the calculated stress increase and the properties of the foundation materials using standard settlement calculation methods, such as those presented by Lambe and Whitman [1969], Duncan [1992], Duncan, et al. [1987], Holtz and Kovacs [1981], or others, as appropriate.

- The impact of the calculated settlement should be evaluated. The calculation results should be evaluated in terms of total settlements, differential settlements, change in slope of the leachate collection system, change in slope of the leachate transmission system gravity line, and impacts (if any) to the liner system components.

2.3.2.4 Impacted Material Settlement

A. Criteria

- Final cover system slopes after settlement must be large enough to prevent ponding of water on the final cover system (ARAR: OAC 3745-27-08(C)(15)).

- Differential settlement of the OSDF final cover system resulting from compression of impacted material placed in the OSDF should not cause grade reversal of the final cover system (design consideration).

- The OSDF cover system drainage layer should be designed to function under the post-settlement grades of that system (design consideration).

- Tensile strains in geosynthetic and soil components of the final cover system due to differential settlement must not cause damage to the components (design consideration).

B. Calculations

Calculations should be performed to evaluate the settlement of the OSDF final cover system. The calculations should be performed as described below.

- The geotechnical characteristics (i.e., consolidation properties, unit weights, moisture characteristics, etc.) of the impacted materials should be evaluated using the site specific data described in Section 1.5 of this DCP, other available information on the characteristics of materials to be placed in the OSDF, and information in the OSDF Impacted Materials Placement Plan.

- Calculations should be performed to evaluate the potential magnitude of settlement of the impacted material placed in the OSDF. The settlement calculation should use the same techniques as for foundation settlement (cited above), taking into account the specific geotechnical characteristics of the

impacted material when placed in the OSDF in the manner required by the *Impacted Material Placement Plan*. The potential for localized settlement due to impacted material non-homogeneity should be considered. If a significant degree of localized non-homogeneity is identified, the potential for localized differential settlements should be evaluated using techniques such as those presented by Giroud et al. [1990], Othman et al. [1995], or other suitable methods.

- Potential effects of the calculated settlement of both the foundation and impacted materials on the final cover system should be evaluated. The impact may be evaluated in terms of: total settlements, differential settlements, changes in slope to the cover system drainage layer, and stresses and strains in final cover system components.

2.3.3 References

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2.4 Liner System

2.4.1 Functional Requirements

The function of the liner system is to isolate impacted material from the environment while containing and collecting leachate generated by the material. As shown on Figure 1-1, the liner system will contain two liners (i.e., primary and

secondary liners), separated by a leak detection system, with the primary liner overlain by a leachate collection system (OU5 ARAR: 40 CFR § 265.301(a)). Both the primary and secondary liners will consist of a geomembrane overlying a geosynthetic clay liner; in addition, these components of the secondary liner will be underlain by a 3-ft (0.9-m) thick layer of compacted, low-permeability clay.

Additional functional requirements of the OSDF liner system are as follows:

- The liner system must extend completely under all areas where impacted material will be placed in the OSDF (ARAR: OAC 3745-27-08(C)(1)(h)).
- The liner system must be effective for up to 1,000 years, to the extent reasonably achievable, and in any case for at least 200 years (ARAR: 40 CFR § 192.02(a)).
- The liner system should effectively resist the applied stresses that will be applied to during construction, filling, closure, and post closure (ARAR: OAC 3745-27-08(C)).
- The liner system should be constructed in a manner that, after placement of the final cover system, completely encapsulated the impacted material placed in the OSDF (design consideration).

2.4.2 Design Criteria

- The number of penetrations through the liner system by leachate collection and leak detection piping should be minimized. In particular, there should be no more than one penetration each for the leachate collection pipe, redundant leachate collection pipe, and leak detection pipe for each cell of the OSDF (design consideration).

- The liner system should allow monitoring of the leachate generation rate of the entire OSDF and flows from the leak detection system of each OSDF cell (design consideration).

- The liner system components must be compatible with the impacted material and leachate (ARAR: OAC 3745-27-08(E)).

- The liner system must be designed to resist upward pressures (with a factor of safety of at least 1.4) on the bottom of the liner that may be caused by ground water (ARAR: OAC 3745-28-08(C)(1)).

- The liner system must be designed to resist damage caused by the loads applied during construction, placement of impacted material, closure, and post-closure care (design consideration).

- The liner system should be installed on the bottom and exterior excavated sides of the landfill and be constructed with a minimum bottom slope of 2 percent and a maximum slope based on: (i) compaction equipment limitations; (ii) slope stability considerations; and (iii) resistance of geosynthetics and geosynthetic seams to tensile stresses (design consideration).

- The liner system should be constructed on a prepared surface that is: (i) free of debris, foreign material, and deleterious material; (ii) able to bear the weight of the OSDF without causing or allowing a failure of the liner to occur through settling; and (iii) without abrupt changes in grade that could cause damage to the geosynthetics (design consideration).

- The liner system must be adequately protected from damage due to desiccation, freeze/thaw cycles, wet/dry cycles, and the intrusion of objects during construction, filling, and closure (design consideration).

2.4.3 Hydrostatic Uplift

An analysis should be performed of the impacts of hydrostatic forces on the liner system. The analysis should consider the potential range of perched-zone ground-water levels within the OSDF foundation. If the highest elevation of perched ground water exceeds the elevation of the bottom of the liner system, an analysis should be conducted to evaluate the uplift potential of the liner system under the anticipated hydrostatic uplift pressure. The analysis should be performed for both end-of-construction and long-term conditions. Procedures for calculating uplift pressures due to high ground water are given in Lambe and Whitman [1969] and Holtz and Kovacs [1981], for example.

2.4.4 Geomembrane Liner

Basic Requirements

The geomembrane liner should be (functional requirements):

- manufactured from high density polyethylene (HDPE) and be at least 80-mil (2.0-mm) thick (nominal thickness);
- placed in intimate contact with the geosynthetic clay liner; and
- protected from damage by drainage layer material by a geotextile cushion layer placed over the geomembrane.

Geomembrane Selection

An evaluation should be performed to confirm that a geomembrane constructed of HDPE and of 80 mil (2.0 mm) thickness is the most appropriate type of geomembrane (in terms of composition, thickness, surface texturing, etc.) for use in the OSDF liner system. The evaluation should consider physical and mechanical properties, durability, and chemical compatibility.

Primary Liner Performance

The performance characteristics of the primary liner should be evaluated in terms of the potential for leachate migration through the liner and into the leak detection system. This information is needed for the design of the leak detection system. The USEPA HELP model [Schroeder et al., 1994a,b], which uses the liner performance models of Giroud and Bonaparte [1989a,b] and Giroud et al. [1992], should be used to evaluate the performance of the primary liner.

Geosynthetic Tension and Anchor Trench Capacity

The geosynthetic components of the liner system should be designed to prevent slippage at their interfaces with adjacent materials and, thus, to preclude the development of tension in these materials. Design methods to establish the requirements to prevent tension are the same as those used to assess liner system stability (described in Section 2.3.2 of this DCP).

Notwithstanding the fact that the geosynthetics will be designed to preclude the development of tensile stresses, an anchor trench should be constructed at the top of the OSDF side slope to anchor the geosynthetic components of the liner system. The anchor trench should be 2 ft (0.6 m) deep to provide for secure anchoring of the liner system geosynthetics.

Resistance to Puncture

The geomembrane component of the liner system must be designed to resist puncture or damage from the stresses applied by overlying drainage layer material. The calculation procedure for this evaluation should consider two loading conditions: (i) long-term case assuming the OSDF is full; and (ii) short-term case assuming that construction equipment is working above the drainage layer material. Using the calculated loads, the geotextile cushion layer overlying the geomembrane should be designed to protect the geomembrane from puncture. Procedures such as those by Koerner et al. [1995], or other suitable procedures, should be used to calculate the required characteristics of the geotextile cushion.

The geotextile cushion layer should also be designed to be robust and have adequate construction survivability characteristics. Design for adequate construction survivability should be performed using the procedure described in Koerner [1994], or other suitable procedures.

Frost Protection

An evaluation should be performed to identify the minimum thickness of soil that must be placed over the geomembrane component of the secondary liner to protect the underlying compacted clay component from freeze-thaw due to winter weather. The evaluation should be performed using the Berggren method [Aldrich and Paynter, 1953].

2.4.5 Compacted Clay Liner

The compacted clay liner must be constructed of soil that satisfies the following criteria (ARAR: 3745-27-08(c)):

- 100 percent of the particles having a maximum dimension not greater than 2 in. (50 mm);
- not more than 10 percent of the particles, by weight, having a dimension greater than 0.75 in. (20 mm);
- not less than 50 percent of the particles, by weight, passing through the standard U.S. No. 200-mesh sieve; and
- not less than 25 percent of the particles, by weight, having a maximum dimension not greater than 0.002 mm (2 μm).

The requirements of the final item are not met by the brown and gray clays that underlie the FEMP property. However, OAC 3745-27-08(C) states that alternatives to the prescriptive requirements for soil liner materials may be sued: "*...if it is*

demonstrated to the satisfaction of the Director that the materials and techniques will result in each lift having a maximum permeability of 1 x 10^{-7} cm/s." The available test data demonstrate that the brown and gray clays are capable of achieving a hydraulic conductivity of not greater than 1 x 10^{-7} cm/s. Therefore, a demonstration will be required pursuant to OAC 3745-27-08(C) to obtain an acceptable alternate to the particle size requirement. The primary considerations in developing this demonstration are given below.

- The primary performance criterion for compacted soil liners in OAC 3645-27-08(C)(1)(a) requires that each lift of the liner have a maximum hydraulic conductivity of 1 x 10^{-7} cm/s. The hydraulic conductivity of a clayey soil is, in part, a function of the percentage of clay-size particles. However, other factors such as soil plasticity, compaction moisture content, and dry density also strongly influence hydraulic conductivity. Benson et al. [1994] performed detailed analyses of how each of these parameters correlate with hydraulic conductivity. The results of their study, which was based on data from 67 landfills, indicate that an average (rather than a minimum) fraction of clay-sized particles exceeding 15 percent is an acceptable criterion for compacted soil liners. In addition, Benson et al. [1994] provided data on a large number of compacted soil liners which do not meet the clay-size particle criterion set forth in OAC 3745-27-08(C)(1)(c)(iv), yet, when constructed using appropriate procedures, have measured hydraulic conductivities less than 1 x 10^{-7} cm/s. It is also noted that widely-accepted guidelines for clay liner materials (e.g., Daniel [1993]) do not contain criteria for the minimum acceptable percentage of clay-size particles.

- As part of the OSDF design, a test pad program will be conducted using soil obtained from the OSDF foundation excavation and the on-site soil borrow area. The test pads will be constructed using equipment and techniques that will subsequently be used to construct the OSDF clay liner. Laboratory and field permeability testing will be performed during the test pad program to define the compaction conditions that will yield a soil liner with a hydraulic conductivity of not greater than 1 x 10^{-7} cm/s. The test pad program will meet the requirements for test pads set forth in OAC 3745-27-08(C)(1)(m).

- The results of the test pad program, including all laboratory and field hydraulic conductivity test results from the program, will be presented in a report that DOE will provide to USEPA and OEPA. This report will specify construction equipment types and construction procedures that result in a compacted clay liner satisfying the hydraulic conductivity performance criterion of OAC 3745-27-08(C)(1).

- During construction of the OSDF liner system, a detailed construction quality assurance (CQA) program will be implemented. The CQA activities will include moisture/density testing of soil liner materials at the frequency required by OAC 3745-27-08(C)(1)(o) to verify that the compaction conditions are consistent with those established during the test pad program, and monitoring activities in accordance with 40 CFR § 264.303(C). In so doing, a high level of assurance will be provided that the hydraulic conductivity of the soil liner material is not greater than 1×10^{-7} cm/s. the CQA program will also include confirmatory hydraulic conductivity testing.

2.4.6 Geosynthetic Clay Liner

The geosynthetic clay liner must (ARAR: OAC 3745-27-08(C)):

- be negligibly permeable to fluid migration interpreted to require that the GCL have a minimum a hydraulic conductivity of 1×10^{-9} cm/s);

- be installed having a minimum overlap of 6 in. (150 mm), or, for end of panel seams, a minimum over of 12 in. (0.3 m) (overlap shall be increased in accordance with manufacturers specifications or to account for shrinkage due to weather conditions);

- have a bentonite mass per unit area of at least one pound per square foot (2 kg/m^2);

- be installed in accordance with the manufacturer's specifications in regard to handling, overlap, and the use of granular or powdered bentonite to enhance bonding at the seams; and

- be constructed above the compacted clay liner.

In addition to the foregoing requirements, the geosynthetic clay liner beneath the primary geomembrane should have a HDPE geomembrane backing on its bottom side to: (i) assure no long-term migration of bentonite into the leak detection system; and (ii) limit hydration of the bentonite and thus improve short-term and interim liner system stability. The geosynthetic clay liner beneath the secondary liner may be similar to the one beneath the primary liner. Alternatively, the geosynthetic clay liner beneath the secondary liner may be of the "internally reinforced" type, which will improve short-term and interim liner system stability compared to the level of stability achieved with an "unreinforced" type geosynthetic clay liner. The benefits of geosynthetic clay liner internal reinforcement or partial hydration should be discounted in evaluating the long-term stability of the liner system.

2.4.7 Chemical Compatibility

Geosynthetic materials used in the OSDF liner system must be physically and chemically resistant to attack by the leachate that will be generated by the facility (ARAR: OAC 3745-27-08(E)). To satisfy this requirement, a liner compatibility study must be implemented to demonstrate the compatibility of the geomembrane component of the liner and final cover systems with the anticipated OSDF leachate. The liner compatibility study should be performed in two parts with the first part consisting of a review of published data on: (i) the general chemical compatibility and durability characteristics of HDPE geomembranes; and (ii) the performance of HDPE geomembranes in similar applications. If the available published data are not adequate to draw conclusions for design, a physical/chemical testing program should be undertaken to generate additional data. The testing program should include:

- immersion of representative geomembrane specimens in simulated OSDF leachate; the immersion procedures should be in accordance with USEPA Method 9090;

- pre- and post-immersion physical, mechanical, and micro-structural testing of the geomembrane specimens; and

- evaluation of the test results for evidence of any adverse impacts of leachate immersion on the geomembranes.

The scope of the liner compatibility study should be described in a work plan that addresses both the literature review and the physical/chemical laboratory testing program. The work plan should provide a detailed description of the immersion testing procedures and the procedures that will be used to evaluate the test results, should testing prove necessary. The work plan should first be developed in draft form for DOE, USEPA, and OEPA review and approval. A final work plan should be issued after incorporation of comments on the draft. A final report should be submitted to DOE, USEPA, and OEPA upon completion of the study.

The liner compatibility study must be complete prior to completion of the pre-final design package.

2.4.8 References

FEMP property data and information required for design of the liner system should be obtained from the references cited in Section 1.5 of this DCP. Additional information for design may be obtained from the general technical references listed below.

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2.5 Leachate Management

2.5.1 Leachate Collection System

A. Design Criteria

The function of the leachate collection system (LCS) is to collect leachate, route it from the OSDF to the leachate transmission system, and limit the buildup hydraulic head on the underlying primary liner to not more than 12 in. (0.3 m). The leachate collection system is also required to:

- extend over all areas that will subsequently be used for impacted material disposal;
- function with minimal maintenance and monitoring;
- function without excessive clogging throughout the design life of the OSDF;
- withstand the stresses that will be imposed during construction, filling, closure, and post-closure care of the OSDF; and
- occupy a minimum volume within the OSDF.

In addition to the foregoing requirements, the leachate collection system should comply with the design criteria given below.

- The maximum permissible leachate head within the leachate collection system is 12 in. (0.3 m) (ARAR: OAC 3745-27-08(C)(4)). The evaluation of maximum head must consider initial and intermediate filling conditions in a cell, as well as conditions after closure. The evaluation need not consider potential transient higher heads due to rainfall that might fall into an open cell during cell start-up activities.

- The leachate collection system must be constructed at a slope of at least 2 percent (ARAR: OAC 3745-27-08(C)(4)).

- The leachate collection system material must have a hydraulic conductivity, k, of at least 1×10^{-3} cm/s and have a negligible amount of fines (ARAR: OAC 3745-27-08(C)(4)). The fines content requirement is interpreted to mean not more than 2 percent of the particles passing a U.S. No. 200 standard sieve.

- The leachate collection system material must not contain carbonate material (ARAR: OAC 3745-27-08(C)(4)), unless it is shown to the satisfaction of USEPA and OEPA that a material with carbonate meets the design requirement.

- Earth materials (i.e., non-carbonate, durable, sound aggregate), not geosynthetic drainage layers, should be used in the leachate collection system to extent possible. An alternative material requirement may be used for the leachate collection system if it is demonstrated to the satisfaction of the USEPA and OEPA that the alternative satisfies all other design requirements.

- The leachate collection system must be designed to resist clogging and crushing (ARAR: OAC 3745-27-08(B)(3)).

- The leachate collection system should be overlain by a filter layer to prevent clogging of the drainage layer (ARAR: OAC 3745-27-08(B)(3)).

- Leachate collection system pipes must (as required by OAC 3745-27-08(C)(4)):

  - be imbedded in the drainage layer;

  - be constructed with a minimum slope of 0.5 percent;

  - be provided with access for clean-out devices;

  - have lengths and a configuration that do exceed the capabilities of clean-out devices;

  - be designed to resist drainage caused by differential settlement;

  - have joints sealed to prevent separation; and

  - be physically and chemically resistant to attack by the OSDF leachate.

- Leachate collection system pipes should be at least 6 in. (15 cm) in diameter to minimize clogging potential and to provide ample access for clean-out equipment (design consideration).

- Leachate collection system pipes should be manufactured from HDPE for durability and chemical compatibility. These pipes should have a standard dimension ratio (SDR) of at least 11 to provide both a high degree of structural stability and a significant wall thickness to minimize the potential for surface degradation (e.g., oxidation) (design consideration).

- Leachate collection system pipes should be perforated to allow inflow of leachate. Perforations must be designed to prevent plugging or clogging by the adjacent drainage material (design consideration).

- The leachate collection system should be provided with a redundant drain pipe to serve as a back-up in the event of unforeseen problems with the main leachate collection system pipe.

- A one-foot (0.3-m) thick protective layer should be placed above the leachate collection system to protect the underlying liner system from damage due to intrusion of objects during construction and filling of the OSDF (ARAR: OAC 3745-27-08(C)(4)).

- The protective layer should consist of impacted or clean soil that contains no sharp objects, debris, or other material that could damage the liner system (design consideration).

- The number of pipes in the leachate collection system should be minimized (design consideration); at a minimum, at least one leachate collection system pipe must be incorporated into the design of each cell.

- The factory of safety for the leachate collection system pipe under initial, intermediate, and long-term flow conditions should be at least 5 and preferably 10 (design consideration).

- The hydraulic conductivities of candidate granular drainage layer materials for the leachate collection system should be evaluated by testing prior to selection of a borrow source (design consideration).

B. Calculations

The quantity of leachate generated in a OSDF cell during filling and after closure must be evaluated as part of the design process. The quantity of leachate should be calculated using the USEPA Hydrologic Evaluation of Landfill (HELP) model, Version 3.03 [Schroeder et al., 1994a,b]. Leachate generation estimates should be made for each representative step in the filling of a OSDF cell (i.e., after placement of an initial thickness of impacted material (initial filling), intermediate filling, and post-closure) and for each representative phase of OSDF development. The results of the calculations

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should be used to design the leachate collection system and leachate transmission system.

Based on the calculated leachate generation rates, the following leachate collection system evaluations should be performed:

- maximum head in the leachate collection system, as calculated using the USEPA HELP computer model and checked using procedures presented by Giroud and Houlihan [1995], or other suitable methods;
- geotextile filter design, using procedures presented by Giroud [1982] or Christopher and Holtz [1984], or other suitable methods;
- flow capacity of leachate collection system pipes (using standard pipe capacity calculation methods);
- potential for clogging of the leachate collection system using procedures described by Koerner and Koerner [1994], or other suitable methods;
- leachate collection system pipe perforation sizing (using grain size distribution analyses); and
- leachate collection system pipe structural stability (using standard methods for evaluating the strength and stability of buried flexible pipes).

2.5.2 Leak Detection System

A. Design Criteria

The following design criteria apply to the leak detection system.

- The leak detection system should allow monitoring of any leachate migrate through the primary liner of each cell of the OSDF (functional requirement).

- The leak detection system should provide for efficient and reliable containment and collection of any leachate migration through the primary liner (design consideration).

- The leak detection system should minimize the buildup of head on the secondary liner under normal and extreme operating conditions, be constructed of durable material, and not be prone to clogging or other form of deterioration (design consideration).

- The leak detection system should be designed to route liquid that enters the system to a collection and measurement location (e.g., manhole or sump) outside of the OSDF (functional requirement).

- The leak detection system should be independent of the leachate collection system (functional requirement).

- The leak detection system drainage material should meet the same design criteria identified in Section 2.5.1 for leachate collection system drainage material (design consideration).

B. Calculations

The following calculations should be performed as part of the design of the leak detection system.

- Flow capacity of the leak detection system and hydraulic head in the leak detection system using the procedure described in Bonaparte and Giroud [1995], or other suitable methods.

- Time of travel in the leak detection system calculated using the procedure described in Bonaparte and Giroud [1995], or other suitable methods.

- Leak detection system pipe flow capacity and factor of safety (using standard pipe capacity calculation procedures).

- Leak detection system structural stability (using standard methods for evaluating the strength and stability of buried flexible pipes).

An action leakage rate (ALR) should be defined for the leak detection system that establishes a threshold for response actions in the event of excessive flow rates from the leak detection system drain pipe. The ALR should be established in accordance with procedures for RCRA Subtitle C facilities, as described in 40 CFR § 264. Response actions will be described in the *Remedial Action Contingency Plan* that will be prepared for the OSDF.

2.5.3 Leachate Transmission System

A. Design Criteria

The leachate transmission system must be designed to convey leachate (and liquids in the leak detection system) from the OSDF cells to a permanent lift station at the OSDF battery limit. From the lift station, the leachate will be pumped through a double-wall forcemain pipe to the AWWT facility. This DCP addresses design of the leachate transmission system up to, and including, the permanent lift station. The design of the forcemain from the lift station to the AWWT facility will be addressed in a separate design package.

The leachate transmission system must be designed to achieve the following (functional requirements).

- Liquid in the leak detection system of a OSDF cell must flow by gravity through a double-wall HDPE pipe (that penetrates the liner system) to a leak detection system manhole located in the perimeter berm on the west side of the OSDF.

- Each OSDF cell must have its own leak detection system manhole. The volume of liquid in the manhole should be monitored on a regular basis. The

design must allow for accumulated liquids in the leak detection system manhole to be pumped from the manhole into a discharge port in the leachate collection system manhole where it should discharge directly into the leachate transmission system gravity line.

- Liquid in the leachate collection system of a OSDF cell must flow by gravity through a double-wall HDPE pipe (which penetrates the liner system) to a leachate collection system manhole located in the perimeter berm on the west side of the OSDF; in the manhole, the leachate should discharge directly into the leachate transmission system gravity line.

- Each OSDF cell must have its own leachate collection system manhole. Each manhole should have a cleanout for maintaining the leachate transmission system gravity line. Each manhole should also have a temporary gate valve on the leachate collection system pipe from the OSDF to prevent flow into the gravity line during periods of gravity line maintenance, extension, repair, etc. The temporary gate valve should also be used to regulate potential storm surge flows that could occur as a result of heavy precipitation into a newly opened cell. The temporary gate valve must be removed from each cell prior to final closure of the OSDF, and preferably sooner.

- All liquid that drains from the OSDF leachate collection system should discharge into the leachate transmission system gravity line. This line should consist of double-wall HDPE pipe having a minimum diameter for the carrier pipe of 8 in. (200 mm). The minimum pipe SDR should be 11. The factor of safety for flow of the leachate transmission system gravity line should be at least 5 and preferably 10.

- The gravity line should be located in the perimeter berm on the west side of the OSDF. The gravity line should run the length of the OSDF, from the first cell near north end of the facility to the last cell near the south end. From the last cell, the gravity line should run to the permanent lift station. To promote gravity flow, the gravity line should be constructed with a minimum slope of 0.25 percent. The gravity line should be buried in a trench

at a sufficient depth below ground to prevent freezing of liquids in the line. The gravity line should be adequately bedded in the trench.

- The inner carrier pipe of the gravity line must be continuous over its entire length (i.e., from its upgradient end to its discharge point at the permanent lift station). The outer containment pipe should be continuous between leachate collection system manholes. These manholes should be periodically inspected for discharge from the containment pipe (which could be indicative of a possible leak in the carrier pipe).

- Leachate collection system manholes for those cells north of the existing east-west utility corridor that transects the battery limit should be installed in conjunction with construction of the first OSDF cell. The leachate transmission gravity line should run through all of these manholes and initially discharge into a temporary lift station located north of the utility corridor. Liquids discharged into the temporary lift station should be pumped through a temporary forcemain to the permanent lift station.

- The permanent lift station should be located near the southwest corner of the battery limit. The permanent lift station should also be installed concurrent with construction of the first OSDF cell. The pumps in the temporary lift station should be sized to pump discharged liquids through a double-wall forcemain to the permanent lift station. The pumps for the permanent lift station should be sized to pump discharged liquid through a forcemain to the AWWT facility. (Note: The pumps for the permanent lift station will be designed as part of the design package for the forcemain that will convey leachate from the permanent lift station to the AWWT facility.)

- The temporary lift station and forcemain should be taken out of service after removal/decommissioning of utilities within the utility corridor. At that time, the leachate transmission system gravity line should be extended to the permanent lift station.

- The temporary forcemain between the temporary and permanent lift stations should consist of double-wall HDPE pipe. The pipe should be installed in a trench at a depth that does not interfere with the existing utilities. The pipe should be adequately bedded in the trench. Alternatively, the forcemain may be placed on existing ground and covered with a soil berm of sufficient thickness to protect the pipe from traffic loads, freeze-thaw, and other stresses. Layout of the forcemain to avoid interference with the utility corridor should be coordinated with the FEMP coordination teams.

- The permanent lift station must be capable of storing the quantity of leachate generated during an average of one-week period at the beginning of the post-closure period (OAC 3745-27-08(C)(5)). The permanent lift station should also have sufficient capacity to store one hour of peak flow from the OSDF under active cell condition (design consideration). Potential storm surge flows from an OSDF cell into the leachate transmission gravity line due to heavy precipitation into a newly opened cell may be regulated using the temporary gate valve in the leachate collection system manhole for that cell.

- Both the temporary and permanent lift stations should contain pump on/off controls, high level alarms, and controls for automatically closing the gravity line in the event of:
  - power failure, or
  - high liquid level in the lift station manhole.

- The lift stations should also have provisions for manually closing the gravity line.

- The lift stations must have sufficient pump capacity to prevent the buildup of liquid in the manhole for maximum discharge conditions from the gravity line. The lift stations should have redundant pump capacity and automatic controls (with manual overrides) for operating the pumps.

- The pumps should be designed to be conveniently removed from the lift stations for periodic maintenance. An extra pump should be maintained on the FEMP property for use during periods of pump servicing.

B. Calculations

Calculations should be performed to ensure that the leachate transmission system can transmit the required quantity of liquid and store leachate as required by the design criteria. Calculations should include the following.

- *Leachate Transmission System Pipe Capacity*. The capacity of the leachate transmission system gravity line should be evaluated using standard pipe capacity calculation methods to ensure that the pipe has sufficient capacity to maintain gravity flow conditions at peak leachate generation rates.

- *Leachate Transmission System Pipe Structural Stability*. The strength and stability of the leachate transmission system gravity line should be evaluated using standard methods for evaluating buried flexible pipes.

- *Leachate Transmission System Pump Requirements*. The pressure head, efficiency, and pumping rate requirements of the pumps that will be installed in the temporary and permanent lift stations should be evaluated using standard pump design procedures. The pumps for the temporary lift station will be designed as part of this design package. The pumps for the permanent lift station will be designed as part of the different design package addressing design of the forcemain from the permanent lift station to the AWWT facility.

- *Leachate Storage Volume*. The permanent lift station should be designed with sufficient volume to contain the peak quantity of leachate generated by the OSDF during a one-hour period under active cells condition and the quantity of leachate generated over a one-week period at the start of the post-closure period. The calculation must demonstrate that the lift station has adequate storage capacity for these quantities of leachate.

2.5.4 References

FEMP property data and information required for design of the leachate management system should be obtained from the references cited in Section 1.5 of this DCP. Additional information for design may be obtained from the general technical references listed below.

Bonaparte, R. and Giroud, J.P., "Waste Containment Systems for Pollution Control: Part II-Hydraulic Design and Performance", Proceedings, NATO Advanced Study Institute, *Recent Advances in Ground-Water Pollution Control and Remediation*, Springer-Verlag, New York, 1995.

Christopher, B.R. and Holtz, R.D., "*Geotextile Engineering Manual*", FHWA-DTFH61-80-C-00094, U.S. Department of Transportation, Federal Highway Administration, 1984.

Giroud, J.P., "Filter Criteria for Geotextiles", *Proceedings, Second International Conference on Geotextiles*, Vol. 1, Las Vegas, NV, Aug 1982, pp. 37-42.

Giroud, J.P. and Houlihan, M.F., "Design of Leachate Collection Layers", *Proceedings of the Fifth International Landfill Symposium*, Sardinia, Italy, October 1995, 28 p.

Gross, B.A., Bonaparte, R., and Giroud, J.P., "Evaluation of Flow from Landfill Leakage Detection Layers", *Proceedings of the Fourth International Conference on Geotextiles, Geomembranes and Related Products*, The Hague, May 1990, pp. 481-486.

Koerner, G.R. and Koerner, R.M., "Biological Activity and Potential Remediation Involving Geotextile Landfill Leachate Filters", *Geosynthetic Testing for Waste Containment Applications, ASTM STP 1081*, R.M. Koerner, Ed., American Society for Testing and Materials, Philadelphia, 1990.

Schroeder, P.R., Aziz, N.M., Lloyd, C.M., and Zappi, P.A., "*The Hydrologic Evaluation of Landfill Performance (HELP) Model: User's Guide for Version 3*", EPA/600/R-94/168a, U.S. Environmental Protection Agency, Office of Research and Development, Washington D.C., 1994a.

Schroeder, P.R., Dozier, T.S., Zappi, P.A., McEnroe, B.M., Sjostrom, J.W., and Peyton, R.L., "*The Hydrologic Evaluation of Landfill Performance (HELP) Model: Engineering Documentation for Version 3*", EPA/600/R-94/168b, U.S. Environmental Protection Agency, Office of Research and Development, Washington D.C., 1994b.

USEPA, "*Action Leakage Rates for Leak Detection Systems*", Supplemental Background Document for the Final Double Liners and Leak Detection Systems Rule for Hazardous Waste Landfills, Waste Piles, and Surface Impoundments, U.S. Environmental Protection Agency, Office of Solid Waste, 1994.

2.6 Final Cover System

2.6.1 Functional Requirements

The final cover system must isolate impacted material in the OSDF, protect the OSDF from inadvertent intrusion, promote vegetative growth, and greatly limit infiltration into the facility after closure. The final cover system must also be designed to minimize requirements for long-term monitoring, maintenance, and repair. The components of the final cover system are shown in Figure 1-1 and include (in descending order), topsoil, vegetative soil layer, filter layer, biointrusion barrier, cover drainage layer, composite cap, and impacted-material contouring layer.

Closure of the OSDF, which includes installation of the final cover system, must be performed in a manner that minimizes the need for further maintenance and the potential for release of leachate to the environment to the extent needed to protect human health and the environment (ARAR: OAC 3745-27-11(O)). The final cover system requirements must also be designed to be effective for 1,000 years, to the extent

reasonable, and in any case, for at least 200 years (ARAR: 40 CFR § 192.02(a)). In addition, the final cover system should meet the following OU2 and OU5 ARARs (40 CFR 265 § 310):

- minimize liquid infiltration into the closed OSDF;
- function with minimal maintenance;
- promote drainage and minimize erosion or abrasion of the cover;
- accommodate settling and subsidence so that the integrity of the cover is maintained; and
- have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present.

2.6.2 Topsoil

A. Design Criteria

- The topsoil layer should promote both short-term vegetation and climax vegetation that is self-sustaining (design consideration).
- The topsoil layer should be designed for minimal erosion by wind and water and to preclude the development of gullies (design consideration).
- Topsoil must have a maximum projected erosion rate of 5 tons/acre/year (11 tonnes/ha/yr) (ARAR: OAC 3745-27-08(C)15)). In addition, the properties of the topsoil and vegetative soil layers must be adequate to result in a cumulative projected volume of eroded material over the design life of the facility that is less than the volume of material contained in the topsoil and vegetative layers.

- Topsoil and vegetation should resist gullying under the tractive forces of surface-water runoff from the cover.

- The characteristics of the topsoil layer material should be selected considering any specific requirements of the vegetative seed mix (design consideration).

- The final vegetation shall be self-sustaining and require minimal maintenance (design consideration).

B. Calculations

Final cover system erosional resistance should be evaluated as described in Section 2.9 of this DCP.

2.6.3 Vegetative Soil Layer

A. Design Criteria

- The vegetative soil layer shall be a well-graded mixture of clayey, silty, and sandy material, at least 21 in. (0.54 m) thick (functional requirement).

- The vegetative soil layer should be designed for minimal erosion by wind and water and to preclude the development of gullies.

- The vegetative soil layer must have sufficient thickness to protect the compacted clay cap from root penetration and the effects of freeze-thaw (ARAR: OAC 3745-27-08(C)(15)).

- For freeze-thaw protection of the compacted clay cap, the vegetative soil layer, together with the overlying topsoil layer and underlying granular filter and biointrusion barrier layers, must have a thickness of at least 30 in. (0.75 m) (ARAR: OAC 3745-27-08(C)(15)).

B. Calculations

Cover system erosional resistance should be evaluated as described in Section 2.9 of this DCP. In addition, calculations must be performed to establish that the thickness of the vegetative soil layer, coupled with the topsoil, granular filter, and biointrusion barrier layers, is adequate to prevent adverse freeze-thaw effects to the final cover system clay cap. These calculations should be performed using the Berggren method [Aldrich and Paynter, 1953].

2.6.4 Granular Filter Layer

A. Design Criteria

A granular filter layer will be constructed above biointrusion barrier component of the OSDF final cover system. The filter must comply with the following design criteria.

- The filter layer should be at least 6 in. (0.15 m) thick (functional requirement).
- The filter layer should be designed using granular earth materials if possible. If a suitable filter cannot be designed using granular earth materials, then geosynthetic materials may be considered (design consideration).
- The granular filter layer should be designed to prevent migration of soil from the vegetative support soil layer through the filter to the biointrusion barrier layer (design consideration).
- The granular filter layer should be continuous over the surface of the biointrusion barrier layer (design consideration).

B. Calculations

Industry standard procedures should be used to establish the opening size and distribution requirements of the granular filter layer. Procedures such as those presented in the UMTRA Technical Approach document [1989] or Cedegren [1977], or other appropriate procedures, should be used. If geotextile filters are needed, the procedures of Giroud [1982] or Christopher and Holtz [1984], or other appropriate references, should be applied.

2.6.5 Biointrusion Barrier

A. Design Criteria

The biointrusion barrier layer will be constructed immediately above the cover drainage layer component of the OSDF final cover system. The purpose of this layer is to prevent intrusion of plant roots and burrowing animals into the OSDF. The biointrusion barrier layer must comply with the following design criteria.

- The biointrusion barrier should consist of durable cobbles (possibly with gravel and boulder size fractions) at least 3 ft (0.9 m) thick (functional requirement).

- The biointrusion barrier should extend at least 40 ft (12 m) laterally beyond the limit of impacted material placement in OSDF. Alternatively, the biointrusion barrier may be terminated in a trench around the perimeter of the OSDF. The bottom elevation of the trench must be no higher than the elevation of the bottom of the adjacent OSDF liner system (design consideration).

- The biointrusion barrier should be designed to prevent plant root or animal intrusion into the OSDF (functional requirement).

- The maximum dimension of the biointrusion barrier material should be 18 in. (0.45 m). The material should consist of sound, dense, and durable crushed rock or natural stone (design considerations).

- The biointrusion barrier material should be free draining (design consideration).

- The biointrusion barrier material should meet the rock durability criteria presented in the UMTRA Technical Approach Document [DOE, 1989] (design consideration).

B. Calculations

The biointrusion barrier should be designed to have rock of sufficient size to deter burrowing animals, yet open void space to allow rapid drainage and discourage root growth. Guideline presented in Hakonson [1986] should be used to establish biointrusion barrier gradation requirements. Information presented in the UMTRA Technical Approach Document [DOE, 1989] should be used to establish the durability requirements of the barrier material. The filter criteria in the UMTRA document or Cedegren [1977], or other suitable methods, should be used to evaluate filter requirements of the biointrusion barrier.

2.6.6 Cover Drainage Layer

A. Design Criteria

The cover drainage layer will be constructed immediately above the geotextile cushion that will, in turn, overlie the geomembrane cap component of the OSDF final cover system. The cover drainage layer must satisfy the following design criteria.

- The drainage layer should limit the buildup of hydraulic head on the geomembrane cap to not more than 1 ft (0.3 m) (design consideration).

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- The drainage layer should be designed to rapidly convey infiltrating liquid off of the OSDF final cover system (design consideration).

- The drainage layer must consist of at least a 1-ft (0.3-m) thick layer of granular material or a geosynthetic drainage layer having equivalent performance capabilities (ARAR: OAC 3745-27-08(c)(15)). The use of a granular drainage material is to be preferred to a geosynthetic material (design consideration).

B. Calculations

Final cover system infiltration potential should be evaluated using the USEPA HELP model, Version 3, [Schroeder, 1994a,b] or other appropriate method. The calculation should be performed, assuming representative properties for the cover system components.

The hydraulic head buildup in the cover drainage layer should also be evaluated using the USEPA HELP model. The procedure presented in Giroud and Houlihan [1995] should be used to confirm the help model results. The calculations should evaluate both the maximum and average head buildup conditions. The maximum head should be compared to the thickness of the drainage layer to confirm that the layer thickness is greater than the maximum head and that the maximum head is less than 1 ft (0. 3 m). The average hydraulic head thickness should be used in calculations to evaluate the slope stability factor of safety of the final cover system. Cover system slope stability calculation requirements are described in Section 2.3.2 of this DCP.

2.6.7 Geotextile Cushion Layer

A. Design Criteria

A geotextile cushion layer must be installed above the geomembrane cap component of the OSDF final cover system to protect the geomembrane from puncture

by particles in the overlying granular filter layer. The geotextile should also be robust enough to resist the effects of construction (i.e., termed construction survivability).

B. Calculations

The design of the geotextile cushion layer to have adequate puncture resistance should be performed using the procedure described by Koerner et al. [1995]. The design of the geotextile cushion layer to have adequate construction survivability should be performed using the procedure described in Koerner [1994].

2.6.8 Composite Cap

A. Design Criteria

The functional requirements (Appendix B) for the OSDF call for the OSDF final cover system to contain three low-permeability infiltration barrier layers designed to isolate impacted material from the surrounding environment while minimizing liquid infiltration into the OSDF. These three layers are, from top to bottom (Figure 1-1):

- 60-mil (1.5-mm) thick geomembrane cap;
- geosynthetic clay cap; and
- 2-ft (0.6-m) thick compacted clay cap.

Taken together, these three layers are called the "composite cap". Design criteria for the composite cap are as follows:

- The composite cap should overlie all areas where impacted material has been placed (ARAR: OAC 3745-27-08(C)(15)).
- The composite cap must have a permeability less than or equal to the permeability of the liner system (ARAR: 40 CFR § 265.310).

- The HDPE geomembrane component of the composite cap must have a minimum thickness of 60 mils (1.5 mm) and be negligibly permeable to fluid migration (ARAR: OAC 3745-27-08(C)(2)).

- The compacted clay component of the composite cap must have a minimum thickness of 24 in. (0.6 m) (functional requirement) and a maximum hydraulic conductivity of 10^{-6} cm/s (ARAR: OAC 3745-27-08(C)(15)).

- The slope of the composite cap must be between 5 and 25 percent (OAC 3745-27-08(C)(15)). A flatter maximum slope should be used if necessary to achieve required slope stability factors of safety.

- The geosynthetic clay cap component of the composite cap should have a hydraulic conductivity of no greater than 1×10^{-9} cm/s (design consideration). The geosynthetic clay cap should be of the "internally-reinforced" or "HDPE-geomembrane backing" type, which will improve short-term and interim cover system stability compared to the level of stability achieved with an "unreinforced" type geosynthetic clay liner. The added strengths associated with the use of these materials should be discounted in evaluating the long-term stability of the final cover system.

- The geosynthetic clay cap must be designed to prevent failure due to long-term creep down the cover system sideslopes (design consideration).

B. Calculations

The potential for infiltration through the final cover system should be evaluated using the USEPA HELP (Version 3) computer model. This computer model has been previously described in this DCP. The results of the evaluation should be used in the leachate generation analysis to estimate leachate generation rates after the final cover system is installed over the OSDF.

2.6.9 References

FEMP property data and information required to design the OSDF final cover system should be obtained from the references cited in Section 1.5 of this DCP. References from the general technical literature that may be used in the design of the final cover system are given below.

Aldrich, H.P. and Paynter, H.M., "Frost Investigations, Fiscal Year 1953, First Interim Report," *Analytical Studies of Freezing and Thawing Soils*, Arctic Construction and Frost Effects Laboratory, New England Division, U.S. Arm Corps of Engineers, Boston, MA, 1953.

Cedegren, H.R., *"Seepage, Drainage, and Flow Nets,"* 2nd Edition, John Wiley and Sons, New York, New York, 1977.

Christopher, B.R. and Holtz, R.D., "*Geotextile Engineering Manual*", FHWA-DTFH61-80-C-00094, U.S. Department of Transportation, Federal Highway Administration, 1984.

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Hakonson, T.H., "Evaluation of Geologic Materials to Limit Biological Intrusion into Low-Level Radioactive Waste Disposal Sites", LA-10286-MS/UC-70B, Los Alamos, National Laboratories, Los Alamos, New Mexico, 1986.

Koerner, R.M., "*Designing with Geosynthetics*", Third Edition, Prentice Hall, Englewood Cliffs, NJ, 1994, 783 p.

Koerner, R.M., Wilson-Fahmy, R., and Narejo, D., "*Puncture Protection of Geomembranes, Part I: Theory, Part II: Experimental, and Part III: Examples*", Geosynthetic Research Institute, 1995.

Schroeder, P.R., Aziz, N.M., Lloyd, C.M., and Zappi, P.A., "*The Hydrologic Evaluation of Landfill Performance (HELP) Model: User's Guide for Version 3*", EPA/600/R-94/168a, U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C., 1994a.

Schroeder, P.R., Dozier, T.S., Zappi, P.A., McEnroe, B.M., Sjostrom, J.W., and Peyton, R.L., "*The Hydrologic Evaluation of Landfill Performance (HELP) Model: Engineering Documentation for Version 3*", EPA/600/R-94/168b, U.S. Environmental Protection Agency, Office of Research and Development, Washington D.C., 1994b.

U.S. Department of Energy, "*Uranium Mine Tailings Remediation Control Act, Remediation Action Design*", Technical Approach Document, Rev. II, December 1989.

2.7 Test Pad Program

2.7.1 Functional Requirements

The function of the test pad program is to provide information regarding the hydraulic conductivity characteristics of the soils that will be used for construction of the compacted clay liner and cap components of the OSDF. The information obtained during the test pad program will be used to qualify the clay borrow source(s) and define construction procedures for the compacted clay liner and cap materials.

To demonstrate that the clay from each borrow source (presently anticipated to include both the OSDF foundation excavation and the on-site borrow area) can meet the criteria for clay liner and cap materials and construction methods, the test pad program should establish that:

- the clay material can be compacted under the anticipated construction conditions to a maximum in-place hydraulic conductivity of 1×10^{-7} cm/s for the clay liner and 1×10^{-6} cm/s for the clay cap; and

- on-site sources exist for clay borrow materials that meet the other design criteria for clay liner and cap material (see Section 2.4.4 of this DCP).

Also, to meet the requirements of OAC 3745-27-08(C)(1)(m), the test pad program must:

- be designed such that the proposed tests are appropriate and their results are valid;

- be designed to establish construction procedures that result in a clay liner or cap with satisfactory hydraulic conductivity; the construction procedures include:
  - borrow material processing requirements;
  - lift thickness;
  - compaction moisture content;
  - compaction dry density; and
  - type, weight, and number of passes of construction equipment; and

- be completed prior to construction of the disposal facility component which the test pad will model.

Lastly, construction procedures for the clay liner and cap should be in general accordance with industry established guidelines, such as those in USEPA [1989, 1993].

2.7.2 Clay Borrow Material Criteria

The clay material used in the test pad program must be obtained from the same sources as the clay material that will be used in the OSDF construction project. The

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clay material must satisfy the following material property requirements (ARAR: OAC 3745-27-08(C)(1)):

- 100 percent of the particles must have a maximum dimension not greater than 2 in. (50 mm);
- not more than 10 percent of the particles, by weight, must have a dimension greater than 0.75 in. (1.9 cm);
- at least 50 percent of the particles, by weight, must pass through the U.S. Standard No. 200 sieve; and
- at least 25 percent of the particles, by weight, must have a maximum dimension less than 0.002 (2 μm).

As described in Section 2.4.4 of this DCP, available borrow at the site may not meet the requirement for the fraction of particles smaller than 0.002 mm (2 μm). A demonstration will need to be submitted to USEPA and OEPA pursuant to OAC 3745-27-08(C)(1) to obtain acceptance of the on-site borrow materials. The test pad program will be an integral part of that demonstration.

2.7.3 Test Pad Layout and Construction Criteria

The test pads should be constructed at one or more locations within the battery limit that meet the following criteria:

- The test pad should be located in an area where the soil conditions are similar to the subgrade conditions that will be encountered in the OSDF construction area (design consideration).
- If possible, the test pad should be located outside the limits of impacted soil removal and remediation (design consideration).

- The location for the test pad should be selected considering ease of access for construction vehicles, presence of perched ground water, surface-water management, etc. (design consideration).

The test pad construction program should adhere to the following basic procedures (design considerations).

- Prior to the start of construction, surface-water management and erosion and sediment controls should be established, and clearing and grubbing should be performed.

- Soils for test pad construction should be obtained from the identified on-site borrow sources.

- The test pads should be constructed using loose lifts of approximately 8 in. (200 mm) in thickness, with a maximum clod size of 3 in. (75 mm) or half of the compacted lift thickness.

- The test pads should be constructed using varying numbers of passes of compaction equipment and specified ranges of moisture content so that a relationship can be established between compaction effort, moisture content, and hydraulic conductivity.

- The target compaction criteria should be established prior to the start of test pad construction. The criteria should be based on the results of pre-construction laboratory testing of samples of the soils to be used to construct the test pads. The target compaction dry density should be at least 95 percent of the maximum standard Proctor dry unit weight according to test method ASTM D 698; target moisture contents should be between the optimum moisture content and 4 to 5 percentage points wet of the optimum moisture content (ARAR: OAC 3745-27-08(C)(1)).

- Specific equipment requirements should be identified for moisture conditioning, clod breakdown, and compaction before the start of the test pad construction project.

- Once constructed, in-situ testing techniques should be used to establish the field hydraulic conductivity of each test pad.

- After testing is complete, the test pad should be decommissioned.

To meet the requirements of OAC 3745-27-08(C)(1), the test pad must:

- be constructed whenever, during construction, there is a significant change in soil material properties;

- have a minimum width three times the width of the compaction equipment and a minimum length two times the length of compaction equipment, including any attachments;

- be comprised of at least four lifts; for each lift a minimum of 3 tests for moisture content and density must be performed;

- be tested for field permeability, following the completion of test pad construction; and

- be reconstructed as many times as necessary to meet the permeability requirement.

2.7.4 Field Test Pad Program Evaluation

The test pad program should involve both pre-construction and construction-phase testing of clay liner and cap materials.

Pre-Construction Testing Program

Pre-construction laboratory testing should be performed on the material that will be used for test pad construction to establish the soil compaction conditions that will be used in test pad construction. The steps that should be included in the pre-construction testing program are given below.

- Step 1. Perform soil index testing of materials from the borrow sources; at a minimum soil index testing should include natural moisture content (ASTM D 2216), grain size distribution (ASTM D 422), and Atterberg limits (ASTM D 4318).

- Step 2. Establish soil moisture-density relationships for several different compactive efforts.

- Step 3. Perform soil hydraulic conductivity testing to evaluate hydraulic conductivity as a function of compaction moisture content and dry density. Hydraulic conductivity testing should be performed in accordance with ASTM D 5084.

- Step 4. Based on the results of Steps 2 and 3, select field target compaction conditions (i.e., acceptable range of moisture contents and dry densities), to be used for each lane of the test pad. Procedures as described by Daniel and Benson [1990] may be used for guidance in establishing moisture-density criteria.

Construction-Phase Testing Program

Field and laboratory testing should be performed during and after test pad construction to verify the adequacy of the construction materials and methods. Testing should include:

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- field moisture content and dry density of each lift of the test pad using a nuclear gauge (ASTM D 2922 and D 3017), periodically checked using a sand cone test (ASTM D 4914) and oven moisture content test;

- laboratory confirmatory standard Proctor compaction testing (ASTM D 698);

- laboratory hydraulic conductivity testing using a flexible wall permeameter (ASTM D 5084) and undisturbed specimens of compacted material obtained using a Shelby tube; and

- field sealed double-ring infiltrometer (SDRI) testing of each completed test pad (ASTM D 3385).

2.7.5 Certified Construction Package Criteria

A certified for construction package (CFC) must be prepared for contracting of the test pad construction work (functional requirement). The construction package should include the following basic components.

- contract documents;

- construction drawings;

- technical specifications;

- construction quality assurance plan; and

- health and safety plan.

2.7.6 Work Plan

A work plan should be prepared to describe the proposed test pad program. The work plan should include drawings showing the test pad layout, typical sections, surface-water management plan, and specifications for construction of the test pad. The work plan should also include the basis for test pad design, requirements for laboratory and field testing, and requirements for construction quality assurance (CQA) monitoring and documentation. The test pad work plan should first be prepared at the pre-final (90%) level of completeness for submittal for review by DOE, USEPA, and OEPA. A final certified for construction (CFC) work plan should be issued after incorporation of review comments.

2.7.7 Cost Estimate

A test pad program cost estimate should be prepared based on the pre-final test pad program work plan. The cost estimate must be in FERMCO format. This format is illustrated by the FERMCO baseline OSDF cost estimate presented in Appendix E of this document.

2.7.8 Report

The results of the test pad program should be analyzed and a report prepared to present the program results. The report should contain: (i) recommendations regarding the suitability of the borrow sources for use as clay liner and cap material; (ii) requirements for borrow source processing; and (iii) recommended criteria for clay liner and cap construction.

2.7.9 Schedule

The CFC test pad work plan must be completed prior to the completion of the OSDF intermediate design package. The test pad program final report must be completed prior to completion of the OSDF final design package.

2.7.10 References

FEMP property data and information required to develop the test pad program should be obtained from the references cited in Section 1.5 of this DCP. References from the general technical literature that may be used to develop the test pad program are given below.

Daniel, D.E. and Benson, C.H., "Water Content-Density Criteria for Compacted Soil Liners", *ASCE Journal of Geotechnical Engineering*, 1990, Vol. 116, No. 12, 1990, pp. 1811-1830.

USEPA, "*Seminar Publication - Requirements for Hazardous Waste Landfill - Design, Construction, and Closure*, EPA/625/4-89/022, U.S. Environmental Protection Agency, 1989.

USEPA, "*Technical Guidance Document - Quality Assurance and Quality Control for Waste Containment Facilities*", EPA/600/R-93/182, U.S. Environmental Protection Agency, 1993.

2.8 Surface-Water Management

2.8.1 Categories of Surface Water

Surface-water management for the OSDF must consider three categories of surface water:

- stormwater runon from outside the battery limit into the battery limit;

- stormwater runoff, which includes all runoff from disturbed areas within the battery limit, except for wastewater explicitly identified below; and

- wastewater, which includes all waters that must be contained, collected, and ultimately discharged to the AWWT facility.

Wastewater generated as a result of development of the OSDF area includes:

- leachate and runoff from impacted material within the OSDF; these wastewaters will be contained in the OSDF, allowed to percolate into the leachate collection system, and discharged to the OSDF leachate transmission system, as described in Section 2.5 of this DCP;

- runoff from impacted-material staging areas and equipment decontamination facilities; these wastewaters will be contained, collected, and discharged to either the leachate transmission system or the FEMP former production area storm drainage control system;

- runoff from impacted-material haul roads; these wastewaters will be contained, collected, and discharged to either the leachate transmission system or the FEMP former production area storm drainage control system; and

- perched ground water that seeps into excavations; these wastewaters will be contained, collected, and discharged to the leachate transmission system.

The remainder of this section of the DCP presents design criteria for management of stormwaters and wastewaters.

2.8.2 Functional Requirements

The functions of the surface-water management system are to: (i) route surface water to a location where it can be either discharged to surrounding surface waters (in the case of stormwater) or treated (in the case of wastewater); and (ii) protect the OSDF from damage caused by precipitation and stormwater runon and runoff. The systems for control of stormwater and wastewater must be kept separate. To minimize wastewater quantities, separate management systems should exist for stormwater and wastewater.

The surface-water management system must perform in a manner that meets the project requirements for both temporary conditions (i.e., during construction, filling, and closure of the OSDF) and long-term conditions (i.e., after closure of the OSDF). The system must prevent stormwater runon to the OSDF and uncontrolled stormwater and wastewater runoff from the OSDF. Features of the permanent surface-water management system must be designed to require minimal monitoring and maintenance. The system should be integrated, to the extent possible, with existing topography, features, and facilities.

2.8.3 Stormwater Management During OSDF Construction/Filling/Closure

A. Design Criteria

- Stormwater management facilities must be designed for the 25-year, 24-hour storm event (ARAR: EPA 40 CFR § 258.40 and OAC 3745-27-08(C)(6)). For the FEMP property, this event has an intensity of 4.5 in (114 mm).

- Construction-phase runon control measures should meet the following criteria (design considerations).

    - Upgradient runon should be prevented from entering active working areas. Such runon should be diverted around work areas using berms,

dikes, or channels as appropriate. This runon should not be allowed to mix with wastewater.

- Runon to temporary excavations should be prevented.

- Runon to areas of stockpiled and/or uncovered impacted material should be prevented to the extent possible using berms and other surface-water control features.

- Prior to placement of impacted material into an OSDF cell, permanent runon controls must be in place to prevent runon into the cell resulting from the 2,000 year, 24-hour storm event. The requirements for permanent runon control are described in more detail in Section 8.4 of this DCP.

- Runoff from all disturbed areas should be routed to the appropriate temporary erosion and sediment (E&S) control basin. There must be no mixing of stormwater runoff and wastewaters (functional requirement).

- Temporary E&S basins must also meet the following criteria of OEPA (ARAR: OAC 3745-27-08(C)(6)):

  - the minimum acceptable basin storage should be established as the larger of the calculated runoff volume from a 10-year, 24-hour storm event, or, 0.125 acre-ft (0.015 ha-m) per year (for each acre (ha) of upgradient disturbed area) multiplied by the scheduled frequency of basin cleanout (in years);

  - the principal spillway should be capable of safely discharging the flow from a 10-year, 24-hour storm event; the inlet elevation of the emergency spillway should be designed to provide flood storage, with no flow entering the emergency spillway during a 25-year, 24-hour storm event, with allowance provided for the flow passed by the principal spillway during the event;

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- the combination of principal and emergency spillways should be capable of safely discharging the flow from a 100-year, 24-hour storm event; the basin embankment design should provide for no less than 1 ft (0.3 m) of net freeboard when flow is at the design depth, after allowance for embankment settlement; and

- the basin should be constructed using a compacted soil liner, a geomembrane, or a combination thereof.

- Open channels for stormwater runoff should be designed to meet the following criteria (design consideration).

  - Channel lining:
    - peak flow velocity in riprap-lined channels should be less than 12 ft per second (3.7 m/s), unless it is demonstrated that greater velocities will not cause erosion or malfunction of the surface-water management feature; and
    - peak flow velocities in grass-lined channels should be less than 5 ft per second (1.5 m/s).

  - Channel sideslopes should be no steeper than 3 horizontal to 1 vertical.

  - Bottom widths may be zero for roadside ditches. The bottom width should be at least 2 ft (0.6 m) in other temporary drainage channels. If the channels is greater than 4 ft (1.2 m) deep, the bottom should be sloped at a minimum of 5 percent toward the ditch center.

  - The ditch freeboard should be at least 0.5 ft (0.15 m) under the design storm event.

  - Channels should be sloped at no less than 0.5 percent to prevent sediment buildup and clogging, unless it can be established by calculation that a lesser slope will not clog or build up sediment that will cause loss of flow capacity in the design storm event. Channel slopes should be no

steeper than 5 percent unless it can be established by calculation that a steeper slope will not cause unacceptable erosion or other malfunction.

- Culverts should be designed according to the following criteria (design consideration).

  - Culverts may be used in locations as needed and where cost-effective. Culverts upgradient of the OSDF should be removed at the completion of construction and should not be incorporated into the permanent stormwater management system. Permanent culverts may be used downgradient of the OSDF if necessary to provide permanent access to the perimeter access corridor if failure of the culvert would not result in damage or interruption of the OSDF.

  - Channels should be protected from erosion using riprap or erosion mats for a distance of at least two culverts diameters upstream and four culvert diameters downstream of the culvert inlet or outlet, respectively.

- Riprap shall be designed according to the following criteria (design consideration).

  - Riprap should meet the following particle size criteria [USDA SCS, 1987]:
    - $D_{max} = 1.5 \times D_{50}$
    - $D_{15} = 0.5$ to $0.75 \times D_{50}$
    - minimum thickness of riprap lining $= 2 \times D_{50}$, where: D_{50} = theoretical spherical diameter of average stone size; D_{max} = theoretical spherical diameter of largest stone size; and D_{15} = theoretical spherical diameter of the stone size for which 15 percent of the material is smaller.

  - Riprap used at channel transitions should extend upstream and downstream of the transition a distance of five times the downstream channel depth; the minimum extension should be 15 ft (4.5 m).

- Geotextile filters may be used to control piping and erosion beneath riprap in temporary facilities. Granular soils should be used for filters in permanent structures containing riprap.

- Rock, grade control structures should be designed according to the following criteria.

  - Rock, grade control structures may be used in temporary facilities. They should be designed in accordance with standard design procedures.

  - The minimum dike height of rock grade control structures should be 1.5 ft (0.45 m) and the minimum top width should be 2 ft (0.6 m).

B. Calculations

The runoff to each temporary E&S basin should be calculated for each contributory area during each representative phase of OSDF development. Runoff to the basin should be used as the basis for basin design. Calculations should be performed using the design storm precipitation events identified previously. Runoff volumes may be calculated as described in Technical Release 55, published by the United States Department of Agriculture Soil Conservation Service [USDA SCS, 1986a]. Basin design should be based on the information and guidance contained in USDA SCS [1986a,b, 1987, and 1989].

Stormwater routing calculations should be performed using either Technical Release 55, published by the USDA SCS [1986a], or the computer program "Pond Pack" [Haestad Methods, 1989], which uses Technical Release-20 [USDA SCS, 1975] techniques. Temporary E&S basins should be designed to release the runoff from the design storm at a rate not larger than the predevelopment discharge rate.

Impacted runoff should be routed to either the leachate transmission system or other controlled discharge points acceptable to the integrated FEMP remediation activities.

2.8.4 Stormwater Management After Closure

A. Design Criteria

- Permanent runon control for the OSDF must be designed to limit damage (i.e., washout) and interruption of the OSDF for the 2,000-year storm event (design criterion for assumption of a DOE Performance Category 2 facility). Runon should be controlled and diverted away from and around the OSDF using swales, channels, or diversion berms (design consideration).

- Runoff control measures must be designed according to the following criteria (design consideration).

  - Runoff from the closed OSDF facility should be conducted by sheet flow to a perimeter drainage swale constructed around the entire perimeter of the OSDF.

  - The perimeter drainage swale should outlet to existing drainage features at the battery limit. The location of the outlet should progress from north to south concurrent with the progressive development of the OSDF. The final outlet location should be immediately southwest of the southern limit of the OSDF.

- The perimeter drainage swale for the OSDF must be designed to limit damage (i.e., washout) and interruption of the facility during the 2,000-year storm event (design criterion for assumption of a DOE Performance Category 2 facility). The perimeter drainage system outlet at the battery limit should also be designed to limit damage and interruption to the OSDF during the 2,000 year storm event.

- Stormwater routing and stormwater management system design for watercourses and structures beyond the battery limit will be addressed in other design packages prepared as part of the integrated FEMP remediation.

- The perimeter drainage swale must be designed to meet the following criteria (design considerations).

  - The dimensions of the swale must be designed to accommodate both normal low flows and peak precipitation runoff flows.

  - The perimeter drainage swale final grade should be no less than 0.5 percent to prevent sediment buildup and clogging, unless it can be established by calculation that a lesser slope will not clog or buildup sediment that will cause loss of flow capacity in the design storm event. Swale slopes should be no steeper than 5 percent unless it can be established by calculation that a steeper slope will not cause unacceptable erosion or other malfunction.

  - Peak flow velocity in swales should not initiate scour in the channel. Flow velocity of runoff during high frequency (e.g., 2-year return frequency) and low-intensity (i.e., approximately 1 in. (125 mm) per hour) storm events should be large enough to limit sedimentation in the channels, to the extent possible.

  - Swale sideslopes should be no steeper than 3 horizontal to 1 vertical.

  - The minimum bottom width for the perimeter drainage swale should be at least 10 ft (3 m). The bottom should have a minimum slope of 5 percent toward the center of the swale.

  - The freeboard in the perimeter drainage swale should be at least 6 in. (0.15 m) during the design storm event.

- Culverts upgradient of the OSDF, if needed, should be removed at completion of construction and should not be incorporated into the permanent stormwater management system. Permanent culverts may be used downgradient of the OSDF if necessary to provide permanent access to the facility and if failure

to the culvert would not result in damage or interruption of the OSDF (design consideration).

- Riprap, if needed, should be designed as described in Section 2.8.3 of this DCP (design consideration).

- Permanent riprap should consist of field stone or rough unhewn quarry stone of approximately rectangular shape. The stone should be hard and angular and of a good quality, consistent with the UMTRA Technical Approach Document [DOE, 1989].

- Granular soils should be used as filters and bedding for permanent riprap features (design consideration).

- Rock, grade control structures, if used, should be designed to meet the criteria listed in Section 2.8.3 of this DCP (design consideration).

B. Calculations

Runoff to the perimeter drainage swale may be calculated as described in Technical Release 55, published by the USDA SCS [1986a], or other suitable method. Analysis of sheet flow on long surfaces and formation of gullies on such surfaces should also be evaluated using the methods published by Temple [1980] and Temple et al. [1987].

Stormwater routing calculations should be performed using either Technical Release 55, published by the USDA SCS [1986a], or the computer program "Pond Pack", by Haestad Methods [1989], which uses the Technical Release-20 [USDA SCS, 1975] techniques.

2.8.5 Wastewater Management

Wastewaters that will be encountered in development of the OSDF were identified in Section 2.8.1 of this DCP. These wastewaters should be managed as follows.

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- *Leachate* - All precipitation or other water that falls into an active OSDF cell will be considered leachate and allowed to percolate into the cell leachate collection system. Placement of impacted material in OSDF cells should be performed such that the cells can always store runoff from active and open portions of the cell resulting from the 25-year, 24-hour storm event (ARAR: OAC 3745-27-08(C)(6)). Leachate will be managed as described in Section 2.5 of this DCP.

- *Impacted Runoff* - Impacted material staging areas and equipment decontamination facilities will be constructed of concrete. Runoff from these areas should drain to sumps. Liquid in the sump of a equipment decontamination facility should be discharged into the leachate transmission system. Liquid from the staging areas should be discharged into the leachate transmission system if the area is located within the battery limit, and to the FEMP former production area storm drainage control system if the stating area is situated in the former production area. Additional discussion of the equipment decontamination facility and the impacted material staging area is presented in Section 2.10 of this DCP. Impacted runoff from impacted material access roads should be contained, collected, and discharged into the leachate transmission system, or if feasible, allowed to flow by gravity to the FEMP former production area storm drainage control system.

- *Perched Ground Water* - Perched ground water that enters the OSDF excavation should be collected in a toe drain, or other suitable drain, and pumped into the leachate transmission system.

2.8.6 References

FEMP property data and information required to design the surface-water management system should be obtained from the references cited in Section 1.5 of this DCP. References from the general technical literature that may be used to design these systems.

Haestad Methods, "Pond Pack," Waterbury, CT, 1989.

Temple, D.M., "Tractive Force Design of Vegetated Channels", in *Transactions*, American Society of Agricultural Engineers, Vol. 23, 1980, No. 4, p. 884-890.

Temple, D.M., Robinson, K.M., Ahring, R.M., and Davis, A.G., *Stability Design of Grass-Lined Open Channels*", U.S. Department of Agriculture, Agriculture Research Service, Agriculture Handbook Number 667, 1987.

USDA-SCS, "*Computer Program for Project Formulation, Hydrology*", Technical Release 20 (TR20), U.S. Department of Agriculture, Soil Conservation Service. Washington, D.C., 1975.

USDA-SCS, "*Urban Hydrology for Small Watersheds*", Technical Release 55 (TR55), U.S. Department of Agriculture, Soil Conservation Service, Washington, D.C., 2nd Edition, 1986a.

USDA-SCS, *Engineering Field Manual for Conservation Practices*, U.S. Department of Agriculture, Soil Conservation Service, 1986b.

USDA-SCS, "*Water Management and Sediment Control for Urbanized Areas*", U.S. Department of Agriculture, Soil Conservation Service, Washington, D.C., 1987.

USDA-SCS, *Ponds - Planning, Design Construction*, Agricultural Handbook Number 590, U.S. Department of Agriculture, Soil Conservation Service, Washington, D.C., November 1988.

U.S. Department of Energy (DOE), "*Uranium Mine Tailings Remediation Control Act, Remediation Action Design*", Technical Approach Document, Rev. II, 1989.

2.9 Erosion and Sediment Control

2.9.1 Functional Requirements

The functional requirements for erosion and sediment control features for the OSDF are given below.

- Permanent erosion control features for the OSDF must be designed to minimize erosion under the design storm, which is a storm event having a recurrence interval of 2,000 years (functional requirement). This storm has a precipitation of 13 in. (330 mm) in a 24-hour time period [Parsons, 1995a].

- The final cover system should be designed to convey runoff to the perimeter drainage swale.

- The permanent drainage swale should be vegetated. A suitable stand of vegetation should be established as soon after grading of the swale as possible. The flow capacity of the swale should be estimated based on the anticipated climax vegetation in the swale (design consideration). The perimeter drainage swale should protect the final cover system from headward and lateral gully intrusion (design consideration).

- Durable gravels, cobbles, or boulders should be placed in the swales, and/or mixed with the topsoil layer if necessary to provide, or augment, the erosion resistivity of the native soils and climax vegetation. The arrangement of the gravels (e.g., gradation, thickness, mix percentage, etc.) should not significantly impede the establishment and growth of climax vegetation in the swales (design consideration).

- During construction, filling, and closure of the OSDF, runoff from all disturbed areas should be routed to temporary E&S basins prior to discharge to natural watercourses, except for wastewaters which should be managed as described in Section 2.8 of this DCP.

- The soil layers of the final cover system must be made thick enough to provide an adequate growing medium for the anticipated types of established and climax vegetation and to provide for their anticipated root depths. The minimum thickness is 6 in. (0.15 m) for topsoil over at least 21 in. (0.53 m) of vegetative soil layer material (functional requirement). The soil should be sufficiently thick to maintain an adequate moisture content, under normal conditions, to support vegetation growth (design consideration).

2.9.2 Erosion Control During OSDF Construction, Filling, and Closure

A. Design Criteria

- Runoff from low intensity, high frequency storm events should not initiate sheet erosion or result in gully initiation or development in disturbed areas.

- The size of any open excavation or disturbed area should be limited to as small an area as possible to minimize the potential for erosion (design consideration).

- Temporary erosion control may be achieved using geosynthetic materials, vegetation, hay bales, silt fences, rock grade control structures, or other appropriate structures.

- To minimize the generation of new contaminated materials, the use of erosion control materials should be avoided, if possible, in impacted soils requiring OSDF disposal. Preference should be given to runoff control, surface grading, and the selective use of erosion resistant impacted materials to control erosion of impacted areas (design consideration).

- To control erosion in temporary drainage ditches or swales, use may be made of shallow grades, gravelly soil, silt fences, hay bales, and the establishment and maintenance of vegetation. Swale erosion should also be controlled by

limiting the flow velocity in swales, whenever possible, to less than that which would initiate gully erosion (design consideration).

- Maintenance and upkeep procedures for temporary erosion control features should be specified in the construction specifications (design consideration).

2.9.3 Erosion Control After Closure

A. Design Criteria

- The OSDF must be designed to limit erosion caused by the maximum design storm event, which for purposes of design is assumed to be 2,000-year, 24-hour recurrence interval storm event (based on the design assumption that the OSDF will meet the Performance Category 2 requirements of DOE Standard 1020-94 [DOE, 1994]).

- Erosion control of the OSDF final cover system should be achieved through combination of flat slopes, smooth slope transitions, and use of appropriate soil types and seed/fertilizer mixes (design consideration).

- Swale erosion control should be achieved by limiting the flow velocity to less than that which would initiate gully erosion (design consideration).

- Erosion potential should be minimized at transitions by utilizing smooth, rounded, and graded transitions wherever possible (preferred) and erosion control structures only when needed (design consideration).

B. Calculations

Final Cover System

The erosion resistance of the final cover system should be evaluated as follows:

- calculate the precipitation intensity for various storm recurrence intervals;

- establish the duration that is associated with the time of concentration that results in the peak runoff flow rates and velocities;

- establish the flow depth, velocity, and shear force for runoff on the cover using the methods established by Temple [1980] and Temple et al. [1987], as described in the DOE Technical Approach Document [1989] and referenced documents;

- establish the resistance to gully initiation of the selected soil and vegetation of the topsoil cover component, as described by Temple et al. [1987]; and

- using the Unified Soil Loss Equation, confirm that erosion of the topsoil and vegetative soil layer does not: (i) exceed 5 tons per acre per year (11.5 tonnes per hectare per year); and (ii) over the (up to) 1,000-year design life of the OSDF, result in exposure of the final cover system components beneath the vegetative soil layer.

Perimeter Drainage Swale

The erosion resistance of the perimeter drainage swale should be evaluated as follows:

- calculate the precipitation intensity and storm routing for various storm durations for the design precipitation recurrence interval to establish flow rates in the swale;

- establish the depth and velocity of flow in the swale using standard hydraulic calculation methods and then evaluate the shear stresses applied to the swale bed due to the flow using the methods established by Temple [1980] and Temple et al. [1987], as described in the DOE Technical Approach Document [DOE, 1989] and referenced documents; and

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- establish the resistance to gully initiation of the selected swale lining material (e.g., topsoil and vegetation) using data from specifications, on-site soil characterization, and local observations; also use standard technical references (for example, Chow [1959]) to compare the soil resistance to erosion by water flow at specific velocities to the calculated velocities in the swales.

2.9.4 Sediment Control Design Criteria

2.9.4.1 Sediment Control During OSDF Construction/Filing/Closure

A. Design Criteria

- Temporary E&S basins should receive only stormwater runoff, not wastewater (design consideration).

- Temporary E&S basins should be designed to meet all relevant OEPA criteria cited in Section 2.8.3 of this DCP (design consideration).

- Temporary E&S basins should have sufficient sediment storage capacity to function without cleaning for at least one month, or longer if shown to be safe and cost-effective (design consideration).

B. Calculations

The capacity of the temporary E&S basins to remove sediment should be calculated. The calculation should be performed using standard USDA-SCS procedures [USDA SCS, 1986a,b, 1987, 1988] to calculate the sediment yield of soils, the rate at which they will be transported to the basins, and the rate of settlement of sediments within the basins.

2.9.4.2 Sediment Control After Closure

After the OSDF is closed, sediment control should not be required (design consideration). The criteria for the layout and construction materials used for the components of the OSDF final cover system are intended to minimize erosion and off-site sedimentation so that sediment removal structures will not needed after closure of the OSDF. Furthermore, the perimeter drainage swale is designed to be vegetated and disturbed areas will be restored to a vegetated state. Therefore, after the OSDF has been closed and after disturbed areas have been stabilized with revegetation, sediment control structures should be decommissioned.

2.9.5 References

FEMP property data and information required to design erosion and sediment control facilities should be obtained from the references cited in Section 1.5 of this DCP. References from the general technical literature that may be used to design these facilities are given below.

Chow, V.T., *Open-Channel Hydraulics*, McGraw-Hill, Inc., 1959.

Haestad Methods, "Pond Pack," Waterbury, CT, 1989.

Parsons, *"2,000-Year Flood and Probable Maximum Flood Sitewide Flood Plain Determination"*, CERCLA/RCRA Unit 2, Project Order 148, Fernald Environmental Management Project, Rev. A, Fairfield, OH, August 1995a.

Temple, D.M., "Tractive Force Design of Vegetated Channels", in *Transactions*, American Society of Agricultural Engineers, Vol. 23, 1980, No. 4, p. 884-890.

Temple, D.M., Robinson, K.M., Ahring, R.M., and Davis, A.G., *Stability Design of Grass-Lined Open Channels*", U.S. Department of Agriculture, Agriculture Research Service, Agriculture Handbook Number 667, 1987.

USDA-SCS, "*Computer Program for Project Formulation, Hydrology*", Technical Release 20 (TR20), U.S. Department of Agriculture-Soil Conservation Service, Washington, D.C., 1975.

USDA-SCS, "*Urban Hydrology for Small Watersheds*", Technical Release 55 (TR55), U.S. Department of Agriculture-Soil Conservation Service, Washington, D.C., 2nd Edition, 1986a.

USDA-SCS, *Engineering Field Manual for Conservation Practices*, U.S. Department of Agriculture-Soil Conservation Service, November 1986b.

USDA-SCS, "*Water Management and Sediment Control for Urbanized Areas*", U.S. Department of Agriculture-Soil Conservation Service, Washington, D.C., 1987.

USDA-SCS, *Ponds - Planning, Design Construction*, Agricultural Handbook Number 590, U.S. Department of Agriculture-Soil Conservation Service, Washington, D.C., November 1988.

U.S. Department of Energy (DOE), "*Uranium Mine Tailings Remediation Control Act, Remediation Action Design*", Technical Approach Document, Rev. II, 1989.

2.10 Support Facilities and Utilities

2.10.1 Functional Requirements

The function of support elements and utilities is to provide support for, and enhance the performance of, the OSDF during construction, filling, closure, and post-closure care. As identified in Section 1.3 of this DCP, the support elements will include administrative support trailers, decontamination facilities for personnel and equipment, staging areas, equipment maintenance facilities, materials storage areas, and access control features. Utilities will include electricity, natural gas, water, wastewater, security, and telephone systems. Design criteria are presented separately in this section for each of these elements.

The support elements must provide adequate and reliable support for the construction activities that will be performed for the OSDF. Utilities must provide reliable service to the support elements for each type of utility. The support elements and utilities should be developed in a manner that is consistent with the requirements of applicable utility codes at the FEMP and with applicable health and safety requirements for the FEMP.

2.10.2 Criteria

2.10.2.1 Utilities

- The utility types and demand should be evaluated based on the requirements for both temporary construction facilities during each stage of construction, filling, and closure of the OSDF and requirements for the post-closure care period (design consideration).

- The utility services design should be from the point of service to the battery limit. Design of the utilities from the battery limit to the utility sources will be performed as part of a separate design package being prepared under the integrated FEMP remediation.

- The design of the utilities must be performed using regulations and guidance from local and state governments, OEPA, Cincinnati Gas & Electric, other public utilities, ASTM, ASCE, ANSI, ACI, NEC, and other groups which promote safety and design standards for utilities supply.

- The routing of utilities should be based on consideration of avoiding areas that are to be demolished or developed, on-site soil remediation areas, and borrow areas in which excavation is planned.

- The utilities should be installed at a depth sufficient to prevent damage due to freeze-thaw effects.

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- The utility lines should be designed to accommodate vehicle and/or railroad loadings at locations where the utilities will cross beneath haul roads, access roads, or railroads.

- A water supply should be provided for dust suppression and moisture control during placement of material in the OSDF. Multiple hose connections should be provided along the western side of the OSDF.

2.10.2.2 Administrative Support Trailers

- A personnel decontamination trailer should be provided in order to pass from the construction staging area to the active work area in an OSDF cell (functional requirement)

- Trailers should be located within a paved or gravel-surfaced construction administration area within the battery limit (design consideration).

- Trailers should be designed having an adequate amount of space for the activities that will occur in the trailer (design consideration).

- The trailers, including construction standards, tiedowns, utility provisions, and access provisions, must satisfy local codes and regulations.

2.10.2.3 Decontamination Facilities

Decontamination facilities will be used for decontamination of personnel and equipment that are exposed to impacted material within the battery limit. The equipment decontamination facilities must be designed to (design consideration):

- be capable of providing decontamination of the undercarriage and exterior of a vehicle to remove particulate matter, using high pressure spray from the sides and bottom; the decontamination stations may be temporary and transportable; side panels should be used to control fugitive emissions from the decontamination stations;

- have a concrete pavement meeting American Association of State Highway and Transportation Officials (AASHTO) H-20 loading criteria;

- be large enough to contain runoff and spray water from decontamination of construction equipment and other equipment that will be decontaminated;

- contain wastewater and solids that are generated by the decontamination process;

- have a secondary containment system beneath the equipment decontamination pad that includes, at a minimum, a HDPE geomembrane liner overlain by a granular drainage layer; the secondary containment system must convey any flow to the decontamination facility sump;

- have a sump, pump, and forcemain system to evacuate decontamination water from the facility and route it to the leachate transmission system; and

- be resistant to chemical attack by the materials that will be contained in the facility.

2.10.2.4 Impacted Material Staging Area

Design criteria for impacted material staging areas are presented in Section 2.12 of this DCP.

2.10.2.5 Equipment Maintenance Facilities

A site-wide fueling truck will service construction vehicles assigned to OSDF construction, filling, and closure. Therefore, a fueling station local to the OSDF will not be required. All day to day maintenance will be provided by the site-wide service. Major equipment repairs will be made in a central maintenance/ decontamination facility at the FEMP. Equipment requiring maintenance will first be decontaminated

at the OSDF equipment decontamination facility, then driven or transported to the central maintenance/decontamination facility, provided with further decontamination, if necessary, and then serviced.

2.10.2.6 Materials Storage Area

The materials storage area will be used by the construction contractor to store materials that will subsequently be used in constructing, filling, and closing the OSDF. The area must be:

- located within the battery limit;
- large enough to contain the materials that will be used during construction of each phase of the OSDF;
- located in an area that is convenient to the OSDF construction area;
- located within an area where runoff is routed to a temporary E&S basin;
- designed to divert runoff to the basin; and
- designed with runon diversion controls.

2.10.2.7 Access Control

The function of the access control system is to provide control over ingress to, and egress from, the OSDF. One of the primary features of the access control system is installation of a construction/security fence around the active construction area, with staging, support, and administration areas also enclosed by construction/security fencing. The fencing is intended to prevent unauthorized access to the OSDF. The access control features must be designed as described below (design considerations).

- Construction/security fencing should be of chain link construction and satisfy Ohio Department of Transportation (ODOT) standard specifications.

- Signs warning unauthorized individuals to keep out should be placed on the fence at 50 ft (15 m) intervals.

- Authorized personnel and vehicle access should be through a lockable access control gate.

- Access gate(s) should be placed at location(s) that are convenient for controlling access to the facility, while not unnecessarily limiting access.

- The construction/security fence should be designed so that it does not inhibit flow at locations where it crosses surface-water drainage features.

2.10.3 References

FEMP property data and information required to design the support facilities and utilities should be obtained from the references cited in Section 1.5 of this DCP.

2.11 Borrow Area

2.11.1 Functional Requirements

The function of the borrow area is to provide soil for construction of the liner and final cover systems, and for other earthwork, related to construction, filling, and closure of the OSDF. This includes soil borrow for construction of the compacted clay liner and cap, vegetative soil layer, compacted fill, and other earthwork associated with the project. The borrow area will be developed over a period of from seven to 25 years, with a 10 year design life used for planning purposes. After the borrow area is restored, it should function with minimal maintenance.

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The borrow area should be developed in a manner that results in efficient utilization of the available soils, provides soils with the required engineering properties at the appropriate phases of OSDF development, and minimizes the costs associated with the development and restoration of the area. In addition to these requirements, the design of the borrow area should consider the requirements described below.

- The borrow area should be laid out in a manner that provides easy ingress and egress to prevent the possibility of accidents.

- The area should be development in a manner that requires minimal additional earthwork after borrow activities are complete to achieve the required restoration grades.

- Restoration should be performed progressively as work is completed in portions of the borrow area.

- Erosion and sediment controls should be implemented in the borrow area during construction and restoration.

2.11.2 Design Criteria

2.11.2.1 Location

- The borrow area should be located in an area having material quantities and types sufficient for OSDF construction, filling, and closure (design consideration).

- The borrow area should be located within the FEMP property and should not encroach on the transmission line, oil pipeline, or other easements (design consideration).

- To the extent possible, the borrow area should not extend vertically into the gray clay. The borrow area should have sufficient final slope (e.g., at least 0.25 percent) to promote drainage (design considerations).

- Within the above constraints, the borrow area should be as deep as possible to minimize the size of the area (design consideration).

- The location of the borrow area should be chosen so that after restoration, minimal maintenance is required and the area is stable (design consideration).

2.11.2.2 Layout

A. Design Criteria

- The borrow area should be laid out to facilitate the phased development of the area (design consideration).

- The borrow area should be laid out to avoid interferences with roads, utility corridors, easements, etc. (design consideration).

- A soil contingency volume should be provided in the borrow area for possible use in (design consideration):

  - construction of a OSDF contingency cell if disposal volumes are larger than anticipated;

  - backfilling to subgrade elevations beneath the footprint of the OSDF in the event that additional excavation of impacted material is necessary;

  - constructing portions of the contouring layer of the cover system with "clean" soil in the event that suitable impacted soil is not available for this purpose; and

  - providing material for interim closure, should such closure be necessary.

- Intermediate borrow area slopes that will not be vegetated should be cut at a safe angle of repose for the material (design consideration).

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- Permanent restored slopes within the borrow area should be no steeper than 5H:1V (design consideration).

B. Calculation

A analysis should be performed to evaluate the engineering properties and volumes of material available in the borrow areas. The available volume of borrow soil should be compared to the required volume taking into account shrinkage/bulking and the possible contingency volume. Calculations should be performed using computer-aided design techniques by comparing the volume between the existing ground surface and the final grades of the borrow area and then subtracting from that volume the estimated volume of impacted material that is expected to be excavated from the ground surface.

2.11.2.3 Surface-Water Management

- Stormwater runoff and runon in the borrow area should be managed in general accordance with the criteria given in Section 2.8 of this DCP (functional requirement).

- During development of the borrow area, stormwater runoff should be discharged from temporary E&S basins at a rate not greater than the predevelopment runoff discharge flow rate (design consideration).

- Stormwater runoff should be managed so that, after restoration of the borrow area, the effects of erosion of the borrow area ground surface are minimal. Long-term erosion of the ground surface in the borrow area must not impact the OSDF (design considerations).

- Stormwater runoff should be routed to the tributary to Paddy's Run located near the southwest cover of the battery limit. During construction, stormwater runoff should be routed through a temporary E&S basin and then discharged to Paddy's Run. Following restoration of the site, stormwater runoff may be routed directly to the tributary to Paddy's Run (design consideration).

2.11.2.4 Development of Borrow Area

- The borrow area should be developed in a manner that produces consistent materials for construction of the OSDF. As part of design, the properties of the borrow area soils should be characterized and locations where suitable soils may be obtained for each component of the OSDF should be identified (design consideration).

- Requirements for processing of the borrow area soils should be identified during design. If possible, such processing should be performed in the borrow area. Such processing could include moisture conditioning, blending, screening, or crushing (design consideration).

- Before the start of borrow area development, the following activities should be performed (design considerations):

  - establishment of temporary stormwater management and erosion and sediment controls for the borrow area, including temporary E&S basins; criteria and procedures described in Section 2.8 and 2.9 of this DCP should be used to design these controls;

  - establishment of perimeter access controls for the borrow area (consistent with the requirements of Section 2.10);

  - removal of impacted soils from within the borrow area (as identified by the applicable OU5 remedial design documents) and transport of the soils to the OSDF or the temporary stockpiling area (according to the procedures described in Section 2.12 of this DCP); and

  - establishment of soil processing facilities (if any are needed).

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2.11.2.5 Material Suitability

The suitability of the earth materials in the borrow area should be confirmed prior to establishing the final location and layout of the borrow area. Suitability should be based on a comparison of the characteristics of the available materials available in the required properties of the materials that will be used to construct the OSDF (based on information presented in other sections of this DCP) (design consideration). Section 1.5 of this DCP cites references of site-specific studies that provide information on the properties and characteristics of candidate borrow soils.

2.11.2.6 Restoration

The borrow area should be restored in accordance with the FEMP site-wide restoration plan (which is currently being developed) to a condition that requires minimal maintenance. The borrow area should be restored to a condition that is consistent with the geomorphological character of the area surrounding the FEMP. Accordingly, the following criteria should be followed in preparing the restoration plan for the borrow area.

- Final grades should be selected that minimize long-term erosion in the area. The final grades should not result in erosion that is greater than the calculated erosion rate for stabilized slopes in the vicinity of the FEMP that have similar grades and similar soil types (design consideration).

- Stormwater runoff from the restored borrow area should drain to the tributary of Paddy's Run located near the southwest corner of the battery limit (design consideration).

- The restored borrow area should be revegetated with plant species that minimize erosion, that can be successfully established on the design final grades and soil types, and that are self-propagating in the expected conditions of the restored borrow area (design consideration).

- The design of the restoration plan should provide for progressive restoration of the borrow area, with commencement of restoration in an area as soon as borrow activities have been completed. To the extent possible, activities should not be performed in portions of the borrow area that have been restored (design consideration).

2.11.3 References

FEMP property data and information required for design of the borrow area should be obtained from the references cited in Section 1.5 of this DCP.

2.12 Impacted Material Management

2.12.1 Functional Requirements

The function of impacted material management activities is to excavate, handle, transport, and place impacted material in the OSDF in a safe and cost-effective manner that prevents the uncontrolled release of impacted material to the environment. In this section of the DCP, the criteria that should be followed for the design of impacted material management facilities associated with the OSDF are described. Impacted material should be placed in accordance with the report entitled "*Impacted Material Placement Plan*," which will be prepared as described in Section 3.2.4.3. Impacted material management activities will include: (i) transporting impacted materials from areas within the battery limit where the materials are excavated to either temporary staging areas and/or the OSDF; (ii) transporting impacted material from operable units to either temporary staging areas and/or the OSDF; (iii) placing the material within the OSDF; and (iv) managing the generation of fugitive emissions and wastewaters during impacted material placement operations.

This DCP addresses impacted material management activities within the battery limit and related to the use of temporary staging areas. Other activities, primarily

associated with remediation of the operable units, will be addressed in other design packages to be prepared as part of the integrated FEMP remediation.

2.12.2 Performance Requirements

Facilities provided to meet the functional requirements for impacted material management should include: (i) construction/security fencing for control of access within the battery limit; (ii) impacted material access roads; (iii) impacted material staging areas; and (iv) equipment and personnel decontamination facilities. Facilities for impacted material management must:

- be located within the battery limit or temporary extensions to the battery limit within the FEMP former production area;
- be located in areas that can easily and efficiently accommodate receipt of impacted material from the various FEMP operable units;
- be separated from clean areas;
- minimize uncontrolled discharge of fugitive emissions;
- minimize the generation of wastewaters;
- comply with project health and safety requirements;
- be removed at the completion of impacted material management activities, with the disposal of affected materials in the OSDF; and
- be designed to minimize the generation of affected materials.

2.12.3 Design Criteria

2.12.3.1 Access From Operable Units

- Design of access from the operable units to the OSDF battery limit will be addressed as part of other design packages prepared as part of the integrated FEMP remediation. Access into the battery limit should be restricted using fences, gates, or other appropriate measures in accordance with the criteria given in Section 2.10.2.7 of this DCP (design consideration).

- Access control facilities should be designed to monitor equipment used to transport impacted material. Access controls within and at the battery limit should be managed and operated by the construction contractor (design consideration).

- Procedures should be prepared (and presented in the *Impacted Material Placement Plan*) to assure the proper routing of vehicles to the OSDF, temporary staging area, or other location within the battery limit designated to receive the impacted material (design consideration).

2.12.3.2 Impacted-Material Haul Roads

A. Design Criteria

Separate temporary haul roads should be provided for the equipment that transports impacted material and the equipment that transports OSDF construction materials. The following criteria should be used in designing impacted material haul roads within the battery limit.

- Roads must be designed for AASHTO H-20 loading (functional requirement).

- The maximum design speed for haul roads should be 20 miles per hour (mph) (36 kilometers per hour or kph) (design consideration).

- The design life for on-site impacted material haul roads should be either five or ten years, depending on the anticipated service lives of the roads (design consideration).

- Road surfacing should be selected based on durability, ease of construction, minimizing maintenance requirements, and minimizing impacts to OSDF cell construction activities (design consideration). Unless otherwise designed, roads may be unpaved. The minimum acceptable road section, from top to bottom, must include:

  - 8-in. (0.2-m) thick layer of ODOT Type A bank or crusher run stone;

  - geotextile separator; and

  - prepared subgrade.

- Road widths should be as follows (design consideration):

  - one-way, single-lane roads for highway vehicles should be 12 ft (3.6 m) wide having shoulders 5 ft (1.5 m) wide on each side;

  - two-way, double-lane roads for highway vehicles should be 24 ft (7.3 m) wide having shoulders 5 ft (1.5 m) wide on each side;

  - one-way, single-lane site roads used by off-highway vehicles should be 16 ft (4.9 m) wide with shoulders of up to 5 ft (1.5 m) to accommodate vehicles having large widths;

  - two-way, double-lane roads for off-highway vehicles should be 32 ft (10 m) wide with shoulders of up to 5 ft (1.5 m); and

  - two-way traffic should be allowed on single-lane roads only if such roads have turnoffs.

- Roads should be designed with a 3 percent cross slope.

- Wherever possible, haul road grades should be 3 percent, or less. Where required to obtain cell access, road grades as steep as 10 percent may be allowed for short distances (design consideration).

- Road turning radii should be at least 50 ft (15 m) at the centerline of the road (design consideration).

Cut and fill slopes for impacted material haul roads should be designed to have a maximum side slope of 3H:1V. Where construction activities or other spatial constraints limit right of way, cut and fill having a maximum slope of 2H:1V may be used if shown to be stable. Drainage ditches should be used to convey impacted runoff from the haul roads to impacted-runoff sumps. Water collected in the sumps should be treated as wastewater and managed as described in Section 2.8.3 of this DCP.

B. Calculations

Impacted material haul roads should be designed for the anticipated type and quantity of traffic that will pass over the road. The roads should be designed using standard techniques for design of unpaved roads (for example, as described by Giroud and Noiray [1981] or using the AASHTO method [1972] for a zero thickness pavement). Roads should be designed using locally available aggregates and construction materials, such as identified in the ODOT standard specifications.

2.12.3.3 Impacted Material Staging Areas

A. Design Criteria

Impacted material staging areas should:

- be constructed on clean foundation material (functional requirement);

- incorporate a concrete working pad designed in accordance with ACI 318-93 [ACI, 1993]; if the staging area is located outside the FEMP former production area, the working pad should include a double-containment system that includes as a minimum, from top to bottom (functional requirement):

  - concrete working surface having a thickness of at least 8 in. (0.2 m) and capable of supporting both on-road and off-road impacted material haul vehicles;

  - 12-in. (0.3-mm) thick layer of ODOT Type A bank or crushed run stone;

  - geotextile cushion layer;

  - 40-mil (1.0-mm) thick HDPE geomembrane; and

  - prepared subgrade.

If the impacted material staging area is within the FEMP former production area, the geomembrane secondary containment area described above is not necessary. Impacted-material staging areas should also:

- contain and control impacted runoff from the staging area and management of that runoff as wastewater using the criteria described in Section 2.8 of this DCP (functional requirement);

- transfer collected runoff to the leachate transmission system for transfer to the AWWT facility (functional requirement);

- prevent stormwater runon to the area through use of a perimeter curb or berm (functional requirement);

- enable access by equipment for placement and removal of material (functional requirement); and

- have provisions for fugitive emissions control using either geosynthetics, water spray, crusting agents (e.g., surfactants), or other appropriate methods (functional requirement).

B. Calculations

An evaluation should be performed of the required size and storage capacity of the impacted material staging area. The evaluation should verify that the maximum anticipated quantity of material requiring staging at any point in time (based on the impacted material receipt schedule presented in Appendix A-4) can be accommodated. Standard engineering methods for calculation of volumes should be used.

2.12.3.4 Impacted Material Excavation, Removal, Handling, and Placement

- As Low As Reasonably Achievable (ALARA) goals should apply to all impacted-material excavation, removal, handling, and placement activities (DOE Order 5400.5, Chapter I(4) and II(2)).

- Procedures should be employed that minimize the need for the use of respirators by on-site workers (design consideration).

- Material removal and handling performance specifications should be provided to allow the construction contractor maximum flexibility in selecting methods (design consideration).

- Impacted soil encountered in the OSDF area should be managed as follows (design considerations).

    - The top layers of soil in areas indicated on the drawings as impacted must be removed. The depth of removal should be addressed as part of other design packages prepared as part of the integrated FEMP remediation. Such soils should either be stockpiled for later placement

in the OSDF or transported and placed directly in the OSDF, depending on the availability of a suitable location within the OSDF.

- Runon to temporarily stockpiled soils should be prevented using upgradient soil berms or perimeter drainage ditches. Stockpiled material should be promptly covered with plastic sheeting or other suitable material to prevent infiltration due to rainfall or snow.

- Runon to excavation areas should be prevented to the extent possible, as described in Section 2.8 of this DCP. The size of the active excavation area should be limited to minimize the potential for stormwater runoff from the area.

- Overexcavation of impacted material should be minimized.

- The soil beneath the removed layer will be sampled and tested as addressed in other plans prepared as part of the integrated FEMP remediation. Additional excavation may be needed based on the results of confirmation sampling.

- Excavated areas that will not undergo further development should be promptly revegetated to minimize the potential for erosion.

2.12.3.5 Impacted Material Transport

A. Design Criteria

The following criteria and requirements should be incorporated into the *Impacted Material Placement Plan*.

- The construction contractor must control the release of fugitive emissions (including dust, radiological, chemical, and asbestos materials) so that air

quality standards are not violated on the site and so that releases are controlled to acceptable levels at the fence line (design consideration).

- Material transport procedures should be designed to cause minimal disturbance to the site and work area (design consideration).

- Material transport must be coordinated with impacted material removal and impacted material placement activities (design consideration).

- Material transport equipment should be capable of transporting a variety of materials so that the quantity of equipment used is minimized.

- Impacted material transport equipment should (design consideration):

  - lend itself to control of airborne particulate emissions;

  - require low maintenance;

  - not require extensive modification for use; and

  - meet all project safety requirements.

- Acceptable emission control methods include (design consideration):

  - transport in closed containers with metal or tarp lids;

  - keeping impacted material moist; and

  - spraying earthen material with a crusting agent.

- Acceptable material handling and transport equipment include backhoes front-end loaders, dozers, cranes, forklifts, scrapers, and trucks (dump and flatbed) (design consideration).

2.12.3.6 Impacted Material Placement

Functional Requirements

In addition to the functional requirements identified in Section 2.12.1 of this DCP, the following additional requirements should apply to impacted material placement activities. The function of placement activities is to dispose impacted material in the OSDF in a manner that prevents unacceptable exposure to impacted material constituents during placement and in a manner that achieves the long-term performance goals of the OSDF. The OSDF must be able to contain the anticipated volumes and types of impacted material.

Material placement must take into account:

- the rate and time at which impacted material will be available for placement in the cell;
- the types of impacted material available for disposal (i.e., soil, flyash, lime sludge, solid waste, and building demolition debris);
- the potential for bulking/shrinkage of impacted material during placement;
- the availability of temporary stockpile capacity;
- the extent to which the disposal cell is constructed and available to receive impacted material;
- the need for suspended or reduced impacted material placement activities during winter and the need for seasonal (winter) cover;
- the potential for interim closure of the OSDF due to a lack of funding, or other reasons; and
- the phased development of the OSDF.

In addition to the foregoing requirements, impacted material placement activities should be designed to achieve the following.

- Impacted material must be placed in the OSDF so that it will achieve the design life goal of 1,000 years to the extent reasonable, and in any case at least 200 years.

- Impacted material must be placed in a manner that is protective of the liner system and final cover system.

- Impacted material must be placed so that it will remain stable under both static and earthquake loading conditions.

- Impacted material must be placed to minimize differential settlement to the extent reasonably achievable.

Design Criteria

- A minimum of 4 ft (1.3 m) of select impacted material should be placed directly over the leachate collection system to provide protection of the system against damage by building debris and other types of impacted material (design consideration).

- To reduce particulate emissions, generation of wastewaters, and erosion of impacted material, the sequence of placement should be arranged to minimize the area of exposed impacted material (design consideration).

- Placement of impacted material in OSDF cells should be performed such that the cells can always store runoff from active and open portions of the cell resulting from the 25-year, 24-hour storm event (ARAR: OAC 3745-027-08(C)(6)).

- Materials should be placed in a manner that achieves a homogenous structure, to the extent possible. Homogeneity should be achieved by distributing

impacted materials throughout the OSDF to avoid large pockets or distinct concentrations of any one type of impacted material in a particular area. The objective of achieving a homogenous waste mass is to minimize the potential for differential settlement (design consideration).

- Municipal solid waste material requiring disposal should be spread out in relatively thin lifts and covered with at least 12 in. (0.3 m) of cover soil. The purpose of this procedure is to minimize the potential for anaerobic decomposition of the waste (and, thus, the generation of landfill gas). Similarly, green waste from excavation activities should be spread out in thin lifts and completely covered with soil. Consideration should be given to chipping tree limbs and branches to reduce the size of the green waste particles prior to disposal (design consideration).

- Impacted material placed in the OSDF must comply with the disposal cell waste acceptance criteria (WAC) identified in the ROD.

- At the end of each work day, the impacted material surface should be graded and maintained to control precipitation runoff and impacted material erosion (design consideration).

2.12.3.7 Seasonal (Winter) Shutdown

Temporary shutdown of impacted material placement activities will be required during periods of freezing conditions and at locations where impacted material will not be placed for at least 30 days. In these cases, a "seasonal" cover should be provided for exposed surfaces. After the period of temporary shut-down is complete, the cover should be removed. If the cover is "clean" soil, the upper zone of the material may be salvaged for future use. However, soil in contact with impacted material should itself be considered impacted. Seasonal cover should meet the following criteria (design considerations):

- have the least volume technically practical in order to limit loss of cell volume (i.e., 6 to 12 in. (0.15 to 0.3 m));

- be cost effective to place;
- be of sufficient thickness to protect underlying geosynthetics from frost effects;
- control stormwater runoff and route runoff to a location where it can be properly managed;
- limit infiltration to the OSDF and minimize impacted material erosion;
- limit fugitive emissions to not more than acceptable levels;
- remain stable and durable for the anticipated period of seasonal shut-down; and
- acceptable interim cover materials include on-site clean soils, off-site clean soils, and on-site impacted materials with suitable surface protection (e.g., Betz Flow-Pro, or equivalent); if the latter is used, a demonstration must be provided that runoff from the seasonal cover surface can be treated as stormwater and not wastewater.

2.12.4 Interim Closure

Interim closure refers to a one or more year closure of the OSDF as a result of insufficient funding or a prolonged closure necessitated by other factors. [Note: The remainder of this section to be prepared prior to regulatory agency submittal.]

2.12.5 References

FEMP property data and information required to design the impacted material management activities should be obtained from the references cited in Section 1.5 of this DCP. References from the general technical literature that may be used to design these activities are given below.

American Association of State Highway and Transportation Officials (AASHTO), "*Interim Guide for Design of Pavement Structures*," 1972.

American Concrete Institute (ACI), "*Building Code Requirements for Concrete (ACI 318-93)*", Detroit, MI, 1993.

Giroud, J.P., and Noiray, L., "Design of Geotextile Reinforced Unpaved Roads," *J. Geotechnical Engineering Division,* ASCE, Vol. 107, No. GT9, September 1981, pp. 1233-1254.

State of Ohio, Department of Transportation (ODOT), "*Construction of Materials Specifications*," Columbus, OH, January 1993.

SECTION 3

3. PROJECT DELIVERABLES

3.1 General Requirements

3.1.1 Introduction

The purpose of this section of the DCP is to identify administrative and substantive requirements for preparation and issuance of project deliverables for this design package. Section 3.1 addresses general administrative requirements. Substantive requirements are addressed in Section 3.2. Required deliverables for other design packages being developed as part of the integrated FEMP remediation are not addressed in this DCP. These other deliverables will be addressed in other appropriate DCPs. The requirements described in this section could change slightly based on the specifics of the OSDF detailed design.

3.1.2 Reports

Reports that will be prepared for this design package are identified in Section 1.6 of this DCP and described in more detail in Section 3.2. The reports must be prepared using the WordPerfect Version 5.1 word processing program and should be submitted both in bound (i.e., assembled and bound in three-ring binders) and unbound, reproducible (i.e., "camera-ready") format. Any spreadsheets that are included in the reports should be prepared in a format compatible with Lotus 123, Version 3.4 software. Reports for regulatory submittal should be provided in sets of twenty bound copies, plus an unbound copy for reproduction.

3.1.3 Calculations

Calculations should be submitted with the preliminary, intermediate, pre-final, final, and CFC design packages. A preliminary list of calculations to be prepared for the OSDF project is presented in Table 1-1 of this DCP. Spreadsheets that are submitted with calculations should be prepared in a format compatible with Lotus 123,

Version 3.4 software. Calculations for regulatory submittal should be provided in twenty bound copies, plus an unbound copy for reproduction.

3.1.4 Drawings

Drawings should be compiled using computer-aided design (CAD) techniques using a system compatible with Microstation (Version 5.0) software. A preliminary list of OSDF drawings is presented in Table 1-2 of this DCP. The drawings should be prepared on 30 in. by 42 in. (76 cm by 110 cm) and half-size sheets. Full-size drawings intended for submittal to regulatory agencies should be printed on both mylar and bond media. Each drawing should be sequentially numbered with a fully-executed title block. Revision blocks should be prepared for each revision to reflect changes to the drawings. After the pre-final submittal, changes made to the drawings should be shown by "clouding" the area that is revised and making a keynote in the revision block; if this method of revision comprises the clarity of the drawings, then the drawing should be replaced and reissued. Drawings should be submitted with the preliminary, intermediate, pre-final, final, and CFC design packages. Drawings for regulatory submittal should be provided in twenty bound copies, plus an unbound copy for reproduction.

3.1.5 Specifications

Specifications should be submitted with the preliminary, intermediate, pre-final, final, and CFC design packages. A preliminary list of construction specifications for the OSDF is presented in Table 1-3. Specifications should be prepared using the standard Construction Specifications Institute (CSI) format for each construction activity. Specifications should provide sufficient detail to control the quality of construction materials and activities, while encouraging competitive procurement of materials and services. Specifications should be prepared using WordPerfect 5.1 format. Specification for regulatory submittal should be provided in bound copies, plus on unbound copy for reproduction.

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3.1.6 Field and Laboratory Test Results and Reports

Field and laboratory test reports should be prepared using the WordPerfect 5.1 word processing program. Reports issued for regulatory submittal should be provided in twenty bound copies, plus an unbound copy for reproduction.

3.1.7 Cost Estimates

Cost estimates should be prepared for OSDF construction, filling, and closure, and for implementation of the test pad program. The cost estimates must be in FERMCO format. This format is illustrated by the FERMCO baseline OSDF cost estimate presented in Appendix E of this document. Cost estimate spreadsheets must be compatible with Lotus 123, Version 3.4 software. Cost estimates for regulatory submittal should be provided in twenty bound copies, plus an unbound copy for reproduction.

3.1.8 Value Engineering

A value engineering session will be conducted after the preliminary design package is prepared to identify and evaluate potential cost-effective design alternatives. The results of the value engineering process must be presented in a report describing the alternatives considered, the advantages and disadvantages of the alternatives, and the recommended alternatives. The value engineering report should be prepared using the WordPerfect 5.1 word processing program. Value engineering reports for regulatory submittal should be provided in twenty bound copies, plus an unbound copy for reproduction.

3.2 Description of Design Deliverables

3.2.1 Design Criteria Package

This DCP should be submitted concurrently with the preliminary design package. This DCP contains criteria for use in the design of the OSDF and support facilities identified in this document. The DCP should be updated throughout the project as new or additional design criteria or design methods are identified and adopted. Updating should be carried out as described in Section 1.7 of this DCP.

3.2.2 Liner Compatibility Study Report

The liner compatibility study report should contain the results of the liner compatibility study. This study will be performed in accordance with the requirements described in Section 2.4.6 of this DCP. The report should describe the work performed to evaluate the durability and chemical compatibility characteristics of the geomembrane liner and final cover system components of the OSDF. The report should also contain conclusions and recommendations for use in selecting and specifying the geomembrane components of the OSDF.

3.2.3 Drawings, Specifications, and CQA Plan

Drawings

Drawings should be prepared in a manner that fully and clearly presents the materials and work activities required of the construction contractor to construct, fill, and close the OSDF. A preliminary list of OSDF design drawings is presented in Table 1-2 of this DCP.

Specifications

Specifications should be prepared for the purpose of defining the construction contractor's responsibilities and duties, acceptable materials of construction, and standards for acceptable work. The specifications should address construction, filling, and closure of the OSDF, and construction, operation, and maintenance of appropriate support facilities. A preliminary list of specifications to be prepared for the OSDF project is presented in Table 1-3 of this DCP. The specifications are to be prepared in standard CSI format and should generally contain the following sections (note: all second level headings need not be used):

PART 1 GENERAL	PART 2 PRODUCTS	PART 3 EXECUTION
Summary	Materials	Examination
References	Manufactured Units	Preparation
Definitions	Equipment	Erection Installation Application
System Description	Components	Field Quality Control
Submittals	Accessories	Adjusting
Quality Assurance	Mixes	Cleaning
Delivery, Storage, and Handling	Fabrication	Demonstration
Project/Site Conditions	Source Quality Control	Protection
Sequencing and Scheduling		Schedules
Warranty		
Maintenance		

CQA Plan

A *Construction Quality Assurance* (CQA) plan should be prepared to describe the quality assurance monitoring, testing, documentation, and nonconformance resolution activities that will be undertaken during construction, filling, and closure of the OSDF. The CQA plan must address both material and construction method conformance with the requirements of the specifications, appropriate regulatory requirements and guidance, and good engineering practice. These activities should be undertaken by a qualified CQA team independent of the construction contractor. The CQA plan should be developed to conform to OEPA requirements (ARAR: OAC 3745-27-08(F)) and to USEPA guidance.

3.2.4 Project Support Plans

3.2.4.1 OSDF Phasing Plan

The OSDF will be constructed in phases (i.e., cells), as discussed previously in this DCP. A phasing plan should be prepared to illustrate the sequence of development of the OSDF. The phasing plan may take the form of layout drawings, detail drawings, and notes included in the design drawing package.

The number of phases should be optimized based on the various design considerations. The optimal number should be between 5 and 10. Inclusion of a "contingency" phase (cell) should also be considered. The layout and details of each phase should be designed based on the following project-specific considerations:

- the schedule of receipt of impacted material from the various operable units;
- the relationship between leachate generation rate and cell size;
- the length of time any one cell is not under cover;
- funding for the OSDF project;

- the requirements for impacted-material placement and control;
- the need for work slow-down during winter and other adverse weather periods; and
- the capacity of temporary staging and stockpile areas.

The design drawings should illustrate the phases of construction of the OSDF. The specifications should set out the requirements for construction of one or more phases of the OSDF and the requirements for continuity from one phase to the next.

3.2.4.2 Impacted Material Placement Plan

A written *Impacted Materials Placement Plan* should be prepared to describe procedures to be followed by the construction contractor for handling impacted material within the battery limit and placing the material in the OSDF. The plan is intended for use by the construction contractor during construction, filling, and closure of the OSDF. The plan should augment the specifications for impacted material handling and placement. The plan should be developed to provide flexibility to the contractor in selecting efficient and cost-effective equipment and material placement procedures.

The *Impacted Materials Placement Plan* must define the following:

- expected volumes of impacted material to be received and the anticipated schedule for receipt;
- expected types and allowable dimensions of impacted material;
- required preparation procedures and measures for impacted material (with particular attention to procedures required for placement of solid waste, lime sludge, and building debris);
- stockpile area locations and operating procedures;

- impacted material handling and transport procedures within the battery limit;
- containment and collection of impacted runoff (wastewater) from impacted-material haul roads;
- protection of the liner system and other engineered components of the OSDF;
- impacted material placement procedures and methods;
- procedures for leachate and surface-water control in active cells;
- procedures to control fugitive emissions (primarily dust);
- procedures for seasonal (winter) closure and other short-term closure due to inclement weather;
- quality assurance and quality control procedures for impacted material placement activities (including quality assurance checks that incoming waste meets the waste acceptance criteria (WACs));
- documentation and records of impacted material placement; and
- worker health and safety considerations.

3.2.4.3 Stormwater Management and Erosion Control Plan

A written *Stormwater Management and Erosion Control Plan* should be prepared to describe the procedures to be followed within the battery limit to control stormwater, minimize erosion, and minimize off-site sedimentation. The plan should be prepared for use by the construction contractor during construction, filling, and closure of the OSDF. The plan should be prepared in a manner that allows reasonable flexibility to the contractor in managing stormwater at the site.

The *Stormwater Management and Erosion Control Plan* should address at least the following:

- relevant stormwater management regulatory requirements and standards;
- OSDF design drawings and specifications relevant to stormwater management and erosion and sediment control;
- procedures to be used to manage and control runon from off-site;
- procedures to be used to manage runoff from within the battery limit;
- procedures for erosion and sediment control;
- maintenance practices for temporary E&S basins;
- criteria for installing and removing stormwater control and erosion protection facilities;
- discharge criteria for water to be released from the battery limit; and
- procedures to be followed to revise design drawings and specifications for stormwater management and erosion control.

The plan should also incorporate the criteria set out in this DCP.

3.2.4.4 Borrow Area Management and Restoration Plan

A *Borrow Area Management and Restoration Plan* should be prepared to describe the procedures to be followed in developing and restoring the on-site borrow area. The plan is intended for use by the construction contractor during development and restoration of the borrow area. The plan should be prepared to augment the specifications and should incorporate the criteria set out in this DCP. The plan should

cross reference the *Stormwater Management and Erosion Control Plan* for borrow area stormwater management and erosion control requirements and procedures.

The *Borrow Area Management and Restoration Plan* should contain information on at least the following aspects of borrow area development and restoration:

- layout;
- access and security;
- phasing;
- borrow area clearing;
- excavation procedures;
- stormwater management;
- erosion and sediment control;
- removal and management of impacted material (if any);
- stockpiling of topsoil and unsuitable borrow material;
- location and testing of acceptable material;
- borrow area restoration; and
- area closure.

The location, layout, and phasing of the on-site borrow area should be shown on the design drawings. Results of field and laboratory testing of materials in the borrow area should be provided and summarized in tabular or graphical form in the plan.

3.2.5 Response Documents

Written responses must be prepared for all formal comments on project deliverables received from DOE and the regulatory agencies (OEPA and USEPA). Response documents are anticipated for the following:

- Design Criteria Package;
- Test Pad Work Plan;
- Liner Compatibility Study Work Plan;
- Preliminary Design Package;
- Intermediate Design Package;
- Pre-Final Design Package; and
- Final Design Package.

3.2.6 Cost Estimates

A construction cost estimate must be prepared for the OSDF project. The cost estimate should include a detailed breakdown of material and construction quantities and a derivation of estimated unit costs for each element of construction. The unit costs should be presented in units similar to the proposed contract payment basis (e.g., time and material costs estimates should be prepared for items to be paid on a time and material basis). Construction cost estimates should be developed after preparation of the preliminary, pre-final, and final design packages. A cost estimate should also be prepared for implementation of the test pad program, as described in Section 2.7.7 of this DCP.

3.2.7 Value Engineering Report

A value engineering report should be prepared that includes:

- description of OSDF preliminary design;
- description of OSDF preliminary construction cost estimate;
- description of value engineering process and procedures;
- alternative design measures considered;
- advantages and disadvantages of considered alternatives; and
- recommendations on alternatives to include in the OSDF design.

3.2.8 Test Pad Report

The results of the test pad program should be analyzed and a report prepared to present the program results. The report should describe the procedures followed for the test pad evaluation, the procedures used to analyze the field and laboratory test data, and the conclusions of the study. The report should contain: (i) recommendations regarding the suitability of the borrow sources for use as clay liner and cap material; (ii) requirements for borrow source processing; and (iii) recommended criteria for clay liner and cap construction.

APPENDIX A

APPENDIX A

OPERABLE UNIT 2 RECORD OF DECISION (SECTIONS 9 AND 10)

FINAL

RECORD OF DECISION

FOR REMEDIAL ACTIONS AT

OPERABLE UNIT 2

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
FERNALD, OHIO

MAY 15, 1995

U.S. DEPARTMENT OF ENERGY

U.S. Environmental Protection Agency, 1992a, "Guidance on Risk Characterization for Risk Assessors and Risk Managers," Memorandum dated February 26, 1992.

U.S. Environmental Protection Agency, 1992b, "Health Effects Assessment Summary Tables, Annual Update FY 1992", including Supplement A, July, 1992, Prepared by the Environmental Criteria and Assessment Office, Cincinnati, OH, for the Office of Emergency and Remedial Response, Washington, DC.

U.S. Environmental Protection Agency, 1993a, "Integrated Risk Information System (IRIS)," computer database, EPA, Washington, D.C.

U.S. Environmental Protection Agency, 1993b, "Health Effects Assessment Summary Tables, FY-1993," OERR, EPA, Washington, D.C.

U.S. Environmental Protection Agency, 1994, "Integrated Risk Information System (IRIS)," computer database, EPA, Washington, DC.

Weston, Inc., Roy F., 1987, "Characterization Investigation Study," prepared for Westinghouse Materials Company of Ohio, U.S. Department of Energy Feed Materials Production Center, Fernald, OH.

REFERENCES

ATSDR, 1990, "Toxicological Profile for 2,3,7,8-Tetrachlorodibenzo-p-dioxin," Draft for Public Comment, U.S. Public Health Service, Atlanta, Georgia.

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended, 42 U.S.C. §9601 *et seq.*

Consent Agreement as Amended Under CERCLA Sections 120 and 106(a), 1991, U.S. Environmental Protection Agency and U.S. Department of Energy, Administrative Docket No. V-W-90-C-057.

Consent Decree, 1988, State of Ohio and U.S. Department of Energy, Civil Action No. C-1-86-0217.

Craig, J.R., U.S. Department of Energy, 1994, Letter to D. Ofte, FERMCO, Subject: Action Memorandum: South Field and Inactive Flyash Seepage Control, 10/25/94.

Dispute Resolution Agreement, 1993, U.S. Environmental Protection Agency and U.S. Department of Energy, Administrative Docket No. V-W-90-C-057.

Dollarhide, J., U.S. Environmental Protection Agency Environmental Criteria and Assessment Office (ECAO), 1993, Letter to P. VanLeeuwen, U.S. Environmental Protection Agency, Region V.

Facemire, C. F., S. I. Guttman, D. R. Sperger, 1990, "Biological and Ecological Site Characterization of the Feed Materials Production Center," FMPC-SUB 018, prepared for Westinghouse Materials Co. of Ohio, Cincinnati, OH.

Federal Facility Compliance Agreement, 1986, U.S. Environmental Protection Agency and U.S. Department of Energy.

Geotrans, Inc., 1987, "Data Input Guide for SWIFTIII, The Sandia Waste Isolation Flow and Transport Model for Fractured Media, Release 2.16, Modifications to NUREG/CR-3162," Geotrans, Herndon, VA.

Jones, T.D. and B.A. Owen, 1989, "Health Risks from Mixtures of Radionuclides and Chemicals in Drinking Water", Oak Ridge National Laboratory, Oak Ridge, Tennessee, ORNL-6533.

National Oil and Hazardous Substances Pollution Contingency Plan (NCP), 40 CFR Part 300.

St. John, F. L., 1993, "Report on the Status of the Sloan's Crayfish (*Orconectes sloanii* Bundy) at the Fernald Environmental Management Project," FERMCO, Cincinnati, OH.

St. John, F. L., 1994, "Addendum to the Report on the Status of the Sloan's Crayfish (*Orconectes sloanii* Bundy) at the Fernald Environmental Management Project," Draft, FERMCO, Cincinnati, OH.

Stipulated Amendment to Consent Decree, 1993, State of Ohio and U.S. Department of Energy, Civil No. C-1-86-0217.

11.0 DOCUMENTATION OF SIGNIFICANT CHANGES

The *Proposed Plan for Remedial Actions at Operable Unit 2* was released for public comment in October 1994. The Proposed Plan identified Alternative 6, Excavation and On-Site Disposal with Off-Site Disposal of Fraction Exceeding the Waste Acceptance Criteria, as the preferred alternative. All written and oral comments submitted during the public comment period were reviewed. Based on these comments, it was determined that no significant changes to the remedy, as it was originally identified in the Proposed Plan, were necessary.

One significant change from the Proposed Plan to this ROD, is a change in the maximum waste acceptance criteria for the on-site disposal facility. The Proposed Plan provided a waste acceptance criteria of 360 pCi/g of uranium-238 and 1,080 ppm of total uranium. A waste acceptance criteria of 346 pCi/g of uranium-238 and 1,030 ppm of total uranium was proposed in the Operable Unit 5 Proposed Plan. This difference in waste acceptance criteria is due to using different, but comparable, computer models for the calculations. The Operable Unit 2 and Operable Unit 5 waste acceptance criteria are essentially the same, however for consistency, Operable Unit 2 has adopted the Operable Unit 5 waste acceptance criteria of 346 pCi/g uranium-238 and 1,030 ppm total uranium. This significant change has been reflected in this ROD.

It should be noted that EPA and OEPA approved the Operable Unit 2 FS Report with comments prior to the public comment period for Operable Unit 2. The Operable Unit 2 FS Report was revised to address the comments from EPA and OEPA. Those comments, and DOE's proposed responses and revisions, were made known to the public and made available for public review during the public comment period; the comments did not result in significant changes or changes that could not be reasonably anticipated by the public.

Aquatic habitats to be disturbed include wetlands, Paddys Run, and the Storm Sewer Outfall Ditch. On-property drainage ditch/swales support shrub and/or emergent vegetation. Broad-leaf cattail (*Typha latifolia*) is the most common species. Numerous woody species in swales include black willow (*Salix nigra*), roughleaf dogwood, and American elm. Surveys found state-listed threatened Sloan's crayfish (*Orconectes sloanii*) residing in Paddys Run (St. John 1993 and 1994). Paddys Run also supports a diverse community of macroinvertebrates and fish. Habitat in the Storm Sewer Outfall Ditch is minimal, as the ditch is dry most of the year.

The 100- and 500-year floodplain of Paddys Run will be directly and indirectly impacted as a result of remedial activities. Limited excavation in the floodplain will occur during remedial activities at the flyash piles and South Field; however, changes in flood elevations are not be expected. Engineering controls will be implemented to minimize indirect impacts (i.e., runoff and sedimentation). Activities performed in the Storm Sewer Outfall Ditch will be in accordance with 404 guidelines of the Clean Water Act. A Floodplain/Wetland Assessment was completed and is provided in Appendix H to the Operable Unit 2 FS Report.

Additionally, consumptive use of geologic resources (e.g., quarried rock, sand, and gravel) and petroleum products (e.g., diesel fuel and gasoline) will be required for removal, construction, and disposal activities. Supplies of these materials will be provided by the construction contractor. Additional fuel use will result from limited off-site transport of the materials. Adequate supplies will be available without affecting local requirements for these products. The treatment processes for the remedial action alternative will require the consumptive use of materials and energy. The stabilization process will require additives such as flyash and lime sludge, which are readily available at the FEMP site.

Approximately 35 acres of the FEMP site, including a 300-foot buffer zone, will be restricted for future use under the Operable Unit 2 selected remedial alternative. The committed land will be actively monitored and maintained. Periodic monitoring of surface water and groundwater at the disposal facility will be performed, and periodic site inspections will identify any damage to the disposal facility. Maintenance activities will be performed, as necessary. The off-site facility (for remediation waste exceeding the on-site waste acceptance criteria) is expected to implement similar measures as required under its specific regulatory criteria.

through excavation and placement in an engineered on-site disposal facility. By combining all the remediation waste into one disposal location, it can be managed more effectively over the long-term. The selected remedy also allows increased flexibility in land use options, a reduced size of buffer area, and centralized operations and maintenance.

The selected remedy does not provide a significant reduction of toxicity, mobility, or volume through treatment. Treatment of leachate and construction water will take place at the on-site AWWT facility and lead-contaminated mixed waste from the South Field Firing Range will be treated before being transported to an off-site disposal facility. Except for the no action alternative, each alternative includes the same amount of treatment.

The selected remedy provides adequate short-term effectiveness and is readily implementable. Because the majority of the waste material will remain on site during remediation, there is very little opportunity for public exposure to the contaminants. The exposure potential to remediation workers will be managed in accordance with a health and safety plan and is, therefore, considered acceptable. The on-site disposal alternative is considered to provide more short-term effectiveness and is more implementable than off-site disposal, but slightly less implementable than consolidation and containment. The selected remedy costs slightly more than consolidation and containment and is half the cost of off-site disposal.

The major tradeoffs that provide the basis for the selection of on-site disposal with off-site disposal of the fraction exceeding the waste acceptance criteria are long-term effectiveness and cost. The selected remedy provides the most reliable method of managing and monitoring the disposal of Operable Unit 2 contaminated material for the least cost. For this reason, Alternative 6 is determined to be the most appropriate remedy for the contaminated material from Operable Unit 2.

10.5 PREFERENCE FOR TREATMENT AS A PRINCIPAL ELEMENT

The selected remedy does not satisfy the statutory preference for treatment as a principal element. The NCP states in 40 CFR §300.430(a)(iii)(A) and (B) that "EPA expects to use treatment to address the principal threats posed by a site" and "to use engineering controls, such as containment, for waste that poses a relatively low long-term threat." Operable Unit 2 wastes are considered to pose a low long-term threat in all subunits except a portion of the waste in the Inactive Flyash Pile and South Field. This waste is considered a principal threat due to the placement of the waste and the

- Equivalent Standard

  This same definition has been used as a threshold criteria in evaluating alternatives in the CERCLA decision making process at the FEMP and specifically in the Operable Unit 2 FS with the addition that constituents in groundwater should not be higher than the proposed MCLs. This alternative meets this threshold criteria.

  Protection of human health has been determined through the risk assessment process based on contaminant transport modeling and the NCP acceptable ILCR range of $1x10^{-4}$ to $1x10^{-6}$ and in compliance with promulgated and proposed MCLs.

Reliability into the future:

The combination of hydrogeologic and engineering controls (including additional controls beyond the requirements for a solid waste disposal facility) provides increased reliability into the future because of the following:

- The biotic barrier in the cap will prevent burrowing animals or vegetative roots from compromising the integrity of the cap and thereby increasing the infiltration.
- Leak detection monitoring will provide an early warning of any problem in leachate containment and allow corrective measures to be undertaken prior to adverse impact to the aquifer.

Time required for results:

Construction of a disposal facility with additional engineering controls will not take significantly longer than the time required for a disposal facility which strictly meets the Ohio Solid Waste Disposal Regulations.

A CERCLA ARAR waiver of the OEPA prohibition of siting a disposal facility over a high-yield sole-source aquifer is justified based on an equivalent standard of performance [40 CFR 300.430 (f)(1)(ii)(C)(4)] to the OEPA policies allowing an exemption to the siting requirements. This waiver is applicable only to Operable Unit 2 on-site remediation wastes. If on-site disposal is chosen as the selected remedy for other FEMP operable units, separate waivers from this Ohio requirement would be necessary.

The disposal facility location and design will be subject to review and approval during the remedial design phase. DOE intends to construct only one disposal facility at the FEMP. Therefore, should

- Equivalent Standard

  The combination of engineering controls and existing hydrogeology proposed in this alternative will provide the same degree of protection to the aquifer as the hydrogeologic conditions described in the OEPA policy alone. Modeling with the combined controls shows that the leachate will not reach the aquifer during the active life of the landfill and a post closure period of thirty years.

  It should be noted that the modeling performed in the Operable Unit 2 FS Report (Appendix D.1) was performed for 1000 years and assumed that the liner system and man-made materials (e.g., leachate collection, leak detection, and synthetic liners) of the disposal facility would fail. This modeling showed that with the enhanced cap to reduce infiltration and the existing hydrogeology, leachate that may eventually reach the aquifer would not cause the constituent concentrations in the aquifer to exceed the promulgated and proposed MCLs.

Level of performance (method based):

- OEPA Standard

  Significant thickness of low permeable material between the disposal facility and the aquifer

- Equivalent Standard

  Modeling has shown that the combination of 12 feet of gray clay with a minimum k_d of 3.1 and a maximum waste acceptance criteria of 346 pCi/g of uranium-238, or 1,030 ppm total uranium, will not exceed the proposed MCL for total uranium at the boundary of the disposal facility or a concentration level based on the 10^{-6} ILCR at the boundary of the FEMP. Only the layers in the engineered cap and the gray clay and unsaturated Great Miami Aquiferhydrogeologic layers were used in this modeling. The liner system and brown clay will increase the protection of the aquifer.

- OEPA Standard

  Lack of inter-connection between the sole source aquifer and any significant zones of saturation

- Equivalent Standard

  Any inter-connections will be minimized by:

  1) locating the disposal facility in an area with the greatest thickness of gray clay and the least occurrence of interbedded granular material; and

  2) providing an increase in the engineered controls to compensate for any reduction of protection due to interbedded granular material; and/or

- within 1,000 feet of an existing residence whose owner has not consented in writing to the location of the facility;
- within 200 feet of a stream, lake, or wetland;
- the isolation distance between the uppermost aquifer system and the bottom of the recompacted soil liner of the disposal facility cannot be less than 15 feet of in situ or added geologic material.

The proposed feasible location of the on-site disposal facility is on the eastern side of the FEMP which is not in a floodplain; near a stream, lake, or wetland; within 1,000 feet of an existing water supply well or developed spring; near enough to an existing public water supply well so that contaminants may reach the well within a period of 5 years. The facility will not be placed within 300 feet of the FEMP property line or within 1,000 feet of an existing residential house. The isolation distance between the uppermost aquifer system and the bottom of the recompacted soil liner will be greater than 15 feet.

The remaining two siting criteria (bullets two and three) cannot be met because of the FEMP's location over a sole-source aquifer that is capable of sustaining a yield of 100 gallons per minute for a 24-hour period. OEPA has established two specific policies (GD202.101 and GD202.102) that identify conditions that would be acceptable to allow an exemption to the siting criteria. While these policies state that several factors will be considered in evaluating an exemption, the specific factors identified indicate that the protection of human health and the environment should be provided solely by the existing hydrogeologic conditions. This has been reaffirmed by OEPA in several meetings.

The primary hydrogeologic standards established by these policies are:

- Significant thickness of low permeable material between the disposal facility and the aquifer
- Lack of inter-connection between the sole-source aquifer and any significant zones of saturation
- Significant amount of sediment [soil] between the disposal facility and the high-yield aquifer to prevent leachate from migrating to the high-yield aquifer during the life of the landfill and the post-closure care period. The post-closure care period for a solid waste landfill is a minimum of 30 years [OAC 3745-17-14(A)].

Table 10-1 illustrates that on-site disposal also brings Operable Unit 2 into compliance with the proposed groundwater MCL for uranium, which would not be met under the No Action Alternative. The maximum groundwater concentration is presented in the table (underneath subunit); therefore, the points of compliance, which are at the boundaries of the subunit and the on-site disposal facility, will also comply with the proposed uranium MCL. Treated construction water will meet the Ohio Water Quality Standards found in Table A-1 of Appendix A.

TABLE 10-1

COMPLIANCE WITH OPERABLE UNIT 2 CHEMICAL-SPECIFIC ARARs

ALTERNATIVE 6

MAXIMUM CROSS-MEDIA GROUNDWATER CONCENTRATIONS[a]							
COC	ARAR Standard	Point of Compliance	Solid Waste Landfill	Lime Sludge Ponds	Inactive Flyash Pile/South Field	Active Flyash Pile	On-Site Disposal Facility
Total Uranium	20 μg/L[b]	Under Subunit	18 μg/L	3.2 μg/L	18.4 μg/L	10.7 μg/L	20 μg/L
		FEMP Fenceline	0.7 μg/L	0.1 μg/L	2.2 μg/L	1.5 μg/L	2.1 μg/L

[a] These concentrations are for the expanded trespasser scenario, which will have higher soil cleanup levels than the on-property resident farmer. Therefore, since the expanded trespasser scenario will meet the ARAR standards, the on-property resident farmer scenario will meet them also. The groundwater modeling procedures and results are presented in detail in the FS Report, Appendix D.
[b] Proposed MCL (56 Federal Register 33050)

10.2.2 Action-Specific ARARs/TBCs

Alternative 6 will meet the principal action-specific ARARs/TBCs discussed in Section 7.5.3 and listed in Tables A-2, A-3, and A-4 of Appendix A. Because Operable Unit 2 includes both low-level radioactive waste/residual radioactive material and solid waste, design and construction of the on-site disposal facility will meet the more stringent requirements for the disposal of low-level radioactive waste/residual radioactive material. EPA states in 40 CFR §192.02(a) that the disposal facility must be designed to be effective for up to 1,000 years, to the extent reasonably achievable, and in any case, for at least 200 years. DOE Order 5820.2A requires compliance with performance objectives for low-level radioactive waste disposal sites, including protection of public health and safety, protection of the public and the environment from releases of radioactivity, and protection of groundwater resources. DOE Order 5400.5 requires that the As Low As Reasonably Achievable (ALARA) policy to minimize radiation exposure be adopted during design and construction.

10.0 STATUTORY DETERMINATIONS

In accordance with the statutory requirements of Section 121 of CERCLA, as amended, remedial actions taken pursuant to Sections 104 and 106 must satisfy the following:

- Be protective of human health and the environment.
- Comply with all ARARs established under federal and state environmental laws (or justify a waiver).
- Be cost effective.
- Utilize permanent solutions and alternative technologies or recovery technologies to the maximum extent practicable.
- Satisfy the statutory preference for remedies that utilize treatment and also significantly reduce the toxicity, mobility, and volume of the hazardous substances, pollutants, or contaminants.

In addition, CERCLA §121(c) requires five year reviews to determine if adequate protection of human health and the environment is being maintained where remedial actions result in hazardous substances remaining on-site above health-based levels. A discussion is provided below on how the selected response action for Operable Unit 2 satisfies these requirements.

10.1 PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT

The selected remedy achieves the requirement of being protective of human health and the environment by removing the sources of contamination and disposing of the excavated material in an engineered on-site disposal facility and a fraction of material at an off-site disposal facility. The on-site disposal facility will utilize engineering design features to prevent human and ecological contact with the contaminated material. The facility will also be designed so that based on current EPA standards and modeling/risk assessment methodologies, it will not pose unacceptable impacts to the Great Miami Aquifer. Baseline cancer risks from current conditions exceed the 10^{-4} to 10^{-6} acceptable risk range established by EPA in the NCP. Under the future land use scenario of continued federal ownership, the residual cancer risk associated with Operable Unit 2 will be reduced to 2.5×10^{-6} which is within the acceptable target risk range. Non-carcinogenic hazards will be reduced to 2.0×10^{-2} which is less than the EPA standard of 1.0.

to be excavated under the selected alternative. The COCs for the secondary cleanup levels pose risks that are close to the 10^{-6} point of departure and contribute a small percentage to the overall risk from Operable Unit 2. Based on existing analytical results from the RI and the volume calculations from the FS, secondary cleanup levels will most likely be achieved by remediation to the primary levels, however, will be confirmed through post-remediation sampling.

TABLE 9-1
(Continued)

Contaminant of Concern (COC)	Units	Background[a]	Cleanup Level[b]	Basis for Cleanup Level
SOUTH FIELD (WASTE/SOIL LOCATED OVER >16 FEET NATURAL SOIL)				
Thorium-230[g]	pCi/g	1.97	6.97	ARAR[j]
Uranium-234[g]	pCi/g	1.04	4.24	10^{-6} ILCR
Uranium 235/236[g]	pCi/g	0.15	3.35	10^{-6} ILCR
Uranium-238[g]	pCi/g	1.12	3.22	10^{-6} ILCR
Uranium-Total[g]	mg/kg	3.4	24.8	ARAR[f]
ACTIVE FLYASH PILE				
Arsenic	mg/kg	8.2	16.9	10^{-6} ILCR
Uranium-234[g]	pCi/g	1.04	8.64	10^{-6} ILCR
Uranium-235/236[g]	pCi/g	0.15	7.75	10^{-6} ILCR
Uranium-238[g]	pCi/g	1.12	6.12	10^{-6} ILCR
Uranium-Total[g]	mg/kg	3.4	28	ARAR[f]

[a]Background value from Operable Unit 2 RI Report, Table 4-1A, surface concentrations.
[b]The cleanup level is the lowest value of the 10^{-6} ILCR, 0.2 Hazard Index, or ARAR standard.
[c]ILCR = incremental lifetime cancer risk. In the case of radionuclides, the cleanup level is the concentration responsible for the incremental risk plus the background concentration.
[d]This value determined by calculating the uranium-238 concentration in uranium-total.
[e]ARAR = applicable or relevant and appropriate requirement
[f]Based on the proposed MCL for uranium (56 Federal Register 33050).
[g]Cleanup level due to off-property resident farmer receptor
[h]The lead cleanup level applies to the Firing Range only, not the entire South Field area.
[i]Based on the EPA "Revised Interim Soil Lead Guidance for CERCLA Sites and RCRA Corrective Action Facilities" (OSWER Directive 9355.4-12).
[j]Based on DOE Order 5400.5, Chapter IV (4)(a)(2).

Source: Table 2-23, Operable Unit 2 FS Report.

9.0 SELECTED REMEDY

Based upon consideration of the requirements of CERCLA, the detailed analysis of the alternatives using the nine criteria, and public comment; DOE and EPA have determined that Alternative 6 is the most appropriate remedy for Operable Unit 2 at the FEMP.

Alternative 6 will be protective of the federal ownership scenario through excavation of all waste materials and soils with COCs above the cleanup levels (presented in Section 9.2), material processing for size reduction and moisture control if required, on-site disposal in an engineered disposal facility, off-site disposal of a small fraction of the excavated material that exceeds the waste acceptance criteria of the on-site disposal facility, and continued federal ownership of the FEMP. The key components of the selected remedy are summarized below.

9.1 KEY COMPONENTS

The selected remedy consists of the following key components:

- Construction of the engineered on-site disposal facility. The on-site disposal facility will be located within the limits of the potentially acceptable region shown on Figure 7-1 and will have at least a 300-foot buffer zone between the waste and the property boundary.

  The on-site disposal facility will be constructed with a composite liner of soil and geosynthetics. The excavated material will be placed on the liner system. The composite cap of soil and geosynthetics will be constructed above the waste and tied-in with the liner system. Construction will also include associated site work and installation of monitoring wells. The composite liner and cap will be as shown on Figure 7-2, or equivalent. The design of the disposal facility is subject to review and approval during remedial design based on additional investigations and the design process.

- Excavation at the Operable Unit 2 subunits to the required depth established by the RI and FS Reports to remove materials with COC concentrations above the cleanup levels (see Section 9.2). Excavation will be performed in such a way as to minimize possible dilution of waste and the concept of ALARA will be documented in the Remedial Action Work Plan and implemented during construction.

- Verification sampling and testing in the excavated area to confirm that material with COC concentrations above the cleanup levels has been removed. If the results of the verification sampling and testing indicate that contamination above cleanup levels remains, then additional excavation and verification sampling and testing will be performed until acceptable results are obtained.

Figure 7-1 depicts the proposed feasible location of the on-site disposal facility. Based on a series of soil borings made in the area, the geology of the disposal facility location identified in the figure in combination with the engineering controls will be protective of human health and the environment. However, the disposal facility location is subject to review and approval during the remedial design phase. DOE intends to construct only one disposal facility at the FEMP. Should on-site disposal be selected for other FEMP operable units, the disposal facility capacity and configuration would be adjusted accordingly during the remedial design process to accommodate other FEMP operable unit remediation wastes (that meet the established waste acceptance criteria). DOE will not dispose of any off-site waste in this on-site disposal facility.

9.2 CLEANUP LEVELS

The goals for protecting human health and the environment depend on the contaminated media and the exposure pathways. The exposure pathways are dependent on the future land use designated for the FEMP site. The two land-use scenarios considered in the FS are continuing federal ownership of the FEMP (with restricted access) and the site being used by a farmer with no use limitations. These scenarios represent two extremes of land use; future land use may be similar to either one of these scenarios or may fall between these two scenarios. Corresponding soil cleanup levels have been determined to meet the acceptable risk range (1×10^{-4} to 1×10^{-6} and a HI = 0.2). If found to be necessary, the Operable Unit 5 ROD will modify the Operable Unit 2 cleanup levels downward to ensure protectiveness of human health and the environment.

The cleanup levels for the selected alternative were developed to protect the expanded trespasser under a future land-use scenario of continued federal ownership. A multi-step process was followed to develop the Operable Unit 2 cleanup levels, which were called Preliminary Remediation Levels (PRLs) in the FS/PP. The first step of the process was to develop risk-based Preliminary Remediation Goals (PRGs), which are cleanup levels based on results of the Baseline Risk Assessment that are protective of human health. Risk-based PRGs were then modified based on a number of factors including access controls, such as fencing to keep intruders out, and proposed engineering controls.

The Operable Unit 2 cleanup levels have been divided into primary and secondary cleanup levels, which are presented in Table 9-1 and Table 9-2, respectively. The COCs for the primary cleanup levels contribute over 90 percent of the risk from Operable Unit 2 and over 99 percent of the volumes

APPENDIX B

APPENDIX B

DRAFT DETAILED FACILITY DESCRIPTION/FUNCTIONAL REQUIREMENTS

ON-SITE DISPOSAL FACILITY

DETAILED FACILITY DESCRIPTION/FUNCTIONAL REQUIREMENTS

PRELIMINARY
Oct 17, 1995

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LIST OF ACRONYMS AND ABBREVIATIONS

ACI	American Concrete Institute
ADT	Average Daily Traffic
A/E	Architect/Engineer
ALARA	As Low as Reasonably Achievable
ANSI	American National Standards Index
ARAR	Applicable or Relevant and Appropriate Requirement
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
AWWT	Advanced Wastewater Treatment
BA	Borrow Area
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CFC	Certified For Construction
CFR	Code of Federal Regulations
cm/sec	centimeters per second
COCs	Contaminant Of Concern
COE	U.S. Army Corps of Engineers
CY	Calendar Year
DF	Disposal Facility
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
FEMP	Fernald Environmental Management Project
FERMCO	Fernald Environmental Restoration Management Company
FRLs	Final Remediation Levels
NAD	North American Datum
NEC	National Electrical Code
OEPA	Ohio Environmental Protection Agency
OSDP	On-Site Disposal Facility
OU2	Operable Unit 2
RCRA	Resource Conservation and Recovery Act
ROD	Record Of Decision
SOW	Statement Of Work
WAC	Waste Acceptance Criteria

1.0 INTRODUCTION AND BACKGROUND

This document presents detailed information in support of the conceptual design for the On -Site Disposal Facility (OSDF) and presents the facility's functional requirements. This document presents that information necessary for inclusion in a Functional Requirements Document pursuant to FERMCO Engineering Procedure No. 12-4001, Revision D. Functional requirements are the fundamental technical criteria and design requirements necessary to develop facility design.

The Fernald Environmental Management Project (FEMP) is a 1,050 acre Department of Energy (DOE) facility located in southwestern Ohio approximately 18 miles northwest of downtown Cincinnati, Ohio. An aboveground, engineered disposal facility for low level radioactive and Resource Conservation and Recovery Act (RCRA) wastes is to be constructed within the boundaries of the FEMP.

The OSDF is a component of the selected remedy for Operable Unit 2, the preferred remedial alternative for Operable Unit 5, and the leading remedial alternative for Operable Unit 3.

2.0 DOCUMENT SCOPE

The functional requirements identified in this document cover the OSDF, relocated entrance road, haul road, leachate conveyance system, and utility support to the OSDF. This disposal facility will encapsulate impacted soil and debris with contamination levels below the waste acceptance criteria (WAC) from operable units at the FEMP.

3.0 GENERAL FUNCTIONAL REQUIREMENTS

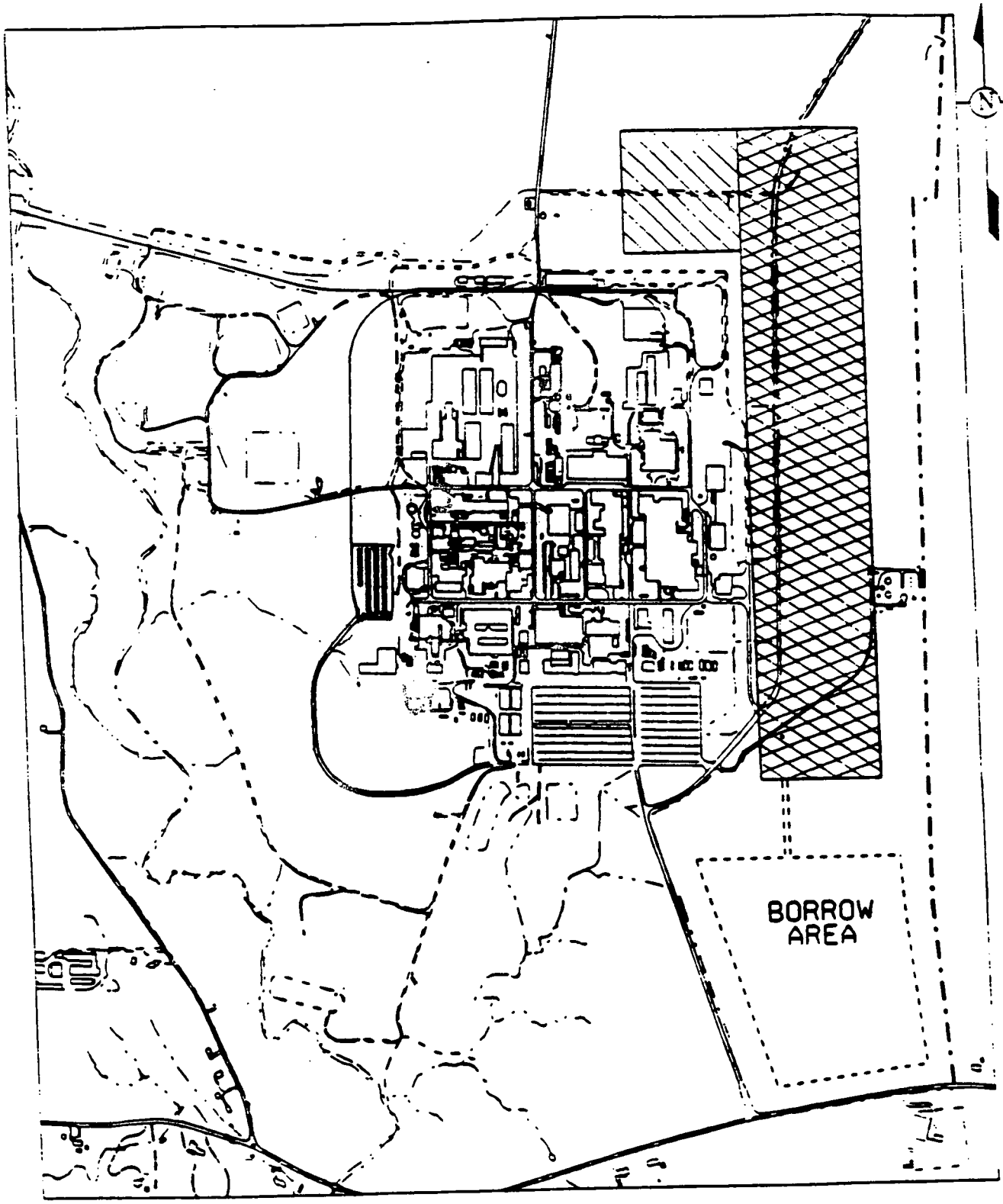
Approximately 2.5 million cubic yards (bank/unbulked) of material will be removed from Operable Units 2, 3, and 5 during remediation activities and will be placed in the OSDF for ultimate disposal. The majority of the material to be placed in the facility will be native soil and building materials impacted with radionuclides.

The design life for the OSDF will be at least 200 years with continued effectiveness for up to 1000 years to the extent practical and reasonably achievable. The design life of specific OSDF components will be determined using a graded approach based on the repairability/maintainability of the component, the consequences of failure to that component, and the ability to reasonably determine or extrapolate the design life of a specific component based on existing data, information and calculation methods. The facility will remain under perpetual Federal control with active maintenance; however, maintenance requirements are to be minimized in the engineering design of the facility.

For planning purposes, it is assumed that the remediation activities will be completed over a 10 year period. Depending on availability of funding, the implementation period could be reduced to seven years or expanded to 25 years or more.

The facility will be sited in an area within the FEMP property limits that has geology which is accepted as being protective of the underlying Great Miami Aquifer. A siting study has been conducted to delineate the most appropriate location. The siting is dependent on the most environmentally protective geology. The site selection and geometric configuration have been chosen to minimize impacts to the environment as well as minimizing settlement within the substrata. The Fate and Transport Model indicates that a minimum of 12 feet of native gray clay provides adequate protection of the Great Miami Aquifer from potential leachate from the facility. The preferred site is an area approximately 800 feet wide and 3700 feet in length located east of the former Production Area. This site is indicated on Figure 1.

The facility will be designed to provide long-term protection from migration of constituents of concern (COCs). A conceptual design for this facility is presented in Appendix E.3 of the Operable Unit 2 Feasibility Study (FS), and Sections 7 and 9 of the Final Record of Decision (ROD) for Remedial Actions At Operable Unit 2. The Waste acceptance criteria (WAC) for this facility have been determined so that the proposed engineered capping and liner system, coupled with the existing geology, will provide adequate protection to human health and the environment. The siting and design will ensure that the



LEGEND:

FEMP BOUNDARY
PREFERRED SITE
POTENTIAL EXPANSION AREA

SCALE
1000 500 0 1000 FEET

FIGURE 1: PREFERRED SITE
OF DISPOSAL FACILITY

contents of the facility will pose no unacceptable risks to potential human and environmental receptors. The conceptual design for the capping and liner systems of the OSDF is shown in Figure 2. A conceptual cross-section is presented in Figure 3.

To accommodate construction of the OSDF, the FEMP north entrance road will be relocated. The north entrance road will be a permanent facility and soil above the final remediation levels will be removed from the vicinity of the road prior to its construction. The road will be a two lane, undivided road with shoulders on each side. Each lane will be 12 feet wide and each shoulder 5 feet wide. It will be an asphalt paved road with gravel shoulders having a 3 percent cross-slope. The design speed is 30 mph. The borrow material from south of the former production area will be used at the OSDF site, so hauling trucks will cross southern portions of the proposed north entrance road at two locations and also the south entrance road at one location. The use of lighted traffic signals will be investigated and, if applicable, included in the design.

A haul road will be constructed to bring OU2 waste materials and impacted soils and debris to the OSDF. The haul road will be located in the contaminated area to transport about 300,000 cu. yd. of waste material from within the operable units to the OSDF. The road will be a two lane, asphalt paved, undivided road with shoulders on each side. A typical section of the road consists of two 12-foot lanes and a 5 ft shoulder on each side.

Leachate and collected stormwater from the active and closed portions of the On-Site Disposal Facility OSDF will be collected at a sump at the southwest corner of the OSDF. The waste liquid will be pumped from the disposal facility collection sump to the treatment/disposal in a buried, double-contained pipeline. The design life of the waste liquid transfer system shall be 200 years. The system shall accommodate the maximum and minimum flow rates expected during and after capping of the OSDF.

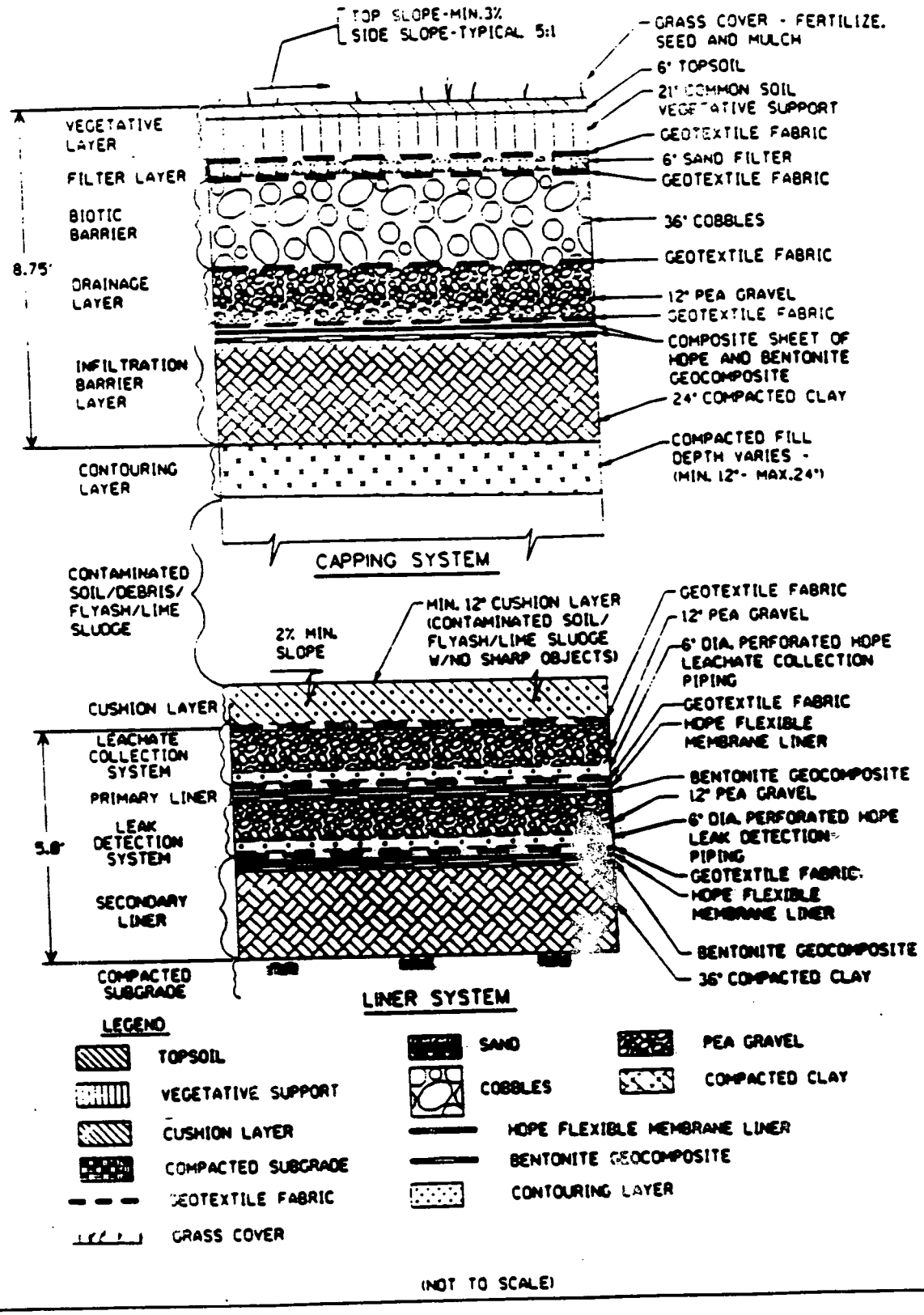


FIGURE 2: PRIMARY COMPONENTS OF DISPOSAL FACILITY

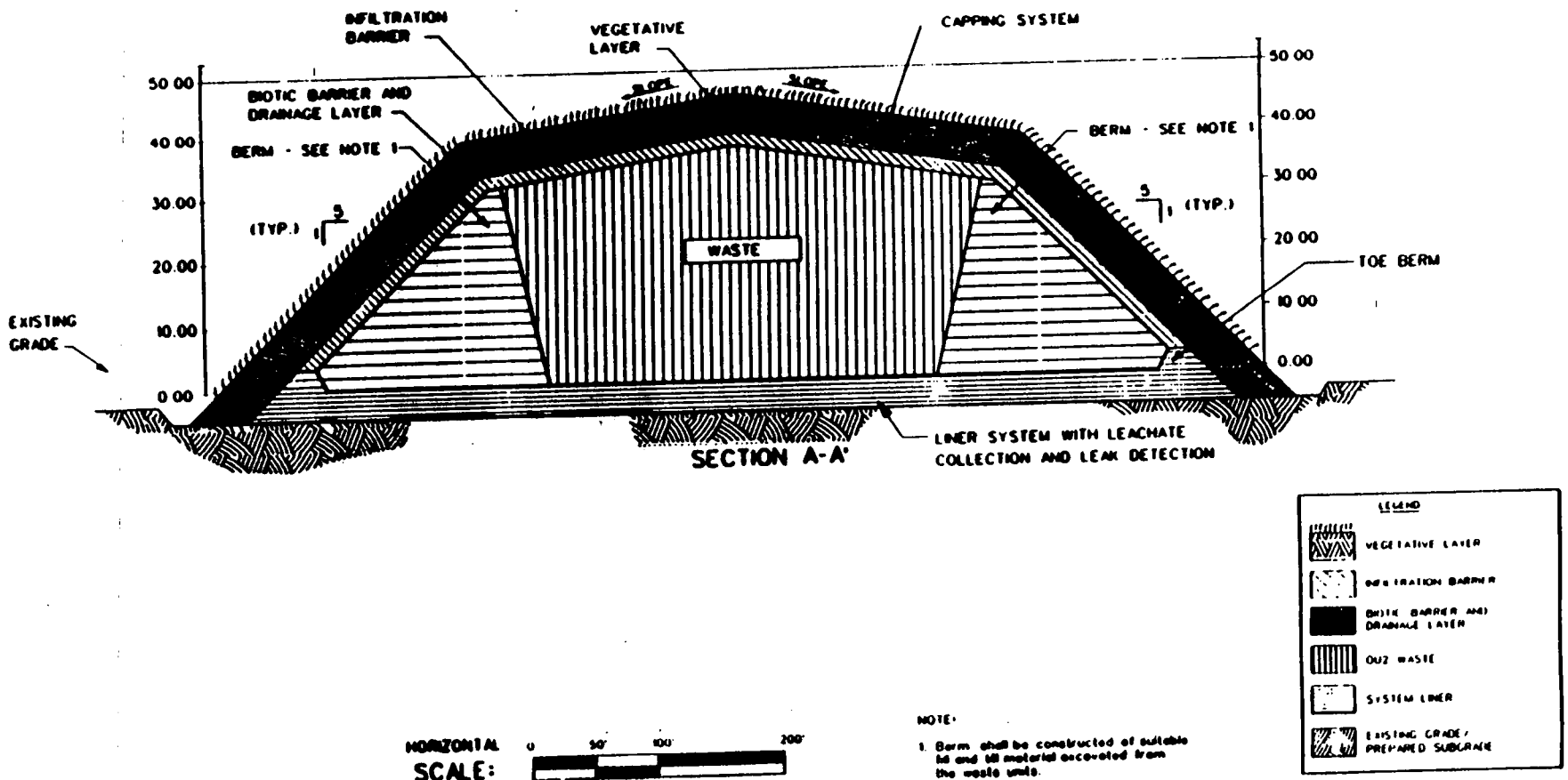


FIGURE 3: CONCEPTUAL CROSS-SECTION

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/USR/HMAS/OU01/DGN/BMP CROSS.DGN

4.0 REGULATORY REQUIREMENTS

The OSDF detailed design will conform with CERCLA §121(d)(2) which requires that remedial actions protect human health and the environment and comply with applicable or relevant and appropriate requirements (ARARs). The complete list of Operable Unit 2 ARARs can be found in the *Operable Unit 2 (ROD)*.

EPA has identified three categories of ARARs:

- *Chemical-specific* ARARs are usually health- or risk-based numerical values or methodologies used to determine acceptable concentrations of chemicals that may be found in or discharged to the environment [e.g., maximum contaminant levels (MCLs) that establish safe levels in drinking water].
- *Action-specific* ARARs are usually technology- or activity-based requirements or limitations on actions or conditions involving special substances.
- *Location-specific* ARARs restrict actions or contaminant concentrations in certain environmentally sensitive areas. Examples of areas regulated under various federal laws include floodplains, wetlands, and locations where endangered species or historically significant cultural resources are present.

Sources of Operable Unit 2 ARARs are federal and state laws, regulations, and guidance and DOE Orders that address the site-specific circumstances in Operable Unit 2.

The chemical-specific requirements include ARARs associated with potential releases to air, surface water, groundwater, and penetrating radiation. Releases of dust and radiation to the air will meet applicable requirements; discharges to surface water will meet Ohio Water Quality Criteria; the groundwater will be protected to drinking water standards; and the public will be protected according to DOE Orders from potential releases of radiation.

Action-specific ARARs require that the OSDF be designed and constructed to comply with appropriate DOE Orders (including the As Low As Reasonably Achievable [ALARA] policy); 40 Code of Federal Regulations (CFR) 192 (uranium mill tailing disposal); RCRA requirements for the disposal of hazardous waste; and Ohio EPA solid waste disposal requirements.

The protection of endangered species, cultural resources, floodplains, and wetlands in the locations of remediation is covered under the location-specific requirements. These requirements also include the Ohio siting requirements for the OSDF. Pursuant to the Operable Unit 2 ROD, a waiver has been granted to allow the facility to be constructed over a high-yield, sole-source aquifer.

5.0 NUCLEAR SAFETY AND RADIATION PROTECTION

Radiation protection shall comply with ARARs identified for this project and ALARA principles. This project will not involve handling, storage, or treatment of special nuclear materials; therefore, safeguards for these materials are not required.

Since the maximum uranium radioactivity of waste materials allowed in the OSDF is less than 1,030 picoCuries/gram, no shielding or special handling requirements are needed.

6.0 SPECIFIC FUNCTIONAL REQUIREMENTS

The primary components of the OSDF are listed below and graphically presented in Figures 2 and 3.

- a liner system consisting of primary and secondary barrier layers with leachate collection, leak detection and a protective cushion layer
- placement and compaction of waste fill material
- management of leachate
- a multi-layered capping system consisting of an infiltration barrier layer overlain by a drainage layer, a biotic barrier, a filter layer and a vegetative layer
- management of surface water
- a relocated North entrance road for FEMP access
- a haul road for transport of impacted material from the South Field to the OSDF
- supply of and relocation of utilities impacted by the DF

6.1 LINER AND LEACHATE SYSTEMS

The basal features of the OSDF include the following:

- liner system
- leachate collection system, and
- leak detection system

These systems and their functional requirements are described in the following section.

6.1.1 Liner System

The liner system will consist of a combination of natural material (soil/rock) and synthetic components. The liner system's primary barrier layer will consist of a synthetic flexible membrane overlying a clay/synthetic geocomposite. The secondary barrier layer will also consist of a synthetic flexible membrane overlying a clay/synthetic geocomposite plus a minimum of three feet of compacted clay. The on-site native clays may be remolded to form this clay layer provided that performance requirements (permeability less than 10^{-7} cm/sec) are met. Otherwise, the clay will be hauled from an off-site borrow source. A passive, leak detection system will separate the barrier zones.

The liner system will, if feasible, be founded within the vertical limits of the brown clay formation which typically overlays the gray clay formation. The liner system must be sited so that at least 12 feet of gray clay exists below the liner. Further, it is desired that no part of the liner system be constructed on fill.

In order to minimize excavation, it is desired that the top of the protective cushion layer for the primary liner system be at or near existing grade. Due to the existing topography, some additional grading may be required at the northeast corner of the preferred site to provide proper drainage.

The liner system components will be keyed into a perimeter toe berm. The horizontal extent of the liner system to be installed in each phase will be delineated by this toe berm. The OSDF should be constructed in several discrete segments with separate leachate collection systems. Each of these is considered to be a phase. The toe berm will serve as a containment/diversion structure for runoff from the active area during placement of impacted material prior to installation of the cap. The liner system will be protected from damage caused by burrowing animals and plant roots.

6.1.1.1 Site Preparation

Prior to commencing excavation in preparation for installation of the liner system, the existing surficial (top 6 to 12 inches) soils identified as (COCs) will be removed as part of the remedial activities for the operable units. These materials will be temporarily stockpiled in a controlled area and protected from erosion, dust, and dermal contact by potential receptors. After completion of the liner system (by phase), the stockpiled surficial soils will be placed with other materials in the OSDF.

Water encountered during the excavation activities shall be considered as containing low level concentrations of COCs. All groundwater and/or surface water removed from the excavation will be transferred to a central sump system. The earthwork contractor will be responsible for submitting a plan with specific procedures for handling waters resulting from the construction activities. The criteria for discharges to the Advanced Waste Water Treatment (AWWT) from the remedial activities will be established by FERMCO. Refer to Section 6.5 for further requirements relative to stormwater management.

6.1.2 Leachate Collection/Management

The leachate collection system will be placed above the primary liner to collect potential water infiltrating the capping system (estimated to be 0.07 inches per year while the synthetic membrane maintains its integrity). This system will be designed based on requirements for leachate collection.

The leachate collection system will be protected by a combination of geotextiles and selected soil material (free of sharp, protruding objects) from the remediation activities. The placement of a cushion layer will not be part of the liner installation, but will be completed as part of the material placement activities. The leachate will be collected by a series of collector pipes. The collector pipe trench will be designed

to provide free draining of the leachate collection layer. Each collector pipe will pass through the toe berm and terminate into a sump. The individual sumps will discharge into an interceptor pipe running along one side of the facility. Cleanouts should be provided on the end of each collector pipe. A central sump (or sumps, as required) will be provided to transfer the collected leachate via a force main to treatment and/or disposal as needed.

6.1.3 Leak Detection

The leak detection system will be a passive system which only uses gravity drainage for flow to an observation sump. The system will be designed to be sensitive to low flows. Each collector (pipe) will pass through the perimeter toe berm to a respective sump. The sumps will not be interconnected nor will the leak detection system be interconnected with the leachate collection system.

6.1.4 Liner Compatibility Study

An evaluation of the compatibility and physical properties of proposed liner materials will be completed by the architect/engineering (A/E) firm. A review of published data on similar applications will be a key component of this evaluation. Physical/chemical testing will be executed where existing data is considered inadequate to verify the design of the liner. Interface testing to evaluate the engineering properties of the material contact will also be performed.

6.2 MATERIAL PLACEMENT

The nominal capacity of the facility has been set at 2.5 million cubic yards (bank/unbulked) based on the estimates of quantities of material to be placed in the facility resulting from the remediation activities at the operable units. These materials will be placed and compacted to form a mound over the liner system. The materials will be placed in a manner to minimize settlement and be compacted into a mass of relatively low permeability with minimal voids or channels through which water could flow unimpeded.

The side slopes of the mound shall be such that the potential erosion is controllable and the embankments are stable while making effective use of the available area. The conceptual design prepared by Operable Unit 2, as depicted in Figure 3, indicates a slope of five-foot horizontal to one vertical coupled with a height of 30 feet (vertical height at the top of the slope of material to be contained within the facility).

A material handling/placement plan will be prepared by the A/E utilizing data on stability from the Geotechnical Investigation and Predesign Siting Study. The A/E will provide performance specifications for handling/placement of material within the OSDF. Sizing of debris will be specified by FERMCO with input from the A/E. The performance specifications will include provisions for quality control

requirements during placement activities. The Placement Plan will also include specific requirements for OSDF worker health and safety. The design of the facility will provide for control of fugitive emissions during placement of impacted material. Real-time air monitoring will be conducted by FERMCO and the construction contractor. The air monitoring plan will prepared by FERMCO with input from the A/E.

The OSDF must accommodate a variety of placement and hauling equipment. Equipment may include track mounted dozers, wheel loaders, rubber-tired backhoes/front end loaders, and/or vibratory tamping compactors. Haul vehicles into the facility may be both off-highway and on-highway trucks.

6.3 CAPPING SYSTEM

The conceptual design of the capping system consists of a layered combination of natural material (soil/rock) and synthetic components. The surface of the compacted materials will be shaped/prepared for placement of the capping system. This "contouring" layer will be typically 12 inches, but not more than 24 inches thick. This contouring layer forms the subbase for the compound barrier zone consisting of a two-foot layer of compacted clay, a clay/synthetic geocomposite with an integral flexible membrane. A drainage layer will be placed above the barrier zone to collect and convey water infiltrating the capping system with direct discharge to the perimeter drainage system (Refer to Section 2.1). This layer may consist of natural (sand) soil material or a combination of natural and synthetic (geonet) materials. A biotic barrier is required above the drainage layer to provide long-term protection from burrowing animals and vegetative root intrusion. A filter layer will be placed above the biotic barrier to separate the vegetative zone from the biotic barrier and prevent loss of the soil from the vegetative zone into the biotic layer. The vegetative zone will consist of a minimum of 6 inches of topsoil overlaying a minimum of 21 inches of soil suitable to support vegetative growth of sufficient thickness to maintain proper moisture control within the plant root zone. The surface cover/vegetation shall provide, to the extent feasible, protection against erosion (DOE Order 1023-92; 2000 year storm recurrence interval).

6.3.1 Interim and Partial Closure

Scheduling/financial constraints may dictate that the facility be closed down at intervals or for extended periods of time during such times all exposed impacted material will be covered, or other engineered controls will be used to control fugitive emissions. Daily/weekly cover may consist of tarps, geotextiles, or a watering system may be used to control fugitive emissions. The exterior side slopes will be closed as soon as possible after the planned vertical extent of waste is achieved for each phase of placement activities. During material placement activities, erosion fabric/tarps or other temporary cover will be used, as necessary, to control erosion on the outer slope.

An extended shutdown of the facility (greater that one-year) may necessitate partial closures. In anticipation of a shutdown (e.g. winter weather), the facility will be graded to promote proper drainage. Exposed surfaces will be covered with a layer of soil. In the event of an extended shutdown (greater than one year) a partial closure will be implemented thus creating a cell within the overall OSDF. All slopes will be graded in compliance with applicable standards, then capped with the barrier layer, drainage layer and vegetative zone described above.

Portions of the liner system that may be subjected to freezing should be protected. It is anticipated that scheduled placement of materials will provide for this protection.

6.4 BORROW MATERIAL FOR LINER/CAP SOIL BARRIER LAYER AND VEGETATIVE ZONE

The requirements for borrow soils will be part of the OSDF design. The A/E will use data from a borrow area geotechnical study to develop borrow excavation and restoration plans. The actual excavation plan will reflect phasing to coincide with the construction activities at the OSDF.

6.5 SURFACE WATER MANAGEMENT

6.5.1 Perimeter Drainage

The facility will be isolated from adjacent land runon by a perimeter drainage system. This perimeter drainage system will divert runoff from abutting land north, east and west of the facility and rejoin the existing drainage channels/ditches south of the former Production Area. The perimeter drainage system will be installed in phases utilizing existing drainage channels wherever feasible. The installation of the first phase of the perimeter swale will precede the installation of the liner system. The design (profile) of the perimeter swale will provide for free discharge from the drainage layer, filter layer and biotic barrier layer which are part of the OSDF cap.

The design of the perimeter drainage system along the north and east sides of the facility will be coordinated with the drainage design for the relocated North Entrance Road.

6.5.2 Management of Stormwater during Construction

The disturbed area shall be kept to a minimum. Erosion and sediment controls will be provided to inhibit soil particles in stormwater runoff. Stormwater retention shall be provided so that the capacity of existing drainage system or treatment systems are not exceeded.

Runoff from undisturbed areas not containing impacted soils shall be isolated from the OSDF's Stormwater Drainage System and directed to the perimeter drainage system. Existing drainage channels are to be used wherever feasible.

Runoff from areas potentially containing COCs shall be collected and transferred to temporary holding/settling tanks. After allowing for settlement of fines, the water shall be decanted from the tanks and piped to treatment and/or disposal as needed.

6.5.3 Stormwater Management within Facility during Placement Activities Prior to Closure

Stormwater shall be contained within the active facility area by the perimeter toe berm and collected by infiltrating into the leachate collection system or by temporary sump(s). Measures to control erosion of particulate matter from the placed material will be provided. A nonwoven geotextile may be placed over the exposed cushion layer to filter the runoff to prevent the accumulation of fines in the leachate collection system. If sumps are used, filter traps are to be provided to screen out solids. The water collected shall be directed to a centralized sump system. This water will be pumped until the utility corridor near the sewage treatment plant is removed. After removal of these utilities, the water will gravity drain. A retention tank or basin may be required to temporarily hold the water depending on available treatment capacity or to relieve ponding over the liner system.

6.5.4 Stormwater Management After Closure (Partial or Final)

Stormwater from areas of the OSDF that have been closed shall be directed to the perimeter drainage system. This perimeter system is described in 6.5.1.

6.6 SUPPORT ELEMENTS

6.6.1 Staging Area

A staging area will be provided near or within the overall footprint of the facility to serve as a temporary holding area for demolition debris and impacted material. This area will be a concrete slab to facilitate rehandling of the debris/material without breaking up the ground surface. The size of the area is dependant on the rate the debris is generated and the availability of space within the facility to place the material for final disposition. The design will provide flexibility to accommodate varied demand by initially constructing a staging area one acre in size and designing expansions to provide an area of up to three acres.

Runoff from the staging area will be collected in a local sump where it will be pumped to treatment and/or disposal as needed. This discharge will be coordinated with other collected waters potentially containing COCs. Secondary containment in the form of a flexible membrane liner, drainage layer and subdrain system will be provided under the concrete slab.

6.6.2 Perimeter Security Fencing/Temporary Fencing

Perimeter security fencing will be installed to limit the work area for the OSDF. Temporary fencing will be installed, as required, to delineate work areas within the limits of work. Requirements for temporary fencing will be developed during the design activities.

6.7 UTILITIES

6.7.1 Utilities to Support OSDF

The construction, waste placement activities, closure, and post-closure of the OSDF and Borrow Area (BA) will require several site utilities to perform its function. These utilities are needed to support functions under varying service requirements. Utilities will be run to the point of service at the OSDF. These utility needs are described below for three phases of OSDF operation.

Construction:

- construction operations center including electrical power, potable water and communications.
- construction service water
- sewerage
- natural gas

Waste Placement and Closure Activities:

- administrative control center, including electrical power, potable water and communications
- waste placement activities service water
- sewage
- natural gas

Post-Closure Care Activities:

- administrative and maintenance control center, including electrical power, potable water and communications
- sewage
- natural gas

Functional Requirements are described below:

- The A/E firm shall determine the types of utilities and capacities of the services required. Interface with the OSDF A/E firm is required.
- The A/E firm will design the utility services from a source of the utility to the interface point with the OSDF. The interface point of these utilities will be determined by FERMCO. The location of the utility source shall be proposed by the A/E firm and approved by FERMCO.
- The design should take into consideration the requirements for safely connecting utility lines to existing live utility service lines ("hot tapping"). If hot tapping is not feasible, the subcontractor shall notify FERMCO as to the requirements for service outages during connection. FERMCO shall make the final determination of requirements for service outages.
- The design of the utilities shall be performed using regulations and guidance from local and state governments, OEPA, Cincinnati Gas & Electric, other public utilities, ASTM, ASCE, ANSI, ACI, NEC, or other groups which promote safety and design standards for utilities supply.
- The AE will evaluate the optimal routing to provide these utilities to the interface point, with consideration given to avoiding areas that are to be demolished, developed, on-site soil remediation areas and borrow areas in which excavation is planned.
- As possible, the utility routing shall be installed in existing utility corridors, as identified by FERMCO.
- The utilities shall be installed at a depth sufficient to resist frost damage/ frost heave, based on local conditions.
- The utility lines shall be designed to accommodate vehicle and/or railroad loadings at locations where the pipeline will cross beneath haul roads, access roads and railroads.
- A water supply will be provided for dust suppression and moisture control during placement of material in the facility. Multiple hose connections will be provided along the western side of the facility.

6.7.2 Relocation of Existing Utilities

It will be necessary to relocate existing utilities located within the proposed footprint of the OSDF. An A/E firm will verify the vertical and horizontal location of the existing utilities to be relocated in coordination with the design/construction of the relocated North Entrance Road and prepare a plan of the confirmed location.

These activities are required to abandon or remove, and relocate utility, service lines, and site facilities within the battery limits of the On-Site Disposal Facility north of the 480,725 north latitude (1982 North American Datum, NAD) line. This may include, but not be limited to: natural gas lines, underground and above ground power lines, buried and above ground telephone lines, sanitary and industrial waste sewers, water lines, and foundations, storm sewers, security fences, and air quality monitoring stations.

Utility relocation activities include the following:

- the determination of which utility lines, and air monitoring stations are to be replaced,
- the design of the replacement facilities,
- determination of the design capacity of each proposed utility line (based on existing and future requirements),
- determination of materials of construction and installation methods consistent with public utility requirements,
- routing of the replacement lines, and
- abandonment of the existing items (e.g., pipelines)

The design of replacement systems and abandonment/removal of existing systems shall be based on public utility, local and state government, OEPA, DOE, and FERMCO requirements.

6.8 SUPPORT FACILITIES FOR THE OSDF

Administrative, hygiene and maintenance facilities will be provided to support operations of the OSDF.

6.8.1 Administrative Support

Trailers will be provided for administrative functions required during placement of impacted material in the OSDF. Parking will be provided adjacent to the administrative trailer for the work crew, office staff and visitors. The parking area will have an all weather surface. An access road will be provided from existing roadways. The support area will be fenced with access controlled by a manually operated and locking gate. Lighting will be provided to illuminate the area for safety and security.

6.8.2 Personnel Contaminant Reduction During Placement Activities

A personnel decontamination trailer will be provided in order to pass from the administrative support area to the active work area of the disposal cell. This decontamination trailer will also contain lockers, complete showers, and sanitary facilities.

Personal vehicular access to the work area will not be permitted from the administrative area with the exception of emergency situations. A normally locked vehicle gate will be provided for emergency access/egress.

6.8.3 Equipment Maintenance

A site-wide fueling truck will service the OSDF equipment and vehicles; therefore, a local fueling station will not be required. All day to day equipment maintenance at the fueling station will be provided by FERMCO.

Major equipment repairs will be made in a central maintenance/decontamination facility provided by FERMCO. Equipment decontamination is discussed below.

6.8.4 Equipment Decontamination

The under carriage and exterior of all haul vehicles leaving the disposal facility work area will be cleaned to remove particulate matter. Each haul vehicle will pass through a decontamination station consisting of high pressure spray from the sides and bottom. These decontamination stations will be temporary facilities or transportable units since the egress points from the facility will vary considerably with time. Side panels will be used to control fugitive emissions from the decontamination stations. In the OSDF prior to shipment to the central maintenance/decontamination facility for complete decontamination and/or service.

6.9 RELATED ACTIVITIES

6.9.1 Test Pad Program

Soil test pads will be constructed within the limits of the OSDF in accordance with Ohio Administrative Code (OAC) 3745-27-08 paragraph (C)(1)(m). Separate test pads will be constructed for each source of soil.

6.9.2 Monitoring Well Closure

Existing monitoring wells located within the limits of the OSDF will be abandoned by overdrilling and grouting with expansive grout.

6.9.3 Monitoring Well Installation

New monitoring wells will be installed in conjunction with each phase of disposal cell construction.

6.9.4 Radiation Monitoring System Relocation

Existing radiation monitoring stations within the limits of the OSDF footprint will be relocated.

6.9.5 Air Monitoring Systems

Existing air monitoring devices located within the limits of the OSDF will be abandoned in conformance with site specifications and relocated as necessary to maintain the overall monitoring of the FEMP. New air monitoring devices for evaluating the performance of the on-site OSDF will be installed in conjunction with each phase of OSDF construction.

6.10 ROADWAYS

Both the haul road and the north entrance road is to be designed for H-20 loading.

6.10.1 Haul Road

The haul road will be located in the contaminated area and will be a two lane, undivided road with shoulders on each side. A typical section of the road consists of two 12-foot lanes and a 5 ft shoulder on each side. It will be an asphalt paved road with gravel shoulders having 3 percent cross-slope. The primary use of the haul road is to transport waste material from within the operable units to the on-site disposal area. It is anticipated that approximately 300,000 CY of material will be hauled from the Operable Unit 2 (OU2) South Field/Inactive Flyash Pile areas to the OSDF. The haul road is to be designed for an average daily traffic (ADT) of 400 and anticipated life of 5 years for the portion west of the proposed OU1 railroad system and 10 years for the eastern portion. The distribution factor for each lane is 50 percent. The eastern portion of the haul road crosses 5 railroad spurs, but these spurs will be non-operational at the time of the haul road construction. The design speed is 20 mph. Since the road is to be used by hauling trucks, the maximum grades will be less than 3%. The use of a lighted traffic signal at the road crossing and at an active railroad track crossing on the west side will be investigated and, if applicable, included in the design. Once the haul road is abandoned, any material not meeting the Final Remediation Levels (FRLs) will be removed and dispositioned in accordance with site policy.

6.10.2 North Entrance Road

The north entrance road will be a permanent facility and soil contaminated above the final remediation levels will be removed from the vicinity of the road prior to its construction. It will be a two lane, undivided road with shoulders on each side. A typical section of the road is shown on Figure A-3 which consists of two 12-foot lanes and 5-foot shoulders. It will be an asphalt paved road with gravel shoulders having a 3 percent cross-slope. The access road to the monitoring wells will be 12-foot wide gravel road with a turn around at the monitoring wells. This road will be used primarily by passenger cars and light trucks. The road is to be designed for an average daily traffic (ADT) of 6000, anticipated life of 20 years, and the distribution factor for each lane is 50 percent.

This road is to be constructed in two phases. The first phase will pass around the existing sewage treatment plant and electrical substation. The second phase will be constructed after the removal of the existing sewage treatment plant and the electrical substation when this road will be straightened. The design will incorporate both phases; however, the phases will be constructed in separate contracts. The design speed is 30 mph.

The borrow material from south of the plant will be used at the disposal site, so hauling trucks will cross southern portions of the proposed north entrance road at two locations and the south entrance road at one location. The use of lighted traffic signals will be investigated and, if applicable, included in the design.

6.11 WASTE LIQUID CONVEYANCE SYSTEM

Leachate and collected stormwater from the active and closed portions of the On-Site Disposal Facility (OSDF) will be collected at a sump at the southwest corner of the OSDF. The collected liquid will be pumped from the disposal facility collection sump to treatment/disposal in a buried, double-contained pipeline. The system includes pumping, piping, flow measurement and monitoring, leak detection, and maintenance fixtures and appurtenances required to safely transfer the collected liquid from the OSDF collection sump to the treatment/disposal collection location. The design life of the liquid transfer system shall be 200 years. The conveyance design shall include determining the flow requirements (depth of flow, velocity, head, etc.) at maximum flow rate as well as at the minimum flow rate expected after completion of the OSDF capping system. The conveyance system design flow rate is expected to vary over the waste placement and post-closure care period of the OSDF.

6.11.1 Pipeline

Functional requirements for the conveyance system pipe design include the following items:

- Pipeline will be designed with sufficient capacity to safely convey leachate and collected stormwater from the OSDF collection sump to the treatment/disposal collection location without back up of liquid into the OSDF leachate collection system. The capacity will be designed to handle the discharge generated during the construction, waste placement, and post-closure phases of the project.

- Pipeline will be double contained such that any leak occurring in the primary conveyance pipeline, would be collected in the secondary, outer pipe, and prevent discharges of water to the environment.

- Pipeline will be designed such that materials specified for the pipe are compatible with the contaminants expected to be present in the leachate, and be resistant to premature wear based on the condition of the liquids and/or surrounding soil. Additionally, the materials of construction will be compatible with the materials used by the OSDF design firm in their leachate collection system installed within the OSDF.

- The pipeline will include provisions for corrosion control, as required, to resist soil conditions encountered along the pipeline route.

- The pipeline will include provisions for inspection and cleanout of accumulated sediment, blockage, or other material that may cause flow constriction/reduction.

- The pipeline will be installed at a depth sufficient to resist frost damage/ frost heave, based on local conditions.

- The pipeline will be designed to accommodate vehicle and/or railroad loadings at locations where the pipeline will cross beneath haul roads, access roads and railroads.

- The pipeline will be designed to accommodate stream or culvert crossings (as applicable).

6.11.2 Leak Detection System/ High Level Alarm

The Functional Requirements of the alarm system for the liquid conveyance system include the following:

- A leak detection sensor will be provided to indicate to FEMP personnel that a leak has occurred in the primary pipe. The leak detection system shall indicate the approximate location of the leak.

- The leak detection system will be compatible with the system designed by the OSDF design firm for the OSDF leachate pipeline.

- A high level alarm system will be designed to alert AWWT operators of such conditions in the leachate collection sump.

6.11.3 Pump System

If a pressurized system is required, a pump system will be designed to deliver the anticipated flow rates (maximum and minimum) to the liquid treatment disposal facility. The pumps shall be installed in the collection sump. The Functional Requirements include the following:

- The pumps will be designed with sufficient flow and head capacity to convey the design flows from the OSDF discharge generated during the construction, waste placement, and post-closure phases of the project.

- The power supply requirements will be similar to those provided for the OSDF pumping system.

- The pump settings will be designed to include a method for removal, repair and replacement of pumps. Duplicate pumps or other arrangements shall be made to provide for uninterrupted delivery of waste liquid to the treatment/disposal facility during pump maintenance.

- The pump system will be designed to turn on and off automatically depending upon water levels in the leachate collection sump at the OSDF. A manual on/off override system will also be provided. The system will include an automatic and manual shutoff of the pumps when upstream conditions at the treatment/disposal facility require no flow, or when a leak is detected in the conveyance system.

- Capacity of the pump sump will be reviewed and modified as required to insure sufficient volume exists to prevent rapid on/off cycling of the pump system.

- Materials of construction of the pumps and seals will be compatible with and chemically resistant to the leachate contaminants.

- The pump system will be capable of handling sediments in the water resulting from runoff from the liner system without excessive wear which may result in premature pump replacement.

6.11.4 Flow Meter

A flow measurement device will be provided, and flow indication will be provided at the facility. The Functional Requirements for the flow meter include the following:

- Flow meter scale will be such that the design flows read at approximately 50% of full scale of the meter. The maximum design flow shall read at approximately 80% of full scale of the meter.

- Materials of construction shall be such that the flow transducer is resistant to corrosion and abrasion from the chemical and physical properties of the liquids being conveyed.

- Flow transducer shall be designed to provide a variable output signal to a flow meter located at the AWWT.

- The flow meter shall be provided with a flow totalizer to allow total flow over specific periods to be measured.

- The design of the flow meter installation shall allow for a method of repair, maintenance, cleaning, and removal of the flow meter transducer.

7.0 REFERENCE MATERIALS

This section identifies the primary documents used for reference during remedial design. This includes those documents prepared to date to support the Remedial Design and Remedial Actions. Specific codes, standards, and DOE Orders which apply to this project will be identified in the Design Criteria Package (DCP) of the OSDF.

The following are the primary reference documents which apply to this project:

- Remedial Investigation Report

  U.S. Department of Energy, 1995a. "Final Remedial Investigation Report for Operable Unit 2, FEMP, Fernald, OH, Remedial Investigation, Feasibility Study" U.S. DOE Fernald Office, Fernald Ohio.

- Feasibility Study

  U.S. Department of Energy, 1995a. "Final Feasibility Study Report for Operable Unit 2, FEMP, Fernald, OH, Remedial Investigation, Feasibility Study" U.S. DOE Fernald Office, Fernald Ohio.

- Record Of Decision

  U.S. Department of Energy, 1995a. "Final Record of Decision for Remedial Actions at Operable Unit 2, FEMP, Fernald, OH," U.S. DOE Fernald Office, Fernald Ohio.

- Remedial Design Work Plan

  U.S. Department of Energy, 1995. "Draft Remedial Design Work Plan for Remedial Actions at Operable Unit 2" FEMP, Fernald, OH," U.S. DOE Fernald Office, Fernald Ohio.

8.0 PROJECT MILESTONES

The following milestones are defined in the "Draft Remedial Design Work Plan for Remedial Actions at Operable Unit 2."

Submit OSDF Preliminary Design Review Package to EPA	12/22/95
Submit OSDF Pre-Final Design Review Package to EPA	06/28/96
Submit OSDF Final Design Review Package/Certified For Construction to EPA.	10/14/96
Submit Primary Waste Haul Road Preliminary Design Review Package to EPA	01/29/96
Submit Primary waste Haul Road Pre-Final Design Review Package to EPA	05/03/96
Submit Primary Waste Haul Road Final Design Review Package/CFC to EPA	07/23/96

APPENDIX C

APPENDIX C

ARARs FOR OPERABLE UNIT 2

TABLE A-1
CHEMICAL-SPECIFIC REQUIREMENTS

Citation	Chemical	Requirement	Determination	Remarks
		GROUNDWATER PROTECTION STANDARDS		
EPA National Primary Drinking Water Regulations 40 CFR §141.15 and §141.16	MCLs for Radiological Contaminants	The following are maximum contaminant levels for radiological contaminants: Combined radium-226 and -228 . . . . . 5 pCi/L Gross alpha particle activity . . . . . 15 pCi/L (including radium-226 but excluding radon and uranium) Beta and photon radioactivity . . . . . 4 mrem/year from man-made radionuclides	Relevant and Appropriate	OEPA MCLs from OAC 3745-81-15 and -16 are the same as the Federal MCLs.
56 Federal Register 33050 (July 18, 1991)	Proposed MCLs for Radiological Contaminants	The following are the proposed maximum contaminant levels for radiological contaminants: Radium-226 . . . . . 20 pCi/L Radium-228 . . . . . 20 pCi/L Radon-222 . . . . . 300 pCi/L Uranium . . . . . 20 μg/L (30 pCi/L) Beta and photon emitters . . . . . 4 mrem ede/year (excluding radium-228) Adjusted gross alpha emitters . . . . . 15 pCi/L (excluding radium-226, uranium, and radon-222)	TBC	
EPA National Primary Drinking Water Regulations 40 CFR §141.61	MCLs for Organic Contaminants	The following are the maximum contaminant levels for organic contaminants: Benzo(a)pyrene . . . . . 0.0002 mg/L Polychlorinated biphenyls (PCBs) . . . . . 0.0005 mg/L	Relevant and Appropriate	Final MCLs are not presented for contaminants for which the non-zero MCLG is less than or equal to the MCL.
EPA National Primary Drinking Water Regulations 40 CFR §141.51	MCLGs for Inorganic Contaminants	The following are the non-zero maximum contaminant level goals for inorganic contaminants: Antimony . . . . . 0.006 mg/L Beryllium . . . . . 0.004 mg/L	Relevant and Appropriate	

TABLE A-1
(Continued)

Citation	Chemical	Requirement	Determination	Remarks
		GROUNDWATER PROTECTION STANDARDS (continued)		
50 Federal Register 46936 (November 13, 1985)	Proposed MCLGs for Inorganic Contaminants	The following are proposed, non-zero, maximum contaminant level goals for inorganic contaminants: Arsenic . . . . . 0.05 mg/L	TBC	
Ohio Drinking Water Regulations OAC 3745-81-11	MCLs for Inorganic Contaminants	The following are the maximum contaminant levels for inorganic contaminants: Arsenic . . . . . 0.05 mg/L	Relevant and Appropriate	Final MCLs are not presented for contaminants for which the non-zero MCLG is less than or equal to the MCL. This MCL is a stricter state standard.
EPA Groundwater Standards for Remedial Actions at Inactive Uranium Processing Sites 40 CFR §192.02(c)(3)(B)	Groundwater Protection Standards	The concentrations of the following constituents in groundwater must not exceed: Arsenic . . . . . 0.05 mg/L Combined radium-226 and radium-228 . . . . . 5 pCi/L Combined uranium-234 and uranium-238 . . . . . 30 pCi/L Gross alpha particle activity . . . . . 15 pCi/L (excluding radon and uranium)	Relevant and Appropriate	

TABLE A-1
(Continued)

Citation	Chemical	Requirement	Determination	Remarks
		OHIO WATER QUALITY STANDARDS		
Ohio Water Quality Standards OAC 3745-1-21	Use Designation	Paddys Run and the Great Miami River are designated as: • warmwater aquatic life habitat • agricultural and industrial water supply • primary contact recreational use	Applicable	In addition to these overall designations: • Ross Rd. (River Mile (RM) 95.7) to Taylorsville Dam (RM 92.6) is a state resource water • RM 130 and RM 118 are public water supplies The FEMP effluent discharge pipe is located at RM 24.73, downstream of the state resource waters and public water supplies.
Ohio Water Quality Standards OAC 3745-1-07	Warmwater Habitat Water Quality Criteria	Parameter (µg/L) — outside mixing zone Max. / Avg. — inside mixing zone Max. Antimony (total): 650 / 190 / 1,300 Arsenic: 360 / 190 / 720 Beryllium (total): 520 / 23 / 1,000 Dieldrin: - / 0.005 / - Polychlorinated Biphenyls (PCBs): - / 0.001 / -	Applicable	Beryllium is based on a water hardness of 100 mg/L calcium carbonate ($CaCO_3$).
Ohio Water Quality Standards OAC 3745-1-07	Human Health and Agricultural Water Supply Criteria	Parameter (µg/L) — Human Health (outside mixing zone) — Agricultural Antimony (total): 780 / - Arsenic: - / 100 Beryllium (total): 1.17 / 100 Dieldrin: 0.00076 / - Polychlorinated Biphenyls (PCBs): 0.00079 / - Polynuclear Aromatic Hyrdrocarbons (PAHs): 0.31 / -	Applicable	

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TABLE A-1
(Continued)

Citation	Chemical	Requirement	Determination	Remarks
		RADIATION DOSE LIMITS		
Radioactive Waste Management DOE Order 5820.2A Chapter III (3)(a)(2)	Protection of the General Population from Releases of Radioactivity	Concentrations of radioactive material which may be released to the general environment in surface water, ground water, soil, plants or animals must not result in an effective dose equivalent that exceeds 25 mrem per year to any member of the public. Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable.	TBC	
Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter II (1)(a)	Public Dose Limits	The exposure of members of the public to radiation sources as a consequence of all routine DOE activities shall not cause, in a year, an effective dose equivalent greater than 100 mrem. Dose evaluations should reflect realistic exposure conditions. Specific authorization may be received for a temporary increase of the dose limit up to 500 mrem in a year.	TBC	
Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter II (1)	Public Dose Limits	The public dose limits include consideration of all exposure modes from all DOE activities (including remedial activities). Effective dose equivalent is the sum of the effective dose equivalent (weighted summation of doses to various organs of the body) from exposures to radiation sources external to the body during the year plus the committed effective dose equivalent from radionuclides taken into the body during the year. Medical sources, consumer products, residual fallout from past nuclear accidents and weapons tests and naturally occurring radiation sources are not included in this summation.	TBC	
National Emission Standards for Hazardous Air Pollutants 40 CFR §61.92, 61.93 Subpart H [Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter II (1)(b)]	National Emissions Standards for Emissions of Radionuclides Other than Radon from DOE Facilities	Emissions of radionuclides (except radon-220 and radon-222) to the ambient air from Department of Energy facilities shall not exceed those amounts that would cause any member of the public to receive in any year an effective dose equivalent of 10 mrem/yr.	Applicable	

TABLE A-1
(Continued)

Citation	Chemical	Requirement	Determination	Remarks
RADIATION DOSE LIMITS (continued)				
National Emission Standards for Hazardous Air Pollutants 40 CFR §61.92, 61.93 Subpart H [Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter II (1)(b)] (continued)	National Emissions Standards for Emissions of Radionuclides Other than Radon from DOE Facilities	To determine compliance with the standard, radionuclide emissions shall be determined and effective dose equivalent values to members of the public calculated using EPA approved sampling procedures, computer models CAP-88 or AIRDOS-PC, or other procedures for which EPA has granted prior approval.	Applicable	
Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter II (3)(a)(5)	Interim Dose Limit for Native Aquatic Animal Organisms	The absorbed dose to native aquatic animal organisms shall not exceed 1 rad per day from exposure to the radioactive material in liquid wastes discharged to natural waterways.	TBC	
Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter IV (4)(c)	External Gamma Radiation	External gamma radiation levels on open lands shall comply with the basic public dose limit of 100 mrem effective dose equivalent in a year and the ALARA process, considering appropriate-use scenarios for the area.	TBC	
EFFLUENT AND AIR EMISSION STANDARDS				
Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter II (1)(d)	Drinking Water System Standards	It is DOE policy to provide a level of protection for persons consuming water from a public drinking water supply operated by the DOE, either directly or through a DOE contractor, that is equivalent to that provided to the public by the public community drinking water standards of 40 CFR Part 141 (listed above). These systems shall not cause persons consuming the water to receive an effective dose equivalent greater than 4 mrem in a year. Combined Ra-226 and Ra-228 shall not exceed $5x10^{-9}$ μCi/mL and gross alpha activity (excluding radon and uranium) shall not exceed $1.5x10^{-8}$ μCi/mL.	TBC	

TABLE A-1
(Continued)

Citation	Chemical	Requirement	Determination	Remarks
		EFFLUENT AND AIR EMISSION STANDARDS (continued)		
Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter II (1)(d) (continued)	Drinking Water System Standards	The liquid effluents from DOE activities shall not cause private or public drinking water systems downstream of the facility discharge to exceed the drinking water radiological limits in 40 CFR Part 141 (listed above).	TBC	
Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter III	Derived Concentration Guides for Air and Water	The derived concentration guides (DCGs) are provided as reference values for conducting radiological environmental protection programs at operational DOE facilities and sites. DCG values are presented in Figures III-1 and III-3 of DOE Order 5400.5 for the following exposure modes: • ingestion of water • inhalation of air • immersion in a gaseous cloud The DCG values for internal exposure are based on a committed effective dose equivalent of 100 mrem for the radionuclide taken into the body by ingestion or inhalation during one year. The DCG values account for only three exposure pathways (ingested water <u>or</u> inhaled air <u>or</u> air immersion) and do not include other potentially significant pathways. When more complex environmental pathways are involved, a more complete pathway analysis is required for calculating public radiation doses resulting from the operation of DOE facilities.	TBC	
Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter II (3)(a)	Discharges of Liquid Waste to Surface Waters	The best available technology is the prescribed level of treatment for liquid radioactive discharges to surface waters that would otherwise contain radioactive concentrations greater than the DCG values. Implementation of the best available technology process is not required for waste streams that contain radionuclide concentrations of not more than the DCG values at the point of discharge to a surface waterway.	TBC	

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TABLE A-1
(Continued)

Citation	Chemical	Requirement	Determination	Remarks
		EFFLUENT AND AIR EMISSION STANDARDS (continued)		
Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter II (3)(a) (continued)	Discharges of Liquid Waste to Surface Waters	The DCG for waste streams containing more than one type of radionuclide shall be the sum of the fractional DCG values.	TBC	
Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter II (3)(a)(4)	Prevention of Radionuclide Buildup in Sediments	Liquid process waste streams containing radioactive material in the solid present in the waste stream must not exceed 5 pCi/g above background level of settleable solids for alpha-emitting radionuclides or 50 pCi/g above background of settleable solids for beta-gamma-emitting radionuclides.	TBC	
National Emission Standards for Hazardous Air Pollutants 40 CFR §61.192 Subpart Q	National Emission Standards for Radon Emissions from Department of Energy Facilities	No source at a Department of Energy facility shall emit more than 20 pCi/m²s as an average for the entire source, into the air.	Applicable	
Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings 40 CFR §192.02 (b) Subpart A 40 CFR §192.32 (b)(1)(ii) Subpart D Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter IV (6)(d)	Control of Radon Emissions	The following standards apply to the: • control of residual radioactive materials from inactive uranium processing sites. • management of uranium byproduct materials after closure of a disposal area. • long-term management of uranium, thorium, and their decay products. Controls shall be designed to provide reasonable assurance that releases of radon-222 from the above materials to the atmosphere will not: • exceed an average annual release rate of 20 pCi/m²s	Relevant and Appropriate	

TABLE A-1
(Continued)

Citation	Chemical	Requirement	Determination	Remarks
		EFFLUENT AND AIR EMISSION STANDARDS (continued)		
Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings 40 CFR §192.02 (b) Subpart A 40 CFR §192.32 (b)(1)(ii) Subpart D Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter IV (6)(d) (continued)	Control of Radon Emissions	• increase the annual average concentration of radon-222 in air or above any location outside the disposal site by more than 0.5 pCi/L.	Relevant and Appropriate	
National Primary and Secondary Ambient Air Quality Standards 40 CFR §50	National Ambient Air Quality Standards	The following are the primary National Ambient Air Quality Standards (NAAQS): Criteria Pollutant / Primary Standard / Averaging Time Carbon Monoxide: 9 ppm, 8-hour; 35 ppm, 1-hour Lead: 1.5 $\mu g/m^3$, Quarterly average Nitrogen Dioxide: 0.053 ppm, Annual Particulate Matter: 50 $\mu g/m^3$, Annual; 150 $\mu g/m^3$, 24-hour Ozone: 0.12 ppm, 1-hour Sulfur oxides: 0.03 ppm, Annual; 0.14 ppm, 24-hour	Relevant and Appropriate	

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TABLE A-1
(Continued)

Citation	Chemical	Requirement	Determination	Remarks
		EFFLUENT AND AIR EMISSION STANDARDS (continued)		
Review of New Sources of Air Toxic Emissions OEPA Proposed Policy January 1994	De Minimis Emission Levels for Carcinogens	The following are the Ohio de minimis emission levels for classes A, B1, and B2 carcinogens: Carcinogen — EPA Class — Emission Level Chromium VI — A — 0.1 ton/year All Others — A, B1, B2 — 1.0 ton/year	TBC	
		RADIONUCLIDE CONCENTRATIONS IN SOILS		
Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings 40 CFR §192.12(a) Subpart B 40 CFR §192.20 Subpart C	Cleanup of Soils Contaminated with Residual Radioactive Materials	Remedial actions shall be conducted so as to provide reasonable assurance that, as a result of residual radioactive materials, the concentration of radium-226 in land averaged over any area of 100 m^2 shall not exceed the background level by more than: • 5 pCi/g, averaged over the first 15 cm of soil below the surface • 15 pCi/g, averaged over 15 cm thick layers of soil more than 15 cm below the surface Compliance with this requirement should be shown through measurements performed within the accuracy of currently available types of field and laboratory instruments in conjunction with reasonable survey and sampling procedures.	Relevant and Appropriate	
Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings 40 CFR §192.21 (f) and §192.22 (b) Subpart C	Supplemental Standards	Where radionuclides other than radium-226 and its decay product are present in sufficient quantity and concentration to constitute a significant radiation hazard from residual radioactive materials, remedial actions shall, in addition to satisfying the standards of 40 CFR §§ 192.02, Subpart A and 192.12, Subpart B (both listed above), reduce other residual radioactivity to levels that are as low as is reasonably achievable.	Relevant and Appropriate	

TABLE A-1
(Continued)

Citation	Chemical	Requirement	Determination	Remarks
		RADIONUCLIDE CONCENTRATIONS IN SOILS (continued)		
Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings 40 CFR §192.32 (b)(2) Subpart D	Management of Uranium Byproduct Material	The requirements for the management of uranium byproduct materials after closure of a disposal area (40 CFR §192.32 (b)(1)) shall not apply to any portion of a disposal site which contains a concentration of radium-226 in land, averaged over areas of 100m², which, as a result of uranium byproduct material, does not exceed the background level by more than the limits specified in 40 CFR §192.12 (a).	Relevant and Appropriate	
Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings 40 CFR §§ 192.40-192.42 Subpart E	Management of Thorium Byproduct Material	The following are requirements for the management of thorium byproduct materials: • the provisions for the management of uranium byproduct material (40 CFR §192.32) shall apply to thorium byproduct material and: - provisions applicable to the element uranium shall also apply to the element thorium - provisions applicable to radon-222 shall also apply to radon-220 - provisions applicable to radium-226 shall also apply to radium-228 With the concurrence of EPA, alternative provisions may be substituted for any of the above requirements provided the alternative provisions will provide at least an equivalent level of protection for human health and environment.	Relevant and Appropriate	
Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter IV (4)(a)	Guidelines for Residual Radioactive Material	Guidelines for residual concentrations of radionuclides other than thorium and radium shall be derived from the basic dose limits by means of an environmental pathway analysis using specific property data where available. Procedures for these derivations are given in DOE/CH-8901. Residual concentrations of radioactive material in soil are defined as those in excess of background concentrations averaged over an area of 100 m².	TBC	

TABLE A-1
(Continued)

Citation	Chemical	Requirement	Determination	Remarks
		RADIONUCLIDE CONCENTRATIONS IN SOILS (continued)		
Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter IV (4)(a)(2),(3)	Generic Guidelines for Residual Concentrations	The generic guidelines for residual concentrations (in excess of background) of radium-226, radium-228, thorium-230, and thorium-232 are: • 5 pCi/g, averaged over the first 15 cm of soil below the surface; and • 15 pCi/g, averaged over 15-cm-thick layers of soil more than 15 cm below the surface.	TBC	
Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter IV (4)(a)(2),(3) (continued)	Generic Guidelines for Residual Concentrations	These guidelines take into account ingrowth of radium-226 from thorium-230 and of radium-228 from thorium-232, and assume secular equilibrium. If both thorium-230 and radium-226, or both thorium-232 and radium-228, are present and not in secular equilibrium, the appropriate guideline is applied as a limit for the radionuclide with the higher concentration. If other mixtures of radionuclides occur, the concentrations of individual radionuclides shall be reduced so that either the dose for the mixture will not exceed the basic dose limit or the sum of the ratios of the soil concentration of each radionuclide to the allowable limit for that radionuclide will not exceed 1. Explicit formulas for calculating residual concentrations guidelines for mixtures are given in DOE/CH-8901.	TBC	
Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter IV (4)(a)(1)	Hot Spots	If the average concentration in any surface or below surface area less than or equal to 25 m^2, exceeds the limit or guideline by a factor of $(100/A)^{0.5}$ [where A is the area (in square meters) of the region in which the concentrations are elevated], limits for "hot spots" shall also be developed and applied. Procedures for calculating these hot spots limits, which depend on the extent of the elevated local concentrations, are given in DOE/CH-8901. In addition, reasonable efforts shall be made to remove any source of radionuclide that exceeds 30 times the appropriate limit in the soil, irrespective of the average concentration in the soil.	TBC	

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TABLE A-1
(Continued)

Citation	Chemical	Requirement	Determination	Remarks
RADIONUCLIDE CONCENTRATIONS IN SOILS (continued)				
EPA Guidance Methods for Evaluating the Attainment of Cleanup Standards, Vol. 1	Attainment of Soil Cleanup Standards	This document describes methods for testing whether soil chemical concentrations at a site are statistically below a cleanup standard or ARAR. If it can be reasonably concluded that the remaining soil or treated soil at a site has concentrations that are statistically less than relevant cleanup standards then the site can be judged protective of human health and the environment.	TBC	
LEAD STANDARDS				
Resource Conservation and Recovery Act 40 CFR §268.41	Requirements for Lead Disposal	The maximum concentration of lead in the extract of any sample of treated soil is 5 mg/L.	Relevant and Appropriate	
Revised Interim Soil Lead Guidance for CERCLA Sites and RCRA Corrective Action Facilities (OSWER Directive 9355.4-12)	Screening Level for Lead in Soil	EPA recommends using 400 ppm soil lead as a screening level for lead in soil for residential scenarios at CERCLA sites and at RCRA Corrective Action sites. Residential areas with soil lead below 400 ppm generally require no further action.	TBC	

TABLE A-2
SOLID WASTE ACTION-SPECIFIC REQUIREMENTS

Citation	Action	Requirement	Determination	Remarks
		DEFINITIONS		
Resource, Conservation, and Recovery Act 42 U.S.C. §6903 (27)	Definition	Solid waste means any garbage, refuse, sludge from a waste treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, including solid, liquid, semisolid, or contained gaseous material resulting from industrial, commercial, mining, and agricultural operations and from community activities, but does not include source, special nuclear, or byproduct material as defined by the Atomic Energy Act of 1954.	Applicable	
Ohio Solid Waste Disposal Regulations OAC 3745-27-01 (B)(40)	Definition	Solid wastes means such unwanted residual solid or semisolid material as results from industrial, commercial, agricultural, and community operations, excluding earth or material from construction, mining, or demolition operations, or other waste materials of the type that would normally be included in demolition debris, nontoxic flyash, spent nontoxic foundry sand, and slag and other substances that are not harmful or inimical to public health, and includes, but is not limited to, garbage, tires, combustible and noncombustible material, street dirt, and debris. Solid waste does not include any material that is an infectious waste or a hazardous waste. For the purpose of this definition, "semisolid material" does not contain liquids which can be readily released under normal climatic conditions, as determined by method 9095 (paint filter liquids test) in SW-846: "Test Methods for Evaluating Solid Wastes, Physical/Chemical Methods".	Applicable	
Resource, Conservation, and Recovery Act 40 CFR §261.3(a)	Definition	A solid waste is a hazardous waste, if: • it is not excluded from regulation as a hazardous waste under 40 CFR §261.4(b). • it exhibits any of the characteristics of hazardous waste. • it is listed in 40 CFR §§ 261.30 - 261.35. • it is a mixture of solid and hazardous wastes.	Applicable	

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TABLE A-2
(Continued)

Citation	Action	Requirement	Determination	Remarks
		DEFINITIONS (continued)		
Ohio Infectious Waste Regulations OAC 3745-27-01 (B)(15) OAC 3745-27-30 (A),(E),(H) ORC 3734.021 (A)(1)(c),(d)	Definition	Infectious waste is defined by 9 categories of waste including human blood specimens and blood products, sharp wastes used in the treatment or inoculation of human beings, and any other waste materials generated in the diagnosis, treatment, or immunization of human beings. A generator who places all sharp infectious wastes and all unused hypodermic needles, syringes, and scalpel blades into a "SHARPS" container before they are transported and who generates less than 50 lbs. of infectious wastes each month and does not hold a certificate of registration as a generator of infectious wastes may transport and dispose of infectious wastes in the same manner as solid wastes. Treated infectious wastes can be transported and disposed in the same manner as noninfectious waste. Infectious waste that is also radioactive shall be managed in accordance with applicable Ohio Department of Health and U.S. Nuclear Regulatory Commission regulations.	Applicable	
Resource, Conservation, and Recovery Act 40 CFR §261.4(b)(4)	Definition	Flyash waste, bottom ash waste, slag waste, and fly gas emission control waste, generated primarily from the combustion of coal or other fossil fuels, are excluded from the definition of hazardous waste.	Applicable	
Ohio Petroleum Contaminated Soil Policy OEPA Policy PP 01 03 200	Definition	The basis of the "contained in" policy is that environmental media, such as soil or groundwater, are not considered to be waste material. Because they are not a solid waste, the mixture rule, as set forth in OAC 3745-51-03, does not apply when they become contaminated with a listed hazardous waste but only contains the waste. The result of this policy is that if the waste constituents can be removed, the soil is no longer considered to contain a hazardous waste. Therefore, since soil is not a waste material it does not have to be de-listed in order for it to be used for its intended purpose. However, as long as the soil contains the waste material, it must be managed as a hazardous waste.	TBC	

TABLE A-2
(Continued)

Citation	Action	Requirement	Determination	Remarks
		DEFINITIONS (continued)		
Ohio Petroleum Contaminated Soil Policy OEPA Policy PP 01 03 200 (continued)	Definition	If we apply this concept to petroleum-contaminated soil, the soils containing a petroleum hydrocarbon would not need to be managed as a solid waste if the contaminants were removed.	TBC	
CERCLA Compliance with Other Laws Manual Section 2.7	Definition	Placement/disposal of waste does not occur under the following circumstances: • waste is consolidated within a unit (including an area of contamination that can be viewed as a single unit); • waste is capped in place, including grading prior to capping; • waste is treated in situ; and • waste is processed within the unit in order to improve its structural stability for closure or for movement of equipment over the area.	TBC	
Resource, Conservation, and Recovery Act 40 CFR §260.10	Definition	Remediation waste means all solid and hazardous waste, and all media (including groundwater, surface water, soils, and sediments) and debris, which contain listed hazardous wastes or which themselves exhibit a hazardous waste characteristic, that are managed for the purpose of implementing corrective action requirements under 40 CFR §264.101 and RCRA section 3008(h). For a given facility, remediation wastes may originate only from within the facility boundary, but may include waste managed in implementing RCRA sections 3004(v) or 3008 (h) for releases beyond the facility boundary.	Relevant and Appropriate	

TABLE A-2
(Continued)

Citation	Action	Requirement	Determination	Remarks
		DEFINITIONS (continued)		
Resource, Conservation, and Recovery Act 40 CFR §264.552 (a),(c)	Definition	For the purpose of implementing corrective action for solid waste management units, the Regional Administrator may designate an area at the facility as a corrective action management unit (CAMU). One or more CAMU's may be designated at a facility. • Placement of remediation wastes into or within a CAMU does not constitute land disposal of hazardous wastes. • Consolidation or placement of remediation wastes into or within a CAMU does not constitute creation of a unit subject to minimum technology requirements. • The CAMU shall facilitate the implementation of reliable, effective, protective, and cost-effective remedies. • Waste management activities associated with the CAMU shall not create unacceptable risks to humans or to the environment resulting from exposure to wastes. • The CAMU shall include uncontaminated areas of the facility only if including such areas for the purpose of managing remediation waste is more protective than management of such wastes at contaminated areas of the facility. • Areas within the CAMU, where wastes remain in place after closure of the CAMU, shall be managed and contained so as to minimize future releases, to the extent practicable. • The CAMU shall expedite the timing of remedial activity implementation, when appropriate and applicable. • The CAMU shall enable the use, when appropriate, of treatment technologies (including innovative technologies) to enhance the long-term effectiveness of remedial actions by reducing the toxicity, mobility, or volume of wastes that will remain in place after closure of the CAMU.	Relevant and Appropriate	Under all of the remedial alternatives, any hazardous waste from the firing range is being sent off-site for disposal. This CAMU rule would only be used if Operable Unit 5 plans to dispose hazardous waste in a centralized disposal cell; the cell would then have to be designed to meet RCRA standards and it would not be cost-effective to send the firing range material off-site for disposal. Because this is dependent on Operable Unit 5, the RCRA disposal requirements will be addressed in Operable Unit 5 ARARs.

TABLE A-2
(Continued)

Citation	Action	Requirement	Determination	Remarks
		DEFINITIONS (continued)		
Resource, Conservation, and Recovery Act 40 CFR §264.552 (a),(c) (continued)	Definition	• The CAMU shall, to the extent practicable, minimize the land area of the facility upon which wastes will remain in place after closure of the CAMU.	Relevant and Appropriate	
Resource, Conservation, and Recovery Act 40 CFR §264.553 (a),(b)	Definition	For temporary tanks and container storage areas used for treatment or storage of remediation wastes during remedial activities, the Regional Administrator may determine that a design, operating, or closure standard applicable to such units may be replaced by alternative requirements which are protective of human health and the environment. Any temporary unit to which alternative requirements are applied shall be: • located within the facility boundary; and • used solely for treatment or storage of remediation wastes.	Relevant and Appropriate	
		SOLID WASTE DISPOSAL		
Ohio Solid Waste Disposal Regulations OAC 3745-27-05 (A)	Solid Waste Disposal Methods	Solid waste shall be disposed of only by the following methods: • sanitary landfill • incineration • composting Methods not mentioned above and not prohibited by this chapter, OAC 3745-27, may be used provided that such methods are demonstrated to the satisfaction of the Director to be capable of disposing of solid waste without creating a nuisance or a health hazard, without causing water pollution, and without violating these regulations and any regulation adopted by the Director pursuant to Ohio Revised Code Chapter 3704 (Air Pollution Control).	Applicable	

TABLE A-2
(Continued)

Citation	Action	Requirement	Determination	Remarks
		SOLID WASTE DISPOSAL (continued)		
US EPA Solid Waste Disposal Regulations 40 CFR §257.3-7	Open Burning Prohibited	The solid waste disposal facility or practice shall not engage in open burning of residential, commercial, institutional, or industrial solid waste. This requirement does not apply to land-clearing debris, diseased trees, debris from emergency clean-up operations, and ordnance.	Applicable	
US EPA Solid Waste Disposal Regulations 40 CFR §257.3-3	Surface Water	A solid waste disposal facility shall not cause a discharge of pollutants into waters of the United States that is in violation of the requirements of the NPDES under section 402 of the Clean Water Act, as amended. A solid waste disposal facility shall not cause a discharge of dredged material or fill material to waters of the United States that is in violation of the requirements under section 404 of the Clean Water Act, as amended. A solid waste disposal facility or practice shall not cause non-point source pollution of waters of the United States that violates applicable legal requirements implementing an area-wide or Statewide water quality management plan that has been approved by the Administrator under section 208 of the Clean Water Act, as amended.	Applicable	
US EPA Solid Waste Disposal Regulations 40 CFR §257.3-4	Groundwater Protection	A solid waste disposal facility or practice shall not contaminate an underground drinking water source beyond the solid waste boundary.	Applicable	
Ohio Solid Waste Disposal Regulations OAC 3745-27-08 (C)(1),(2),(3),(4),(5),(6),(7),(9)	Landfill Construction	The following layers must be installed in the construction of a sanitary landfill (from bottom to top):	Applicable	This applies to new disposal of solid waste.
		Recompacted Soil Liner		
		The recompacted soil liner shall be: • constructed using loose lifts 8 inches thick with a maximum permeability of 1×10^{-7} cm/s. • constructed of a soil with a maximum clod size of 3 inches or half the lift thickness, whichever is less.		

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TABLE A-2
(Continued)

Citation	Action	Requirement	Determination	Remarks
		SOLID WASTE DISPOSAL (continued)		
Ohio Solid Waste Disposal Regulations OAC 3745-27-08 (C)(1),(2),(3),(4),(5),(6),(7),(9) (continued)	Landfill Construction	• constructed of soil with: - 100% of the particles having a maximum dimension not greater than 2 inches. - not more than 10% of the particles, by weight, having a dimension greater than 0.75 inches. - not less than 50% of the particles, by weight, passing through the 200-mesh sieve. - not less than 25% of the particles, by weight, having a maximum dimension not greater than 0.002 millimeters. • compacted to at least 95% of the maximum "Standard Proctor Density" using ASTM D-698 or at least 90% of the maximum "Modified Proctor Density" using ASTM D-1557. • compacted at a moisture content at or wet of optimum. Alternatives for the above requirements may be used if it is demonstrated to the satisfaction of the Director that the materials and techniques will result in each lift having a maximum permeability of 1×10^{-7} cm/s. Additionally, the recompacted soil liner shall: • not comprised of solid waste. • be constructed using the same number of passes and lift thickness, and the same or similar type and weight of compaction equipment established by testing (as defined in this table). • be placed on the bottom and exterior excavated sides of the landfill and have a minimum bottom slope of 2% and a maximum slope based on: - compaction equipment limitations;	Applicable	

TABLE A-2
(Continued)

Citation	Action	Requirement	Determination	Remarks
		SOLID WASTE DISPOSAL (continued)		
Ohio Solid Waste Disposal Regulations OAC 3745-27-08 (C)(1),(2),(3),(4),(5),(6),(7),(9) (continued)	Landfill Construction	- slope stability; - maximum friction angle between any soil-geosynthetic interface and between any geosynthetic-geosynthetic interface; and - resistance of geosynthetics and geosynthetic seams to tensile forces. • constructed on a prepared surface that shall: - be free of debris, foreign material, and deleterious material; - be able to bear the weight of the landfill and its construction operations without causing or allowing a failure of the liner to occur through settling; and - not have any abrupt changes in grade that may result in damage to geosynthetics. • be at least 5 feet thick, although the Director may approve an alternate thickness, to be no less than 3 feet, based upon the result of calculations or on a design that is no less protective of human health and the environment. • be at least 3 feet thick with a geosynthetic clay liner that meets the specifications in paragraph (C)(3) of this rule although the Director may approve an alternate thickness to be no less than 1½ feet, based upon the results of calculations or on a design that is no less protective of human health and the environment. • have a factor of safety for hydrostatic uplift not less than 1.4. • be adequately protected from damage due to desiccation, freeze/thaw cycles, wet/dry cycles, and the intrusion of objects during construction and operation.	Applicable	

TABLE A-2
(Continued)

Citation	Action	Requirement	Determination	Remarks
		SOLID WASTE DISPOSAL (continued)		
Ohio Solid Waste Disposal Regulations OAC 3745-27-08 (C)(1),(2),(3),(4),(5),(6),(7),(9) (continued)	Landfill Construction		Applicable	
	C	**Flexible Membrane Liner**		
	1	The flexible membrane liner shall be:		
	a	• placed on the recompacted soil liner.		
	b	• sixty mil high density polyethylene (HDPE).		
	c	• be protected from the drainage layer by a cushion layer, as required by the Director		
	2	Other materials or thicknesses may be used if, at a minimum, the flexible membrane liner meets all the following:		
	a	• negligibly permeable to fluid migration.		
	b	• physically and chemically resistant to chemical attack by the solid waste, leachate, or other materials which may come in contact with the flexible membrane liner.		
	c	• seamed to allow no more than negligible amounts of leakage with seaming material that is physically and chemically resistant to chemical attack by the solid waste, leachate, or other materials which may come in contact with the seams.		
	d	• have properties for its installation and use which are acceptable to the Director.		
	e	• protected from the drainage layer by a cushion layer, as required by the Director.		
	f	• have a minimum thickness of 40 mils.		
		Geosynthetic Clay Liner		
		The geosynthetic clay liner used in lieu of part of the recompacted soil liner shall be:		

TABLE A-2
(Continued)

Citation	Action	Requirement	Determination	Remarks
		SOLID WASTE DISPOSAL (continued)		
Ohio Solid Waste Disposal Regulations OAC 3745-27-08 (C)(1),(2),(3),(4),(5),(6),(7),(9) (continued)	Landfill Construction	• negligibly permeable to fluid migration. • be installed to allow no more than negligible amounts of leakage by a minimum overlap of 6 inches, or, for end of panel seams, a minimum over of 12 inches. Overlap shall be increased in accordance with manufacturers specifications or to account for shrinkage due to weather conditions. • have a bentonite mass per unit area of at least 1 pound per square foot. • be installed in accordance with the manufacturers specifications in regards to handling, overlap, and the use of granular or powdered bentonite to enhance bonding at the seams. • be constructed above the recompacted soil liner.	Applicable	
		Leachate Management System		
		The leachate management system shall: • be designed to prevent clogging and crushing of the system and to limit the level of leachate in areas other than lift stations to a maximum of 1 foot. • include a drainage layer placed on top of the flexible membrane liner composed of granular material that must: - have a minimum permeability of 1×10^{-3} cm/s; - have a minimum thickness of 1 foot; - have a negligible amount of fines; and - not contain carbonate material. An alternate material and/or thickness may be used if it is demonstrated to the satisfaction of the Director that the material meets the requirements.		

TABLE A-2
(Continued)

Citation	Action	Requirement	Determination	Remarks
		SOLID WASTE DISPOSAL (continued)		
Ohio Solid Waste Disposal Regulations OAC 3745-27-08 (C)(1),(2),(3),(4),(5),(6),(7),(9) (continued)	Landfill Construction	• include leachate collection pipes to remove leachate from the bottom of the landfill. The pipes must: - be imbedded in the drainage layer; - have a minimum slope of 0.5%; - have lengths and configuration which shall not exceed the capabilities of clean-out devices; - be provided with access for clean-out devices which shall be protected from differential settling; - have joints sealed to prevent separation; and - be physically and chemically resistant to attack by the solid waste, leachate, or other materials that they may come in contact with. Sealing material and means of access for clean-out devices shall also be physically and chemically resistant to attack by the solid waste, leachate, or other materials that they may come in contact with. An alternate means for leachate removal may be used if it is demonstrated to the satisfaction of the Director that the means for leachate removal meets the requirements. • include a filter layer to prevent clogging of the leachate collection system. • include a protective layer to protect the recompacted soil liner, flexible membrane liner, geosynthetic clay liner (if applicable), and leachate collection system from the intrusion of objects during construction and operation.	Applicable	

TABLE A-2
(Continued)

Citation	Action	Requirement	Determination	Remarks
		SOLID WASTE DISPOSAL (continued)		
Ohio Solid Waste Disposal Regulations OAC 3745-27-08 (C)(1),(2),(3),(4),(5),(6),(7),(9) (continued)	Landfill Construction	• include lift stations which are to be protected from adverse effects from leachate and differential settling. If manholes are used as lift stations, they must be equipped with automatic high level alarms located no greater than 6 feet above the invert of the leachate inlet pipe. Lift station pipes should be of adequate capacity and shall automatically commence pumping before the leachate elevation activates the high level alarm.	Applicable	
		Leachate Collection and Storage		
		Any leachate conveyance and storage structures located outside the limits of solid waste placement shall be no less protective of the environment than the landfill facility, as determined by the Director, and: • The structures must be monitored, as required by the Director. • Storage tanks must be provided with spill containment • Leachate lines must be double-cased • Storage structures must have a minimum of 1 week of storage capacity using design assumptions simulating final closure. • If at any time leachate is evaluated to be hazardous in accordance with rule 3745-52-11 of the OAC, it shall be managed in accordance with Chapters 3745-50 to 3745-69 of the OAC, and the generator standards for storage shall apply in accordance with Chapter 3745-52 of the OAC.		

TABLE A-2
(Continued)

Citation	Action	Requirement	Determination	Remarks
SOLID WASTE DISPOSAL (continued)				
Ohio Solid Waste Disposal Regulations OAC 3745-27-08 (C)(1),(2),(3),(4),(5),(6),(7),(9) (continued)	Landfill Construction	**Surface Water Control** • Any permanent or temporary surface water control structures shall be designed to accommodate, by non-mechanical means, the peak flow from the 25-year/24-hour storm event. • Surface water control structures shall be designed to minimize silting and scouring. • If sedimentation ponds are used, they shall be designed and constructed according to OAC 3745-27-08 (C)(6)(b).	Applicable	
		Benchmarks • At least 3 permanent third order benchmarks on separate sides of the landfill facility shall be within easy access to the limits of solid waste placement and shall be constructed in accordance with OAC 3745-27-08(C)(7)(a)-(c).		
		Groundwater Control • Any permanent groundwater control structures shall adequately control groundwater infiltration through the use of non-mechanical means such as impermeable barriers or permeable drainage structures. • No permanent groundwater control structures may be used to dewater an aquifer system, except if the recharge and discharge zone of the aquifer system are located entirely within the boundary of the landfill facility.		

TABLE A-2
(Continued)

Citation	Action	Requirement	Determination	Remarks
		SOLID WASTE DISPOSAL (continued)		
EPA Criteria for Municipal Solid Waste Landfills 40 CFR §258.40	Landfill Design Criteria	The liner and leachate system shall be designed and constructed to maintain less than a 30-cm depth of leachate over the liner. The geomembrane must be at least 30-mil thick.	Relevant and Appropriate	
EPA Criteria for Municipal Solid Waste Landfills 40 CFR §258.26	Run-On/Run-Off Control Systems	The landfill shall have: • a run-on control system to prevent flow onto the active portion of the landfill during the peak discharge from a 25-year storm. • a run-off control system from the active portion of the landfill to collect and control at least the water volume resulting from a 24-hour, 25-year storm.	Relevant and Appropriate	
Ohio Solid Waste Disposal Regulations OAC 3745-27-08 (D) and (E)	Landfill Construction	Prior to being used in the construction of the recompacted soil liner and drainage layer of the sanitary landfill or the landfill cap, the following characteristics of the earthen materials must be determined to show that the material is suitable for use in construction of the landfill. **Soil Material Specifications** The following tests shall be performed on representative samples at least once for every 1,500 yd^3 of soil except the recompacted permeability test, which shall be performed at least once for every 10,000 yd^3 of soil. • recompacted permeability at construction specifications; • moisture content and density using an approved ASTM method; • grain size distribution using ASTM D-422 for sieve and hydrometer methods; and • Atterberg limits using ASTM D-4318.	Applicable	

TABLE A-2
(Continued)

Citation	Action	Requirement	Determination	Remarks
		SOLID WASTE DISPOSAL (continued)		
Ohio Solid Waste Disposal Regulations OAC 3745-27-08 (D) and (E) (continued)	Landfill Construction	**Granular Drainage Material Specifications** The following tests shall be performed at least once for every 3,000 yd^3 of material. • permeability; • grain size distribution using ASTM D-422 for the sieve method; and • chemical compatibility testing may be required by the Director. **Geosynthetic Material Specifications** Geosynthetics, other synthetic materials, and joint sealing compounds used in the construction of the flexible membrane liner, geosynthetic clay liner, and leachate management system for a sanitary landfill facility or a sanitary landfill cap system shall be shown to: • be physically and chemically resistant to attack by the solid waste, leachate, or other materials that they may come in contact with using USEPA Method 9090 or other documented data. • have properties acceptable for installation and use.	Applicable	
Ohio Solid Waste Disposal Regulations OAC 3745-27-08 (C)(1)(m),(o) and (C)(2)(g)	Landfill Construction	The following activities must be performed to ensure that the components of the sanitary landfill facility meet the specifications of this rule.	Applicable	

TABLE A-2
(Continued)

Citation	Action	Requirement	Determination	Remarks
		SOLID WASTE DISPOSAL (continued)		
Ohio Solid Waste Disposal Regulations OAC 3745-27-08 (C)(1)(m),(o) and (C)(2)(g) (continued)	Landfill Construction	**Test Pads** The recompacted soil liner and the recompacted soil barrier layer in the cap system shall be modeled by the construction of test pads. The test pads shall: • be designed such that the proposed tests are appropriate and their results are valid. • be constructed to establish the construction details which are necessary to obtain sufficient compaction to satisfy the permeability requirement. The construction details include: - lift thickness; - water content necessary to achieve the desired compaction; and - type, weight, and number of passes of construction equipment. • be constructed prior to the construction of the sanitary landfill component which the test pad will model. • be constructed whenever there is a significant change in soil material properties. • have a minimum width three times the width of the compaction equipment, and a minimum length two times the length of compaction equipment, including power equipment and any attachments. • be comprised of at least four lifts.	Applicable	

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TABLE A-2
(Continued)

Citation	Action	Requirement	Determination	Remarks
		SOLID WASTE DISPOSAL (continued)		
Ohio Solid Waste Disposal Regulations OAC 3745-27-08 (C)(1)(m),(o) and (C)(2)(g) (continued)	Landfill Construction	• be tested for field permeability, following the completion of test pad construction. For each lift a minimum of 3 tests for moisture content and density shall be performed. • be reconstructed as many times as necessary to meet the permeability requirement. Any amended construction details shall be noted. An alternative to test pads may be used if it is demonstrated to the satisfaction of the Director that the alternative meets the requirements.	Applicable	
		Moisture Content and Density Testing		
		Moisture content and density testing of the recompacted soil liner and recompacted soil barrier in the cap system shall be performed at a frequency of no less than 5 tests per acre per lift. Any penetrations shall be repaired using methods acceptable to the Director.		
		Flexible Membrane Liner Testing		
		• For the purpose of testing every seaming apparatus in use each day, peel and shear tests shall be performed on scrap pieces of flexible membrane liner at the beginning of the seaming period and every four hours thereafter. • Nondestructive testing shall be performed on 100% of the flexible membrane liner seams. • Destructive testing for peel and shear shall be performed at least once for every 500 feet of seam length. An alternate means may be used if it is demonstrated to the satisfaction of the Director that the alternate means meets the requirements.		

TABLE A-2
(Continued)

Citation	Action	Requirement	Determination	Remarks
		SOLID WASTE DISPOSAL (continued)		
Ohio Solid Waste Disposal Regulations OAC 3745-27-08 (G)	Landfill Construction	All tests failing to meet the specifications outlined above must be investigated and the areas reconstructed to meet specifications.	Applicable	
Ohio Solid Waste Disposal Regulations OAC 3745-27-08 (F)	Landfill Construction	The following testing procedures shall be included in a Quality Assurance/Quality Control Plan: • sampling and testing procedures to be used in the field and in the laboratory; • testing frequency; • parameters and sample locations; • procedures to be followed if a test fails; • the management structure and the experience and training of the testing personnel; and • contingency plan for anticipated construction difficulties. The following components shall be included in a Quality Assurance/Quality Control Plan: • in-situ foundation preparation; • recompacted soil and/or geosynthetic clay liner system; • flexible membrane liner; • leachate management system; • cap system; • permanent ground water control structures; and • explosive gas control/extraction systems.	Applicable	

TABLE A-2
(Continued)

Citation	Action	Requirement	Determination	Remarks
		SOLID WASTE DISPOSAL (continued)		
Ohio Solid Waste Disposal Regulations OAC 3745-27-19 (E)(19)	Sanitary Landfill Operation	To demonstrate that the solid wastes to be received at the landfill facility will not compromise the integrity of any material used to construct the landfill facility, the Director may require chemical compatibility testing to be performed.	Applicable	
Ohio Solid Waste Disposal Regulations OAC 3745-27-19 (E)(26)	Sanitary Landfill Operation	The integrity of the engineered components of the landfill facility shall be maintained and any damage to, or failure or, the components shall be repaired.	Applicable	
Ohio Solid Waste Disposal Regulations OAC 3745-27-19 (J)(1), (4)	Sanitary Landfill Operations	Surface water shall be diverted from areas where solid waste is being, or has been, deposited. The facility shall be designed, constructed, maintained, and provided with surface water control structures, as necessary, to control run-on and run-off of surface water to ensure minimal infiltration of water through the cover material and cap system, and minimal erosion of the cover material and cap system. If ponding or erosion occurs on areas of the landfill facility where solid waste is being, or has been, deposited, action will be taken to correct the conditions causing the ponding or erosion.	Applicable	
Ohio Solid Waste Disposal Regulations OAC 3745-27-19 (K)(1)	Sanitary Landfill Operations	If leachate is detected on the surface of the landfill facility, then the outbreak(s) shall be repaired and: • leachate shall be contained and properly managed at the sanitary landfill facility. • if necessary, leachate shall be collected and disposed in accordance with paragraph (K)(5) and (K)(6) of OAC 3745-27-19. • actions shall be taken to minimize, control, or eliminate the conditions which contribute to the production of leachate.	Applicable	
Ohio Solid Waste Disposal Regulations OAC 3745-27-19 (K)(2)	Sanitary Landfill Operations	At least one lift station back-up pump shall be kept at the sanitary waste landfill facility at all times.	Applicable	

TABLE A-2
(Continued)

Citation	Action	Requirement	Determination	Remarks
		SOLID WASTE DISPOSAL (continued)		
Ohio Solid Waste Disposal Regulations OAC 3745-27-19 (K)(3)	Sanitary Landfill Operations	The collection pipe network of the leachate management system shall be inspected after placement of the initial lift of waste to ensure that crushing has not occurred and shall be inspected annually thereafter to ensure that clogging has not occurred.	Applicable	
Ohio Solid Waste Disposal Regulations OAC 3745-27-19 (K)(4)	Sanitary Landfill Operations	If authorized by the Director, leachate may be temporarily stored within the limits of solid waste placement until the leachate can be treated and disposed.	Applicable	
Ohio Solid Waste Disposal Regulations OAC 3745-27-10	Groundwater Monitoring Program	The groundwater monitoring system for detection monitoring, assessment monitoring, or corrective measures shall consist of a sufficient number of wells, installed at appropriate locations and depths, to yield groundwater samples from both the uppermost aquifer system and any significant zones of saturation that exist above the uppermost aquifer system that: • represent the quality of the background groundwater that has not been affected by past or present operations; and • represent the quality of the groundwater passing directly downgradient of the limits of solid waste placement. The groundwater monitoring program shall include consistent sampling and analysis procedures and statistical methods that are protective of human health and the environment and that are designed to ensure monitoring results that provide an accurate presentation of groundwater quality at the background and downgradient well. If contamination from the landfill is discovered, corrective measures shall be taken.	Applicable	

TABLE A-2
(Continued)

Citation	Action	Requirement	Determination	Remarks
		SOLID WASTE DISPOSAL (continued)		
Ohio Solid Waste Disposal Regulations OAC 3745-27-11 (H)	Final Closure of Landfill Facilities	At final closure of a landfill facility: • all land surfaces shall be graded to prevent ponding of water where solid waste has been placed. Drainage facilities shall be provided to direct surface water from the landfill facility. • a groundwater monitoring system shall be designed and installed in accordance with OAC 3745-27-10, if a system is not already in place.	Applicable	
Ohio Solid Waste Disposal Regulations OAC 3745-27-11 (O)	Final Closure of Landfill Facilities	Closure of the sanitary landfill facility must be completed in a manner that minimizes the need for further maintenance and minimizes post-closure formation and release of leachate and explosive gases to air, soil, groundwater, or surface water to the extent necessary to protect human health and the environment.	Applicable	
Ohio Solid Waste Disposal Regulations OAC 3745-27-08 (C)(15)	Construction of a Landfill Cap System	A composite cap system which shall minimize infiltration, must be constructed in all areas of solid waste placement: • The cap system shall have a slope of between 5% and 25% or some greater slope based on stability analyses. • The cap system shall have a maximum projected erosion rate of 5 tons/acre/year. • Any penetrations into the cap system shall be sealed so that the integrity of the soil barrier layer is maintained. The cap system shall, at a minimum, consist of the following (from bottom to top):	Applicable	
		Recompacted Soil Barrier Layer		
		The recompacted soil barrier layer of the cap shall be:		

TABLE A-2
(Continued)

Citation	Action	Requirement	Determination	Remarks
		SOLID WASTE DISPOSAL (continued)		
Ohio Solid Waste Disposal Regulations OAC 3745-27-08 (C)(15) (continued)	Construction of a Landfill Cap System	• a minimum of 18 inches thick and constructed in accordance with the specifications outlined above for construction of the recompacted soil liner for a landfill facility ((C)(1)(a) to (C)(1)(g) and (C)(1)(m) to (C)(1)(o) of OAC 3745-27-08) with the exception that the maximum permeability of the recompacted soil barrier shall be $1x10^{-6}$ cm/sec; OR • a geosynthetic clay liner of equal or less permeability as the recompacted soil barrier layer, with an engineered subgrade constructed in accordance with the following requirements: • The thickness of the subgrade shall be sufficient to achieve an evenly graded surface and shall be a minimum of 12 inches. • Be constructed of a soil with 100% of the particles have a maximum dimension not greater than 2 inches and with not more than 10% of the particles, by weight, having a dimension greater than 0.75 inches. • Be compacted to at least 95% of the maximum "Standard Proctor Density" using ASTM D-698 or at least 90% of the maximum "Modified Proctor Density" using ASTM D-1557. • After being smooth-rolled, the surface shall not have sharp edged or protruding particles. • The particle size and proctor density required shall be verified by tests performed on representative samples based on the variability and homogeneity of the material, but no less than a minimum of once for every 5,000 cubic yards of material used in the engineered subgrade.	Applicable	

TABLE A-2
(Continued)

Citation	Action	Requirement	Determination	Remarks
		SOLID WASTE DISPOSAL (continued)		
Ohio Solid Waste Disposal Regulations OAC 3745-27-08 (C)(15) (continued)	Construction of a Landfill Cap System	• Field density testing shall be performed at a frequency not less than 5 tests per acre. Any penetrations in the subgrade as a result of the testing must be repaired using bentonite or a bentonite-soil mixture.	Applicable	
		Flexible Membrane Liner		
		The flexible membrane liner for the cap system shall be constructed on top of the soil barrier layer or geosynthetic clay liner in accordance with the specifications listed above for a flexible membrane liner for a landfill facility [OAC 3745-27-08 (C)(2)].		
		Drainage Layer		
		The drainage layer shall be: • a minimum of 1 foot of granular material; OR • a drainage net that has equivalent performance capabilities as the granular material. • constructed on top of the flexible membrane liner in accordance with the specifications outlined above for the drainage layer included in the leachate management system of a sanitary landfill facility ((C)(4)(a) of 3745-27-08 of the OAC).		
		Frost Protection Layer		
		The frost protection layer shall be: • placed on top of the drainage layer. • a minimum of 30 inches thick.		

TABLE A-2
(Continued)

Citation	Action	Requirement	Determination	Remarks
		SOLID WASTE DISPOSAL (continued)		
Ohio Solid Waste Disposal Regulations OAC 3745-27-08 (C)(15) (continued)	Construction of a Landfill Cap System	If the drainage layer is constructed with granular material instead of a drainage net, the drainage layer may be used as part of the frost protection layer.	Applicable	
		Soil Vegetative Layer		
		The soil vegetative layer shall: • consist of soil and vegetation placed on top of the frost protection layer. • have soil of sufficient thickness and fertility to support its vegetation and to protect the recompacted soil barrier layer and flexible membrane liner from damage due to root penetration. • have healthy grasses or other vegetation that form a complete and dense vegetative cover. Soil from the frost protection layer may be used as a part of the vegetative layer. Comparable materials and/or thicknesses for the soil barrier layer, the granular drainage layer, and the soil vegetative layer may be used if approved by the Director.		
Ohio Solid Waste Disposal Regulations OAC 3745-27-11 (H)(5) (b)	Final Closure of Landfill Facilities	A notation must be recorded on the deed to the sanitary landfill facility property, or on some other instrument which is normally examined during title search, that will in perpetuity notify any potential purchaser of the property that the land has been used as a sanitary landfill facility. The notation shall include information describing acreage, exact location, depth, volume, and nature of the solid waste deposited in the sanitary landfill facility.	Applicable	

TABLE A-2
(Continued)

Citation	Action	Requirement	Determination	Remarks
		SOLID WASTE DISPOSAL (continued)		
Ohio Solid Waste Disposal Regulations OAC 3745-27-14 (A)(1), (2)	Sanitary Landfill Post-Closure Care	Following completion of final closure activities in accordance with rule 3745-27-11 of the OAC, post-closure care activities shall be conducted at the sanitary landfill facility for a minimum of 30 years. Post-closure care activities for all sanitary landfill facilities shall include, but are not limited to: • continuing operation and maintenance of the leachate management system, the surface water management system, any explosive gas extraction and/or control system, any explosive gas monitoring system, and the groundwater monitoring system • maintaining the integrity and effectiveness of the cap system, including making repairs to the cap system as necessary to correct the effects of settling, dead vegetation, subsidence, erosion, leachate outbreaks, or other events, and preventing run-on and run-off from eroding or otherwise damaging the cap system	Applicable	
EPA Criteria for Municipal Solid Waste Landfills 40 CFR §258.61	Post-Closure Care	The Director of Ohio EPA may allow the owner or operator to stop managing leachate if the owner or operator demonstrates that leachate no longer poses a threat to human health and the environment.	Relevant and Appropriate	
		POLYCHLORINATED BIPHENYL (PCB) DISPOSAL		
PCB Manufacturing, Processing, Distribution, and Use Prohibitions 40 CFR §761.3	Excluded PCB Materials	PCB materials which appear at concentrations less than 50 ppm are excluded from the PCB disposal requirements in this regulation.	Relevant and Appropriate	Operable Unit 2 does not contain PCB materials which have a concentration greater than 50 ppm.

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TABLE A-2
(Continued)

Citation	Action	Requirement	Determination	Remarks
		ASBESTOS MANAGEMENT AND DISPOSAL		
National Emission Standard for Asbestos 40 CFR §61.151 (a) Ohio Asbestos Handling Regulations OAC 3745-20-07 (A),(C)	Inactive Asbestos Waste Disposal Sites	Each owner or operator of an inactive asbestos waste disposal site shall do one of the following: • discharge no visible emissions from an inactive waste disposal site; • cover the asbestos-containing waste material with at least 6 inches of compacted nonasbestos-containing material and grow and maintain a cover of vegetation on the area adequate to prevent exposure of the asbestos-containing waste material; or • cover the asbestos-containing waste material with at least 2 feet of compacted nonasbestos-containing material, and maintain the cover to prevent exposure of the asbestos-containing waste material. The owner or operator may use an alternative control method that has received prior approval of the Administrator.	Federal Relevant and Appropriate, Ohio Applicable	The Federal requirement is relevant and appropriate because it specifically applies to a type of facility that is not found in Operable Unit 2. The Ohio requirement is generally applicable to any inactive asbestos waste disposal site.

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TABLE A-3
RADIOLOGICAL ACTION-SPECIFIC REQUIREMENTS

Citation	Action	Requirement	Determination	Remarks
		DEFINITIONS		
Atomic Energy Act 42 U.S.C. §2014 (e)(2), (ee) Nuclear Waste Policy Act 42 U.S.C. §10101 (12), (16),(23)	Definition	The term low-level waste means radioactive material that is not: • high-level radioactive waste, the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations. • spent nuclear fuel, fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing. • transuranic waste, material contaminated with elements that have an atomic number greater than 92, including neptunium, plutonium, americium, and curium, and that are in concentrations greater than 10 nanocuries per gram. • byproduct material, the tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content.	Applicable	
Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter IV	Definition	Residual radioactive material is defined as: • residual concentrations of radionuclides in soil (soil is defined as unconsolidated earth material, including rubble and debris that might be present in the earth material); • concentrations of airborne radon decay products; • external gamma radiation; • surface contamination; and • radionuclide concentrations in air or water resulting from, or associated with, any of the above.	TBC	

TABLE A-3
(Continued)

Citation	Action	Requirement	Determination	Remarks
		DEFINITIONS (continued)		
Radioactive Waste Management DOE Order 5820.2A Chapter III (3)(i)(6) Attachment 2 (1)	Definition	Radioactive material that is below regulatory concern is a definable amount of low-level waste that can be deregulated with minimal risk to the public. Waste containing amounts of radionuclides below regulatory concern, as defined by Federal regulations, may be disposed without regard to radioactivity content.	TBC	
		DOE ALARA POLICY		
Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter I (4) and Chapter II (2)	As Low As Reasonably Achievable (ALARA) Process	The order adopts the ALARA process in planning and carrying out all DOE activities. ALARA requires judgement with respect to what is reasonably achievable. Factors that relate to societal, technological, economic, and other public policy considerations shall be evaluated to the extent practicable. Factors to be considered, at a minimum, shall include: • maximum dose to members of the public; • collective dose to the population; • alternative processes, such as alternative treatment of discharge streams, operating methods, or controls; • doses for each process alternative; • cost for each of the technological alternatives; • examination of the changes in cost among alternatives; and • changes in societal impact associated with process alternatives (e.g., differential doses from various pathways).	TBC	

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TABLE A-3
(Continued)

Citation	Action	Requirement	Determination	Remarks
		DOE ALARA POLICY (continued)		
Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter I (4) and Chapter II (2) (continued)	As Low As Reasonably Achievable (ALARA) Process	Except for meeting requirements of NEPA, qualitative analyses are acceptable, in most instances, for ALARA judgements, especially when the potential doses are well below the dose limit. The bases for these judgements should be documented. More detailed analyses should be considered if the decision might result in doses that approach the limit.	TBC	
		GENERAL RADIOACTIVE MATERIALS DISPOSAL REQUIREMENTS		
Radiation Protection of the Public and the Environment DOE Order 5400. 5 Chapter II (3)(b)	Discharges of Liquid Waste to Aquifers and Phaseout of Soil Columns	New or increased discharges of radionuclides in liquid waste to active soil columns and virgin soil columns is prohibited.	TBC	
		MANAGEMENT OF LOW-LEVEL RADIOACTIVE WASTE		
Radioactive Waste Management DOE Order 5820.2A Chapter III (3)(a)	Performance Objectives of Low-Level Radioactive Waste Management	DOE low-level radioactive waste shall be managed to accomplish the following performance objectives: • protection of public health and safety; • protection of the public and the environment from releases of radioactivity (see chemical-specific requirements for radioactive dose limitations); and • protection of groundwater resources, consistent with Federal, State, and local requirements.	TBC	
Radioactive Waste Management DOE Order 5820.2A Chapter III (3)(c)	Low-Level Radioactive Waste Generation	Technical and administrative controls shall be directed to reducing the gross volume of waste generated and/or the amount of radioactivity requiring disposal. Waste reduction efforts shall include consideration of process modification, process optimization, materials substitution, and decontamination.	TBC	

TABLE A-3
(Continued)

Citation	Action	Requirement	Determination	Remarks
MANAGEMENT OF LOW-LEVEL RADIOACTIVE WASTE (continued)				
Radioactive Waste Management DOE Order 5820.2A Chapter III (3)(c) (continued)	Low-Level Radioactive Waste Generation	All DOE low-level waste generators shall establish auditable programs to assure that the amount of low-level waste generated and/or shipped for disposal is minimized. Each DOE low-level waste generator shall separate uncontaminated waste from low-level waste to facilitate cost effective treatment and disposal. Each DOE low-level waste generator preparing a design for a new process or process change shall incorporate principles into the design that will minimize the generation of low-level waste.	TBC	
Radioactive Waste Management DOE Order 5820.2A Chapter III (3)(d)	Waste Characterization	Low-level waste shall be characterized with sufficient accuracy to permit proper segregation, treatment, storage, and disposal. This characterization shall ensure that, upon generation after processing, the actual physical and chemical characteristics and major radionuclide content are recorded and known during all stages of the waste management process. Waste characterization data shall be recorded on a waste manifest and shall include: • the physical and chemical characteristics of the waste; • volume of the waste (total of waste and any solidification or absorbent media); • weight of the waste (total of waste and any solidification or absorbent media); • major radionuclides and their concentrations; and • packaging date, package weight, and external volume.	TBC	These requirements will apply when low-level radioactive waste is transported off-site for disposal.

TABLE A-3
(Continued)

Citation	Action	Requirement	Determination	Remarks
MANAGEMENT OF LOW-LEVEL RADIOACTIVE WASTE (continued)				
Radioactive Waste Management DOE Order 5820.2A Chapter III (3)(f)	Waste Treatment	Waste shall be treated by appropriate methods so that the disposal site can meet the performance objectives stated above. Waste treatment techniques such as incineration, shredding, and compaction to reduce volume and provide more stable waste forms shall be implemented as necessary to meet performance requirements. Use of waste treatment techniques to increase the life of the disposal facility and improve long-term facility performance, by improved site stability and reduction of infiltrating water, is required to the extent it is cost effective. The development of large scale waste treatment facilities shall be supported by the appropriate National Environmental Policy Act documentation. Operation of waste treatment facilities shall be supported by adequate documentation.	TBC	
Radioactive Waste Management DOE Order 5820.2A Chapter III (3)(g)	Waste Shipment	The volume of waste and number of shipments of low-level wastes shall be minimized and the shipments will be conducted based on plans developed by field organizations. Generators shall provide an annual forecast in the third quarter of the fiscal year to the field organizations managing the off-site disposal facility to which the waste is to be shipped. Generators must receive advance approval from the receiving facility and shall certify prior to shipment that waste meets the receiving facility waste acceptance criteria. The certification program shall be auditable and able to withstand independent review.	TBC	
Radioactive Waste Management DOE Order 5820.2A Chapter III (3)(i)(1)-(6)	Waste Disposal	Low-level waste shall be disposed of by methods appropriate to achieve the performance objectives stated in paragraph 3a (listed above), consistent with the radiation dose limits in paragraph 3b (see chemical-specific requirements).	TBC	

TABLE A-3
(Continued)

Citation	Action	Requirement	Determination	Remarks
		MANAGEMENT OF LOW-LEVEL RADIOACTIVE WASTE (continued)		
Radioactive Waste Management DOE Order 5820.2A Chapter III (3)(i)(1)-(6) (continued)	Waste Disposal	Engineered modifications (stabilization, packaging, burial depth, barriers) for specific waste types and for specific waste compositions for each disposal site shall be developed to achieve the performance objectives. Site specific waste classification limits may be developed if operationally useful in determining how specific wastes should be stabilized and packaged for disposal. Disposition of waste designated as greater than class C, as defined in 10 CFR §61.55, must be handled as a special case. Disposal systems for such waste must be justified by a specific performance assessment through the NEPA process and with the concurrence of DOE headquarters. The following are additional disposal requirements intended either to improve stability of the disposal site or to facilitate handling and provide protection of the health and safety of personnel at the disposal site: • Waste must not be packaged for disposal in cardboard or fiberboard boxes, unless such boxes meet DOT requirements and contain stabilized waste with a minimum of void space. For all types of containers, void spaces within the waste and between the waste and its packaging shall be reduced as much as practical. • Liquid wastes, or wastes containing free liquid, must be converted into a form that contains as little freestanding and noncorrosive liquid as is reasonable achievable, but, in no case, shall the liquid exceed 1 percent of the volume of the waste when the waste is in a disposal container, or 0.5 percent of the volume of the waste processed to a stable form. • Waste must not be readily capable of detonation or of explosive decomposition or reaction at normal pressures and temperatures, or of explosive reaction with water.	TBC	

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TABLE A-3
(Continued)

Citation	Action	Requirement	Determination	Remarks
MANAGEMENT OF LOW-LEVEL RADIOACTIVE WASTE (continued)				
Radioactive Waste Management DOE Order 5820.2A Chapter III (3)(i)(1)-(6) (continued)	Waste Disposal	• Waste must not contain, or be capable of generating quantities of toxic gases, vapors, or fumes harmful to persons transporting, handling, or disposing of the waste. This does not apply to radioactive gaseous waste packaged as identified in the next requirement. • Waste in a gaseous form must be packaged at a pressure that does not exceed 1.5 atmospheres at 20°C. • Waste must not be pyrophoric. Pyrophoric materials contained in waste shall be treated, prepared, and packaged to be nonflammable.	TBC	
Radioactive Waste Management DOE Order 5820.2A Chapter III (3)(i)(8)	Disposal Facility and Disposal Site Design	Design criteria shall be established prior to selection of new disposal facilities, new disposal sites, or both. These design criteria shall be based on analyses of physiographic, environmental, and hydrogeological data to assure that the policy and requirements of this Order can be met. The criteria shall be also based on assessments of projected waste volumes, waste characteristics, and facility and disposal site performance. Disposal units will be designed consistent with disposal site hydrology, geology, and waste characteristics and in accordance with NEPA.	TBC	
Radioactive Waste Management DOE Order 5820.2A Chapter III (3)(i)(9)	Disposal Facility Operations	Operating procedures for low-level waste disposal facilities shall be developed so that they: • protect the environment, health and safety of the public, and facility personnel; • ensure the security of the facility; • minimize the need for long-term control; and • meet the requirements of the closure/post-closure plan. Permanent identification markers for disposal excavations and monitoring wells shall be emplaced.	TBC	

TABLE A-3
(Continued)

Citation	Action	Requirement	Determination	Remarks
MANAGEMENT OF LOW-LEVEL RADIOACTIVE WASTE (continued)				
Radioactive Waste Management DOE Order 5820.2A Chapter III (3)(i)(9) (continued)	Disposal Facility Operations	Operating procedures shall include training for disposal facility operating personnel, emergency response plans, and a system of reporting unusual occurrences to DOE. Waste placement into disposal units should minimize voids between containers. Operations are to be conducted so that active waste disposal operations will not have an adverse effect on filled disposal units.	TBC	
Radioactive Waste Management DOE Order 5820.2A Chapter III (3)(j)	Disposal Site Closure/Post Closure	Site-specific comprehensive closure plans shall be developed for new and existing operating low-level waste disposal sites. The plan shall address closure of disposal sites within a 5-year period after each is filled and shall conform to the requirements of the NEPA process. Performance objectives for existing disposal sites shall be developed on a case-by-case basis as part of the NEPA process. During closure and post closure, residual radioactivity levels for surface soils shall comply with existing DOE decommissioning guidelines. Corrective measures shall be applied to new disposal sites or individual disposal units if conditions occur or are forecasted that could jeopardize attainment of the performance objectives of this Order. Inactive disposal facilities, disposal sites, and disposal units shall be managed in conformance with RCRA, CERCLA, and the Superfund Amendments and Reauthorization Act (SARA). Closure plans for new and existing operating low-level waste disposal facilities shall be reviewed and approved by the appropriate field organization.	TBC	

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TABLE A-3
(Continued)

Citation	Action	Requirement	Determination	Remarks
MANAGEMENT OF LOW-LEVEL RADIOACTIVE WASTE (continued)				
Radioactive Waste Management DOE Order 5820.2A Chapter III (3)(j) (continued)	Disposal Site Closure/Post Closure	Termination of monitoring and maintenance activity at closed facilities or sites shall be based on an analysis of site performance at the end of the institutional control period.	TBC	
Radioactive Waste Management DOE Order 5820.2A Chapter III (3)(k)	Environmental Monitoring	Each low-level waste treatment, storage, and disposal facility shall be monitored by an environmental monitoring program that, at a minimum, meets the following requirements: • The program shall be designed to measure: - operational effluent releases; - migration of radionuclides; - disposal unit subsidence; and - change in disposal facility and disposal site parameters which may affect long-term site performance. • Based on the characteristics of the facility being monitored, the program may include, but not necessarily be limited to, monitoring surface soil, air, surface water, and, in the subsurface, soil and water, both in the saturated and the unsaturated zones. • The monitoring program shall be capable of detecting changing trends in performance sufficiently in advance to allow application of any necessary corrective action prior to exceeding performance objectives. The monitoring program shall be able to ascertain whether or not effluents from each treatment, storage, or disposal facility or disposal site meet the requirements of applicable EH Orders.	TBC	

TABLE A-3
(Continued)

Citation	Action	Requirement	Determination	Remarks
		LOW-LEVEL RADIOACTIVE WASTE CONFINEMENT		
General Design Criteria DOE Order 6430.1A 1324-5.3	Low-Level Solid Waste Confinement	Low-level solid waste that is disposed to the ground shall be confined by a site-specific system of barriers that may include, but not necessarily be limited to, waste form, waste packaging, and the geologic setting. When site permeability characteristics do not provide the required confinement capabilities, the confinement system shall be augmented by the following: • constructing low permeability walls around the low-level waste; • lining the walls and bottom of the excavated area with low permeability material; and • other suitable methods for reducing permeability. Means shall be provided to minimize contact of emplaced low-level waste with water. Active water control measures shall not be required following permanent closure. Typical requirements for water control are as follows: • placing a layer of highly permeable material beneath the low-level waste to channel any percolating water to a sump; • mounding the soil surface to facilitate surface water runoff; • use of a suitable low-permeability cover material (e.g., clay) over the disposal area to prevent contact of the waste by infiltrating rainwater. This cover material shall be protected by a layer of overburden (e.g., sand, gravel, top soil). • a site diversion system for surface water runoff during operation of the facility; • temporary protective covers (e.g., tarpaulin) before the completion of the natural in-place soil barrier over the low-level waste;	TBC	

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TABLE A-3
(Continued)

Citation	Action	Requirement	Determination	Remarks
		LOW-LEVEL RADIOACTIVE WASTE CONFINEMENT (continued)		
General Design Criteria DOE Order 6430.1A 1324-5.3 (continued)	Low-Level Solid Waste Confinement	• revegetation of the overburden layer; and • other suitable and reliable means for minimizing water contact with low-level waste.	TBC	
General Design Criteria DOE Order 6430.1A 1324-6	Radioactive Solid Waste Confinement Systems	The following requirements outline the confinement system for radioactive solid waste: • Primary confinement consists of process systems equipment and its associated ventilation and off-gas system, storage containers, or other waste and site-specific engineered barriers. • Secondary confinement consists of process cell barriers and the ventilation systems associated with the cells or building, or a large storage building or structure. In some cases, a drum, cask, or other waste and site-specific engineered barrier shall provide secondary confinement. • The natural geologic setting composes the tertiary confinement system. In addition, the tertiary confinement system shall meet the following performance objectives: • Following permanent closure, on-going site maintenance shall not be needed. • In the absence of unplanned natural processes or human contact with a low-level waste disposal facility, calculated contaminant levels in groundwater at the site boundary shall not exceed the maximum contaminant levels (MCLs) established pursuant to the Safe Drinking Water Act (see chemical-specific requirements).	TBC	

TABLE A-3
(Continued)

Citation	Action	Requirement	Determination	Remarks
LOW-LEVEL RADIOACTIVE WASTE CONFINEMENT (continued)				
General Design Criteria DOE Order 6430.1A 1324-6 (continued)	Radioactive Solid Waste Confinement Systems	• In the event of human-induced activities following permanent closure, or reasonably foreseeable but unplanned natural processes, the guidelines of DOE Order 6430.1A, Section 1300-1.4.2, Accidental Releases, shall not be violated. Institutional controls may be relied on for a limited time following closure. For the purposes of calculation, these controls shall not be relied on for more than 100 years following permanent closure.	TBC	
CONTROL OF URANIUM AND THORIUM BYPRODUCT MATERIAL				
Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings 40 CFR §192.02 (a) Subpart A	Control of Residual Radioactive Materials	Controls of residual radioactive materials from inactive uranium processing sites shall be designed to be effective for up to 1,000 years, to the extent reasonably achievable, and in any case, for at least 200 years.	Relevant and Appropriate	
Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings 40 CFR §192.20 Subpart C	Implementation	Reasonable assurance to show compliance with 40 CFR §192.02 (Subpart A) standards should be done through the use of analytical models and site-specific analyses.	Relevant and Appropriate	
Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings 40 CFR §192.32 (b)(1)(i) Subpart D	Management of Uranium Byproduct Material	Disposal areas for the management of uranium byproduct materials after closure shall each comply with the closure performance standard in 40 CFR §264.111 with respect to nonradiological hazards and shall be designed to provide reasonable assurance of control of radiological hazards to be effective for 1,000 years, to the extent reasonable, and, in any case, for at least 200 years	Relevant and Appropriate	

TABLE A-3
(Continued)

Citation	Action	Requirement	Determination	Remarks
CONTROL OF URANIUM AND THORIUM BYPRODUCT MATERIAL (continued)				
Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings 40 CFR §§ 192.40-192.42 Subpart E	Management of Thorium Byproduct Material	The provisions for the management of uranium byproduct material (40 CFR §192.32) shall apply to thorium byproduct material and provisions applicable to the element uranium shall also apply to the element thorium	Relevant and Appropriate	
MANAGEMENT OF RESIDUAL RADIOACTIVE MATERIAL				
Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter II (5)	Release of Property	Real property (land and structures), personal property, materials, and equipment shall be released if the concentration of radioactivity is within the limits of residual radioactive contamination.	TBC	
Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter IV (6)	Control of Residual Radioactive Material Above the Guidelines	Residual radioactive material with concentrations above the generic guidelines (see chemical-specific requirements) shall be managed in accordance with Chapter II, Requirements for Radiation Protection of the Public and the Environment, and operational and control requirements.	TBC	
Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter IV (6)(d)	Long-Term Management of Residual Radioactive Material	To properly manage uranium, thorium, and their decay products, access to a property and use of on-site materials contaminated by residual radioactive material should be controlled through appropriate administrative and physical controls such as those described in 40 CFR 192. These controls should be designed to be effective to the extent reasonable for at least 200 years.	TBC	
Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter IV (7)	Supplemental Limits and Exceptions for Residual Radioactive Material	If special specific property circumstances indicate that the concentration guidelines or authorized limits are not appropriate, supplemental limits or an exception may be requested to those guidelines or limits.	TBC	

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TABLE A-4
OTHER ACTION-SPECIFIC REQUIREMENTS

Citation	Action	Requirement	Determination	Remarks
		AIR POLLUTION CONTROL		
Ohio General Provisions on Air Pollution Control OAC 3745-15-07 ORC 3704.01-.05	Prevention of Air Pollution Nuisance	Measures shall be taken to adopt and maintain a program for the prevention, control, and abatement of air pollution in order to protect and enhance the quality of the state's air resource so as to promote the public health, welfare, and economic vitality of the people of the state. The emission or escape into open air from any source whatsoever of smoke, ashes, dust, dirt, grime, acids, fumes, gases, vapors, odors, and combinations of the above in such a manner or in such amounts as to endanger the health, safety, or welfare of the public or to cause unreasonable injury or damage to property shall be declared to be a public nuisance. It is unlawful for any person to cause, permit, or maintain any such public nuisance.	Applicable	
Ohio Permit to Install New Sources of Pollution OAC 3745-31-05 (A)(3)	Best Available Technology (BAT)	The installation or modification and operation of an air contaminant source must employ the best available technology.	Relevant and Appropriate	
Ohio Ambient Air Quality Standards OAC 3745-17-02 OAC 3745-17-05	Particulate Ambient Air Quality Standards	The level of the primary and secondary 24-hour ambient air quality standards for total suspended particulates is 150 $\mu g/m^3$, 24-hour average concentration. The level of the primary and secondary annual standards for total suspended particulates in 50 $\mu g/m^3$, annual arithmetic mean. The significant and avoidable deterioration of air quality in any part of the area where presently existing air quality is equal to or better than the particulate ambient air quality standards shall be prohibited.	Applicable	
Ohio Particulate Matter Standards OAC 3745-17-07	Control of Visible Particulate Emissions from Stationary Sources	Visible particulate emissions from any stack shall not exceed 20 percent opacity, as a six-minute average. Transient exceedance limits are included in this regulation.	Applicable	

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TABLE A-4
OTHER ACTION-SPECIFIC REQUIREMENTS

Citation	Action	Requirement	Determination	Remarks
		AIR POLLUTION CONTROL (continued)		
Ohio Emissions of Particulate Matter OAC 3745-17-07(B)(4),(5),(6)	Control of Visible Particulate Emissions	There shall be no visible particulate emissions from any paved roadway or parking area except for a period of time not to exceed six minutes during any sixty-minute observation period. There shall be no visible particulate emissions from any unpaved roadway, parking area, or material storage piles except for a period of time not to exceed thirteen minutes during any sixty-minute observation period.	Applicable	
Ohio Emissions of Particulate Matter OAC 3745-17-08	Restriction of Emission of Fugitive Dust	No person shall cause or permit any fugitive dust source to be operated; or any materials to be handled, transported or stored; or a building or its appurtenances or a road to be used constructed, altered, repaired or demolished without taking or installing reasonably available control measures to prevent fugitive dust from becoming airborne. Such reasonably available control measure shall include, but not be limited to, one or more of the following which are appropriate to minimize or eliminate visible particulate emissions of fugitive dust: • the use of water or other suitable dust suppression chemicals for the control of fugitive dust from the demolition of existing buildings or structures, construction operations, the grading or roads or the clearing of land; or • the periodic application of asphalt, oil, water, or other suitable dust suppression chemicals on dirt or gravel roads and parking lots, and any other surfaces which cause emissions of fugitive dust.	Relevant and Appropriate	This requirement is applicable only to certain cities in Butler and Hamilton Counties.
Ohio Particulate Matter Standards OAC 3745-17-11	Restrictions on Particulate Emissions	The following are restrictions for particulates from any operation, process, or activity which releases or may release particulate emissions into the ambient air. These limits are based on the weight of material being processed.	Applicable	

TABLE A-4
(Continued)

Citation	Action	Requirement	Determination	Remarks
AIR POLLUTION CONTROL (continued)				
Ohio Particulate Matter Standards OAC 3745-17-11 (continued)	Restrictions on Particulate Emissions	Process Weight at Maximum Capacity lb/hr. / Allowable Rate of Particulate Emission lb/hr. 100 / 0.551 200 / 0.877 400 / 1.40 600 / 1.83 800 / 2.22 1000 / 2.58	Applicable	
Standard of Performance for Nonmetallic Mineral Processing Plants 40 CFR §60.672 (a),(d),(e)	Restrictions on Particulate Emissions From Crushers	No owner or operator shall cause to be discharged into the atmosphere from a crusher any emissions which: • contain particulate matter in excess of 0.05 grams per dry cubic meter at standard conditions (g/dscm); and • exhibit greater than 7 percent opacity Truck dumping of nonmetallic minerals into any crusher is exempt from these requirements.	Relevant and Appropriate	
WATER POLLUTION CONTROL				
National Pollutant Discharge Elimination System 40 CFR §122.26 (a)(1)(ii) 40 CFR §122.26 (b)(14)(v),(x)	Storm Water Discharge Associated with Industrial Activity	A discharge composed entirely of storm water associated with industrial activity is required to obtain a NPDES permit. These categories of facilities are considered to be engaging in "industrial activity": • landfills, land application sites, and open dumps that receive or have received any industrial wastes (waste that is received from any of the facilities described under this subsection) including those that are subject to regulation under subtitle D of RCRA; and	Applicable	Engineering controls will be implemented to monitor and control stormwater runoff during removal, treatment, and disposal of Operable Unit 2 material.

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TABLE A-4
(Continued)

Citation	Action	Requirement	Determination	Remarks
		WATER POLLUTION CONTROL (continued)		
National Pollutant Discharge Elimination System 40 CFR §122.26 (a)(1)(ii) 40 CFR §122.26 (b)(14)(v),(x) (continued)	Storm Water Discharge Associated with Industrial Activity	• construction activity including clearing, grading, and excavation activities that disturbs 5 acres or more of total land area.	Applicable	
Clean Water Act §404 (33 U.S.C. §1344) Guidelines for Specifications of Disposal Sites for Dredged or Fill Material 40 CFR §230.10	Discharge of Dredged or Fill Material	No discharge of dredged or fill material shall be permitted: • if there is a practicable alternative to the proposed discharge which would have less adverse impact on the aquatic ecosystem, so long as, the alternative does not have other significant adverse environmental consequences. • unless appropriate and practicable steps have been taken which will minimize potential adverse impacts of the discharge on the aquatic ecosystem. No discharge of dredged or fill material shall be permitted if it: • causes or contributes, after consideration of disposal site dilution and dispersion, to violations of any applicable state water quality standard. • violates any applicable toxic effluent standard or prohibition under section 307 of the Clean Water Act. • jeopardizes the continued existence of species listed as endangered or threatened under the Endangered Species Act of 1973, as amended, or results in likelihood of the destruction or adverse modification or a habitat which is determined to be a critical habitat under the Endangered Species Act of 1973, as amended.	Applicable	

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TABLE A-4
(Continued)

Citation	Action	Requirement	Determination	Remarks
		WATER POLLUTION CONTROL (continued)		
Clean Water Act Nationwide Permit Program 33 U.S.C. §1341(a)(1),(d) 33 CFR §330.1 (c)	Nationwide Permits - Terms and Conditions	An activity is authorized under an NWP only if that activity and the permittee satisfy all of the following NWPs terms and conditions. Potentially applicable NWPs include: • Nationwide Permit #26 - Headwaters and Isolated Waters Discharges - The discharge does not cause the loss of more than 10 acres of waters of the United States. - The permittee notifies the district engineer if the discharge would cause the loss of waters of the United States greater than one acre. - For discharges in special aquatic sites, including wetlands, the notification must also include a delineation of affected special aquatic sites, including wetlands. - The discharge, including all attendant features, both temporary and permanent, is part of a single and complete project. • Nationwide Permit #38 - Cleanup of Hazardous and Toxic Waste - This permit authorizes specific activities required to effect the containments, stabilization or removal of hazardous or toxic waste materials that are performed ordered, or sponsored by a government agency with established legal or regulatory authority provided the permittee notifies the district engineer. - For discharges in special aquatic sites, including wetlands, the notification must also include a delineation of affected special aquatic sites, including wetlands.	Applicable	In a January 17, 1992 letter to the U.S. Army Corps of Engineers, OEPA conditionally certified that projects authorized by these Nationwide Permits will comply with the applicable provisions of the Federal Water Pollution Control Act.

TABLE A-4
(Continued)

Citation	Action	Requirement	Determination	Remarks
		WATER POLLUTION CONTROL (continued)		
Clean Water Act Nationwide Permit Program 33 U.S.C. §1341(a)(1),(d) 33 CFR §330.1 (c) (continued)	Nationwide Permits - Terms and Conditions	- This nationwide permit does not authorize the establishment of new disposal sites or the expansion of existing sites used for the disposal of hazardous or toxic waste.	Applicable	
Clean Water Act Nationwide Permit Program 33 CFR §330.4 (c)(1) Ohio Section 401 Water Quality Certifications OAC 3745-32	Nationwide Permits - Terms and Conditions	State 401 water quality certification pursuant to section 401 of the Clean Water Act, or waiver thereof, is required prior to the issuance or reissuance of individual or nationwide permits authorizing activities which may result in a discharge into waters of the United States	Applicable	
Clean Water Act General Regulatory Policies 33 CFR §323.3	Permits for Discharges of Dredged or Fill Material	Permits will be required for the discharge of dredged or fill material into waters of the United States including wetlands. Certain discharges specified in 33 CFR Part 330 are permitted by that regulation (nationwide permits). If a discharge of dredged or fill material is not permitted by 33 CFR Part 330 (Nationwide Permits), an individual section 404 permit will be required for the discharge of dredged or fill material into waters of the United States. Discharges of dredged or fill material into waters of the United States done by or on behalf of any Federal agency, other than the Corps of Engineers, are subject to the authorization procedures of these regulations.	Applicable	
Ohio Water Pollution Control Regulations ORC 6111.04	Acts of Pollution Prohibited	No person shall cause pollution or place or cause to be placed any sewage, industrial waste, or other wastes in a location where they cause pollution of any waters of the state.	Applicable	

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TABLE A-4
(Continued)

Citation	Action	Requirement	Determination	Remarks
WATER POLLUTION CONTROL (continued)				
Ohio Water Pollution Control Regulations ORC 6111.04 (continued)	Acts of Pollution Prohibited	No person to whom a permit has been issued shall place or discharge, or cause to be placed or discharged, in any waters of the state any sewage, industrial waste, or other wastes in excess of the permissive discharges specified under such existing permit without first receiving a permit from the Director to do so.	Applicable	
NOISE POLLUTION CONTROL				
Noise Control Act 42 U.S.C. §4901, *et seq.* Noise Pollution and Abatement Act 42 U.S.C. §7641	Noise Pollution Control	The public must be protected from noises that jeopardize health and welfare.	Applicable	

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TABLE A-5
LOCATION-SPECIFIC REQUIREMENTS

Citation	Location	Requirement	Determination	Remarks
THREATENED AND ENDANGERED SPECIES PROTECTION				
Procedures for Implementing the National Environmental Policy Act 40 CFR §6.302(h) Endangered and Threatened Wildlife and Plants 50 CFR §17.21,§17.94 Interagency Cooperation-Endangered Species Act 50 CFR §402.01	Endangered Species and Critical Habitat	All Federal agencies must insure that any action authorized, funded, or carried out by them is not likely to jeopardize the continued existence of any listed species or result in the destruction or adverse modification of the constituent elements essential to the conservation of a listed species within a defined critical habitat.	Applicable	In 1994, surveys were conducted for potential threatened or endangered plant species; no individuals were found. In 1993 and 1994, surveys have verified the presence of the state-threatened Sloan's crayfish [*Orconectes sloanii*] in Paddys Run. Suitable habitat for the Indiana bat [*Myotis sodalis*], a federally-listed endangered species, also exists on the Fernald property.
Interagency Cooperation-Endangered Species Act 50 CFR §402.12 (a),(b)	Biological Assessment	A biological assessment shall evaluate the potential effects of the action on listed and proposed critical habitat and determine whether any such species or habitat are likely to be adversely affected by the action and is used in determining whether formal consultation or a conference is necessary. These procedures are required for Federal actions that are "major construction activities".	Applicable	No critical habitat is present on the Fernald property.
Ohio Endangered Species Regulations ORC 1531.25	Endangered Animal Species	No person shall take or possess any native species of wild animal, or any eggs or offspring thereof, that is threatened with state-wide extinction.	Applicable	See first remark.
Ohio Endangered Species Regulations ORC 1518.02 OAC 1501:18-1	Endangered Plant Species	No person shall root up, injure, destroy, remove, or carry away on or from public highways, public property, or waters of the state, or on or from the property of another, without the written permission of the owner, lessee, or other person entitled to possession, any endangered or threatened plant listed in OAC 1501:18-1.	Applicable	See first remark.

TABLE A-5
(Continued)

Citation	Location	Requirement	Determination	Remarks
THREATENED AND ENDANGERED SPECIES PROTECTION (continued)				
Classification of Solid Waste Disposal Facilities and Practices 40 CFR §257.3-2	Any	Solid waste disposal facilities or practices shall not cause or contribute to the taking of any endangered or threatened species of plants, fish, or wildlife. Solid waste disposal facilities or practices shall not result in the destruction or adverse modification of the critical habitat of endangered or threatened species as identified in 50 CFR Part 17.	Applicable	See first remark.
HISTORIC AND CULTURAL RESOURCE PROTECTION				
Antiquities Act of 1906 16 U.S.C. §431	Antiquity Preservation	No person may appropriate, excavate, injure, or destroy any historic or prehistoric ruin or monument, or any object of antiquity situated or controlled by the Government of the United States.	Applicable	An assessment of the Operable Unit 2 waste units was performed in March 1993 and it was determined that the areas had already been sufficiently disturbed so that there would be no requirement to consult the State Historic Preservation Officer (SHPO). Archaeological investigations will be conducted for the disposal facility study area. Any other proposed areas of disturbance for Operable Unit 2 remedial actions will be surveyed and the SHPO consulted as necessary.
Archaeological Resources Protection Act 16 U.S.C. §47099 Procedures for Implementing the National Environmental Policy Act 40 CFR §6.301(c) Protection of Archaeological Resources 43 CFR §7.4(a)	Archaeological Resource Recovery and Preservation	Whenever any Federal agency finds, or is notified, in writing, by an appropriate historical or archaeological authority, that its activities in connection with any Federal construction project or federally licensed project, activity, or program may cause irreparable loss or destruction of significant scientific prehistorical, historical, or archaeological data, such agency shall notify the Secretary of the Interior, in writing, and shall provide the Secretary with appropriate information concerning the project, program, or activity.	Applicable	See above remark.

TABLE A-5
(Continued)

Citation	Location	Requirement	Determination	Remarks
HISTORIC AND CULTURAL RESOURCE PROTECTION (continued)				
Archaeological Resources Protection Act 16 U.S.C. §47099 Procedures for Implementing the National Environmental Policy Act 40 CFR §6.301(c) Protection of Archaeological Resources 43 CFR §7.4(a) (continued)	Archaeological Resource Recovery and Preservation	No person may excavate, remove, damage, or otherwise alter or deface or attempt to excavate, remove, damage, or otherwise alter or deface any archaeological resource located on public lands unless such activity is pursuant to a permit. If an EPA activity may cause irreparable loss or destruction of significant scientific, prehistoric, historic, or archaeological data, the responsible official or the secretary of the Interior is authorized to undertake data recovery and preservation activities.	Applicable	See above remark.
National Historic Preservation Act 16 U.S.C. §470 36 CFR 800 Procedures for Implementing the National Environmental Policy Act 40 CFR §6.301 (a),(b)	Historic Preservation	A Federal agency must take into account how each of its undertakings could affect historic properties. The purpose of this Act is not only to protect those properties listed in or eligible for the National Register of Historic Places, but also those properties that have not been listed or formally determined eligible for the listings. The heads of all Federal agencies shall assume responsibility for the preservation of historic properties which are owned or controlled by such agency. Prior to any Federal undertaking which may directly and adversely affect any National Historic Landmark, the head of the responsible agency shall, to the extent possible, minimize the harm to such landmark.	Applicable	See above remark.
Native American Graves Protection and Repatriation Act 25 U.S.C. §3001	Protection of American Indian Grave Sites	Provides for the return of human remains and cultural objects from Native American graves to affiliated tribes.	Applicable	

TABLE A-5
(Continued)

Citation	Location	Requirement	Determination	Remarks
HISTORIC AND CULTURAL RESOURCE PROTECTION (continued)				
American Indian Religious Freedom Act 42 U.S.C. §1996	Protection of American Indian Religious Freedom	Provides for tribal access by native peoples to grave sites and sites of cultural, symbolic, or religious significance.	Applicable	
FLOODPLAINS/WETLANDS PROTECTION				
Procedure for Implementing the National Environmental Policy Act 40 CFR §6.302(a) [Executive Order 11990]	Protection of Wetlands	Federal agencies conducting certain activities must avoid, to the extent possible, the adverse impacts associated with the destruction or loss of wetlands and to avoid support of new construction in wetlands when a practicable alternative exists.	Applicable	An updated site-wide delineation of Fernald wetlands, performed in accordance with the U.S. Army Corps of Engineers Wetland Delineation Manual, was completed in March 1993. Although there are wetlands located near the Lime Sludge Ponds, the Solid Waste Landfill is the only subunit with wetlands located inside the battery limits. These wetlands may be affected during the Operable Unit 2 remedial action. Wetlands in other areas of the site may also be impacted by construction and operation of the on-site disposal facility. A Wetland/Floodplain Assessment was conducted.
Procedures for Implementing the National Environmental Policy Act 40 CFR §6.302(b) [Executive Order 11988]	Floodplain Management	Federal agencies must evaluate the potential effects of actions they may take in a floodplain to avoid, to the extent possible, adverse effects associated with direct and indirect development of a floodplain.	Applicable	An updated floodplain determination was performed for Paddys Run in October 1993 using the Army Corps of Engineers' standard HEC2 water surface profile analysis program. The 100-year flood elevations reach the western slope of the Inactive Flyash Pile and the toe of the South Field slope. Indirect, short-term floodplain impacts will occur during remediation. A Wetland/Floodplain Assessment was conducted.

TABLE A-5
(Continued)

Citation	Location	Requirement	Determination	Remarks
		FLOODPLAINS/WETLANDS PROTECTION (continued)		
DOE Compliance with Floodplain/Wetlands Environmental Review Requirements 10 CFR §1022.3(a), (b)(1),(2),(3),(5),(6),(c), (d),(e)	Floodplain/Wetlands	DOE shall exercise leadership and take action to: • avoid to the extent possible the long- and short-term adverse impacts associated with the destruction of wetlands and the occupancy and modification of floodplains and wetlands, and avoid direct and indirect support of floodplain and wetlands development wherever there is a practicable alternative. • incorporate floodplain management goals and wetlands protection considerations into its planning, regulatory, and decision-making processes and shall to the extent practicable: - reduce the hazard and risk of flood loss. - minimize the impact of floods on human safety, health, and welfare. - restore and preserve natural and beneficial values served by the floodplains. - minimize the destruction, loss, or degradation of wetlands. - preserve and enhance the natural and beneficial values of wetlands • undertake a careful evaluation of the potential effects of any DOE action taken in a floodplain and any new construction undertaken by DOE in wetlands not located in a floodplain • identify, evaluate, and as appropriate, implement alternative actions which may avoid or mitigate adverse floodplain/wetlands impacts • provide opportunity for early public review of any plans or proposals for actions in floodplains and new construction in wetlands	Applicable	

TABLE A-5
(Continued)

Citation	Location	Requirement	Determination	Remarks
		FLOODPLAINS/WETLANDS PROTECTION (continued)		
DOE Compliance with Floodplain/Wetlands Environmental Review Requirements 10 CFR §1022.5(b),(h)	Floodplain/Wetlands	This part shall apply to all proposed floodplain/ wetlands actions, including those sponsored jointly with other agencies, where practicable alternatives to the proposed actions are still available. The policies and procedures of this part which are applicable to floodplain actions shall apply to all proposed actions which occur in a wetlands located in a floodplain.	Applicable	
DOE Compliance with Floodplain/Wetlands Environmental Review Requirements 10 CFR §1022.11(a),(b), (c)	Floodplain/Wetlands	Concurrent with its review of a proposed action to determine appropriate NEPA requirements, DOE shall determine applicability of the floodplain management and wetlands protection requirements of this part. In making a floodplain determination, DOE shall utilize the Flood Insurance Rate Maps (FIRMs) or the Flood Hazard Boundary Maps (FHBMs) prepared by the Federal Insurance Administration of the Department of Housing and Urban Development to determine if a proposed action is located in the base or critical action floodplain, as appropriate. For a proposed action in an area of predominantly Federal or State land holdings where FIRM or FHBM maps are not available, information shall be sought from the land administering agency (e.g., Bureau of Land Management, Soil Conservation Service, etc.) or from agencies with floodplain analysis expertise.	Applicable	
DOE Compliance with Floodplain/Wetlands Environmental Review Requirements 10 CFR §1022.12(a)	Floodplain/Wetlands	If DOE determines, pursuant to 10 CFR §§ 1022.5 and 1022.11, that this part is applicable to the proposed action, DOE shall prepare a floodplain/wetlands assessment, according to the requirements in this section (10 CFR §1022.12).	Applicable	

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TABLE A-5
(Continued)

Citation	Location	Requirement	Determination	Remarks
FLOODPLAINS/WETLANDS (continued)				
DOE Compliance with Floodplain/Wetlands Environmental Review Requirements 10 CFR §1022.15(a)	Floodplain/Wetlands	If DOE finds that no practicable alternative to locating in the floodplain/wetlands is available, consistent with the policy set forth in Executive Order 11988, DOE shall, prior to taking action, design, or modify its action in order to minimize potential harm to or within the floodplain/wetlands.	Applicable	
Ohio Solid Waste Disposal Regulations OAC 3745-27-20 (C)(2)	Floodplain	The limits of solid waste placement and the leachate management system cannot be located in a regulatory floodplain, unless deemed acceptable by the Director.	Applicable	
Ohio Solid Waste Disposal Regulations OAC 3745-27-07 (H)(4)(d)	Stream, Lake, or Wetland	The limits of waste placement cannot be located within 200 feet of a stream, lake, or wetland, unless deemed acceptable by the Director.	Applicable	
GROUNDWATER PROTECTION				
Safe Drinking Water Act 42 U.S.C. §1424(e)	Sole Source Aquifer	All Federal financially assisted projects constructed in the area of a sole source aquifer and its principal recharge zone will be subject to EPA's review to insure that these projects are designed and constructed so that they do not create a significant hazard to public health.	Applicable	A notice in 53 FR 15876 (May 4, 1988) designated the Buried Valley Aquifer System of the Great Miami/ Little Miami River Basins of southwestern Ohio as a sole or principal source of drinking water. The Fernald site is located above this aquifer.
Ohio Solid Waste Disposal Regulations OAC 3745-27-07 (H)(3)(a)	Any	A sanitary landfill facility may not be located within the surface and subsurface areas surrounding a public water supply well through which contaminants may move toward and may reach the public water supply well within a period of 5 years.	Applicable	
Ohio Solid Waste Disposal Regulations OAC 3745-27-07 (H)(2)(c)	Any	A sanitary landfill facility cannot be located above an aquifer declared by the federal government under the Safe Drinking Water Act to be a sole source aquifer.	Applicable	

TABLE A-5
(Continued)

Citation	Location	Requirement	Determination	Remarks
		GROUNDWATER PROTECTION (continued)		
Ohio Solid Waste Disposal Regulations OAC 3745-27-07 (H)(2)(d)	Any	A sanitary landfill facility cannot be located above an unconsolidated aquifer capable of sustaining a yield of 100 gallons per minute for a 24-hour period to an existing or future water supply well located within 1,000 feet of the limits of solid waste placement, unless deemed acceptable by the Director.	Applicable	
Ohio Solid Waste Disposal Regulations OAC 3745-27-07 (H)(3)(c)	Water Supply Well or Developed Spring	The limits of sold waste placement cannot be located within 1,000 feet of an existing water supply well or developed spring unless it is deemed acceptable by the Director or it is: • controlled by the applicant, is needed as a source of nonpotable water, no other reasonable alternate water source is available, and the well is constructed to prevent contamination of the groundwater, OR • located at least 500 feet hydrogeologically up-gradient from the limits of solid waste placement, OR • separated from the limits of solid waste placement by a hydrogeologic barrier, OR • constructed and used solely for monitoring groundwater quality	Applicable	
Ohio Solid Waste Disposal Regulations OAC 3745-27-07 (H)(2)(e)	Any	The isolation distance between the uppermost aquifer system and the bottom of the recompacted soil liner of a sanitary landfill system cannot be less than 15 feet of in situ or added geologic material deemed acceptable by the Director.	Applicable	
OEPA Guidance on Solid Waste Siting Criteria: Material Acceptable to the Director GD202.104	Any	For geologic material to be deemed acceptable to the Director as added fill under OAC Rule 3745-27-07 (B)(15), it must be able to meet the following criteria: • the geologic material must be impermeable enough so it will not store, transmit or yield a significant amount of water to a well or spring	TBC	

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TABLE A-5
(Continued)

Citation	Location	Requirement	Determination	Remarks
		GROUNDWATER PROTECTION (continued)		
OEPA Guidance on Solid Waste Siting Criteria: Material Acceptable to the Director GD202.104 (continued)	Any	• the geologic material must be able to impede both physically and chemically, the flow of leachate constituents through it In order to meet both criteria listed above, the added geologic material should: • be classified as CL, SC, GC, CL-ML, or CH under the Unified Soil Classification System (USCS) • be composed of particles of which at least 25% by dry weight will pass through a No. 200 (75 μm) sieve • be composed of no more than 25% by dry weight particles which will not pass through a No. 4 sieve • no particle should be greater than 8 inches in diameter • have a final permeability of no more than $1x10^{-8}$ cm/sec • be recompacted in a manner that when the landfill is constructed on it, no damage to the landfill liner will occur due to settling of the added material	TBC	
Ohio Solid Waste Disposal Regulations OAC 3745-27-07 (H)(4)(b)	Any	The limits of waste placement cannot be located within 300 feet of the sanitary landfill facility's property line, unless deemed acceptable by the Director.	Applicable	
Ohio Solid Waste Disposal Regulations OAC 3745-27-07 (H)(4)(c)	Any	The limits of solid waste placement cannot be located within 1,000 feet of an existing domicile whose owner has not consented in writing to the location of the sanitary landfill facility.	Applicable	

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TABLE A-5
(Continued)

Citation	Location	Requirement	Determination	Remarks
		GROUNDWATER PROTECTION (continued)		
Ohio Solid and Hazardous Waste Rules ORC 3734.02(A)	Protection of Human Health and the Environment	The director of environmental protection shall adopt and may modify, suspend, or repeal rules for all solid waste facilities in order to ensure that the facilities will be located, maintained, and operated, and will undergo closure and post-closure care, in a sanitary manner so as not to create a nuisance, cause or contribute to water pollution, create a health hazard, or violate 40 CFR § 257.3-2 or 257.3-8.	Applicable	
		RADIOLOGICAL SITING CRITERIA		
Radioactive Waste Management DOE Order 5820.2A Chapter III (7)	Disposal Site Selection	Disposal site selection criteria (based on planned waste confinement technology) shall be developed for establishing new low-level waste disposal sites. Disposal site selection shall be based on an evaluation of the prospective site in conjunction with planned waste confinement technology, and in accordance with the National Environmental Policy Act process. Site selection shall also be based on the following criteria: • The disposal site shall have hydrogeologic characteristics which, in conjunction with the planned waste confinement technology, will protect the groundwater resource. • The potential for natural hazards such as floods, erosion, tornadoes, earthquakes, and volcanoes shall be considered in site selection. • Site selection criteria shall address the impact on current and projected populations, land use resources development plans and nearby public facilities, accessibility to transportation routes and utilities, and the location of waste generation.	TBC	

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TABLE A-5
(Continued)

Citation	Location	Requirement	Determination	Remarks
RADIOLOGICAL SITING CRITERIA (continued)				
Joint NRC-EPA Guidance on Siting of Mixed Low-Level Radioactive and Hazardous Waste Units (March 13, 1987)	Any	Areas with highly vulnerable hydrogeology deserve special attention in the siting of a mixed low-level waste disposal facility. Hydrogeology is considered vulnerable when groundwater travel time along any 100-foot flow path from the edge of the engineered containment structure in less than approximately 100 years. Disposal sites located in areas of vulnerable hydrogeology may require extensive, site-specific investigations which could lead to and provide bases for restrictions or modifications to design or operating practices. However, a finding that a site is located in an area of vulnerable hydrogeology alone, based on the EPA criteria, is not considered sufficient to prohibit siting under RCRA.	TBC	

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APPENDIX D

APPENDIX D

ARARs FOR OPERABLE UNIT 5

APPENDIX B

APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS AND TO BE CONSIDERED REQUIREMENTS FOR OPERABLE UNIT 5

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LIST OF ACRONYMS

AEA	Atomic Energy Act
ALARA	as low as reasonably achievable
ARAR	applicable or relevant and appropriate requirement
AWWT	advanced wastewater treatment [facility]
BUSTR	Bureau of Underground Storage Tank Regulations
CAA	Clean Air Act
CAMU	corrective action management unit
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
COC	constituent of concern
CRARE	comprehensive response action risk evaluation
CWA	Clean Water Act
DFO	director's findings and orders
DOE	U. S. Department of Energy
DOT	U. S. Department of Transportation
EIS	environmental impact statement
EPA	U. S. Environmental Protection Agency
FEMP	Fernald Environmental Management Project
FERMCO	Fernald Environmental Restoration Management Corporation
FS	feasibility study
HDPE	high-density polyethylene
HEPA	high-efficiency particulate air [filter]
HWMU	hazardous waste management unit
LDR	land disposal restriction
MCL	maximum contaminant level [under SDWA]
MCL	maximum concentration limit [under RCRA]
MCLG	maximum contaminant level goal [under SDWA]
MTR	minimum technology requirements
NAAQS	National Ambient Air Quality Standards
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NEPA	National Environmental Policy Act
NESHAP	National Emission Standards for Hazardous Air Pollutants
NPL	National Priorities List
NRC	Nuclear Regulatory Commission
NTS	Nevada Test Site
OAC	Ohio Administrative Code
OEPA	Ohio Environmental Protection Agency

LIST OF ACRONYMS (Continued)

ORC	Ohio Revised Code
PAH	polycyclic aromatic hydrocarbon
PCA	polychloroethylane
PCB	polychlorinated biphenyl
PEIS	programmatic environmental impact statement
PP	proposed plan
ppb	parts per billion
ppm	parts per million
PRG	preliminary remediation goal
PRL	preliminary remediation level
RA	remedial action
RAC	Radiological Assessments Corporation
RCRA	Resource Conservation and Recovery Act
RI/FS	remedial investigation/feasibility study
ROD	record of decision
SARA	Superfund Amendments and Reauthorization Act
SCS	Soil Conservation Survey
SDWA	Safe Drinking Water Act
SOWC	Southwestern Ohio Water Company
SSOD	storm sewer outfall ditch
STP	site treatment plan
SWMU	solid waste management unit
TBC	to be considered
TSCA	Toxic Substances Control Act
TU	temporary unit
UMTRCA	Uranium Mill Tailings Radiation Control Act
USDA	U. S. Department of Agriculture
UST	underground storage tank
VOC	volatile organic compound
WAC	waste acceptance criteria

B.0 APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS AND TO BE CONSIDERED REQUIREMENTS FOR OPERABLE UNIT 5

The tables in this appendix identify the chemical-, location-, and action-specific applicable or relevant and appropriate requirements (ARARs) for Operable Unit 5; two types of tables are provided for each.

The first type (Tables B.1, B.2 and B.3) identifies the regulations that may be an ARAR or a to be considered (TBC) criteria for any anticipated remedial activities at the FEMP, and includes: 1) an explanation of what the requirement is about, 2) identification as an ARAR or TBC, and 3) why it is an ARAR or TBC. Note that the requirements column in these tables provides only a summary; the regulation, statute, or Federal Register citation listed in the tables should be consulted for a full description of the requirement.

The second type (Tables B.4.A through B.4.C) summarizes what will be necessary to comply with the requirements for the Operable Unit 5 selected remedy. TBCs (proposed requirements) are not included in these tables because, not being ARARs, they are not used to determine if the selected remedy will be in compliance with environmental regulations.

TABLE B.1

OPERABLE UNIT 5 CHEMICAL-SPECIFIC [illegible]REMENTS

Citation	Requirement	ARAR/TBC	Rationale
DRINKING WATER			
MCLs for Radiologic Contaminants			
EPA National Primary Drinking Water Regulations 40 CFR §141.15 and §141.16 Ohio Drinking Water Regulations OAC 3745-81-15 OAC 3745-81-16	The following are maximum contaminant levels for radiological contaminants: Combined radium-226 and -228 ..... 5 pCi/L Gross alpha particle activity ..... 15 pCi/L (including radium-226 but excluding radon and uranium) Beta and photon radioactivity ..... 4 mrem/year from man-made radionuclides Strontium 90 ..... 8 pCi/L	Relevant and Appropriate	This requirement is not applicable to OU5 activities because there are no public drinking water systems involved with this remediation. The MCLs are considered relevant and appropriate to the GMA as it is a sole source aquifer currently used to supply drinking water to the regional area.
Proposed MCLs for Radiologic Contaminants			
56 Federal Register 33050 (July 18, 1991)	The following are the proposed maximum contaminant levels for radiological contaminants: Radium-226 ..... 20 pCi/L Radium-228 ..... 20 pCi/L Radon-222 ..... 300 pCi/L Uranium ..... 20 µg/L Beta and photon emitters ..... 4 mrem cede/year (excluding radium-228) Adjusted gross alpha emitters ..... 15 pCi/L (excluding radium-226, uranium, and radon-222)	TBC	These proposed MCLs are not ARARs because they are not promulgated. The proposed MCLs have been adopted as TBCs because they represent health-based guidance for application to the GMA to ensure protectiveness of human health.

TABLE B.1 (Continued)
OPERABLE UNIT 5 CHEMICAL-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
Groundwater Standards (Uranium Mill Tailings Radiation Control Act)			
Groundwater Standards for Remedial Actions at inactive Uranium Processing Sites 40 CFR §192.02 (a)(3)	The following are drinking water standards for processed and unprocessed uranium mill tailings: Uranium (234+238) ..... 30 pCi/L Molybdenum ..... 0.1 mg/L	Relevant and Appropriate	These standards are relevant and appropriate because uranium mill tailings were processed at the Fernald Facility. Compliance with standards set for other constituents under this requirement will be met through the Safe Drinking Water Act as prescribed by the NCP.
MCLs and MCLGs for Volatile Organic Contaminants (Safe Drinking Water Act)			
EPA National Primary Drinking Water Standards for MCLGs 40 CFR §141.12 and §141.50 EPA National Primary Drinking Water Standards for MCLs 40 CFR §141.61 Ohio Drinking Water Regulations for MCLs OAC 3745-81-12	The following are the non-zero Federal maximum contaminant level goals (MCLG) and State of Ohio and Federal maximum contaminant levels (MCL) for volatile organic contaminants in mg/L: Benzene: Federal MCLG - ; Federal or Ohio MCL 0.005 Carbon tetrachloride: - ; 0.005 Chloroform: - ; 0.1/0.08 Dibromochloropropane (DBCP): - ; 0.0002 Dichloroethane (1.2-): - ; 0.005 Dichloroethylene (1,1-): 0.007 ; 0.007 Dichloromethane: - ; 0.005 Dichloropropane (1,2-): - ; 0.005 Ethylbenzene: 0.7 ; 0.7 Monochlorobenzene: 0.1 ; 0.1 Styrene: 0.1 ; 0.1 Toluene: 1 ; 1 Trichloroethane (1,1,1-): 0.2 ; 0.2 Trichloroethane (1,1,2-): 0.003 ; 0.005 Trichloroethylene: - ; 0.005 Vinyl chloride: - ; 0.002 Xylenes: 10 ; 10	Relevant and Appropriate	This requirement is not applicable to OU5 activities because there are no public drinking water systems involved with this remediation. The MCLs and non-zero MCLGs are considered relevant and appropriate to the GMA as it is a sole source aquifer currently used to supply drinking water to the regional area. Where the State of Ohio standard is more stringent than the federal standard, the Ohio standard is presented. - = Represents a MCLG of zero. Only non-zero MCLGs are pertinent per CERCLA.

TABLE B.1 (Continued)
OPERABLE UNIT 5 CHEMICAL-SPECIFIC REQUIREMENTS

Citation	Requirement			ARAR/TBC	Rationale
MCLs and MCLGs for Semivolatile Organic Contaminants (Safe Drinking Water Act)					
EPA National Primary Drinking Water Regulations for MCLGs and MCLs 40 CFR 141.11 40 CFR 141.51 40 CFR 141.62 Ohio Drinking Water Regulations OAC 3745-81-11 OAC 3745-81-23	The following are the Federal maximum contaminant level goals (MCLG) and State of Ohio and Federal maximum contaminant levels (MCL) for semivolatile organic contaminants in mg/L.			Relevant and Appropriate	This requirement is not applicable to OU5 activities because there are no public drinking systems involved with this remediation. The MCLs and MCLGs are considered relevant and appropriate to the GMA as it is a sole source aquifer currently used to supply drinking water to the regional area.
		Federal MCLG (mg/L)	Federal or Ohio MCL (mg/L)		
	Benzo(a)pyrene (PAH)	-	0.0002		- = Represents a MCLG of zero. Only non-zero MCLGs are pertinent per CERCLA.
	Dichlorobenzene o-	0.6	0.6		
	Dichlorobenzene m-	0.6	0.6		
	Dichlorobenzene p-	0.075	0.075		
	Hexachlorobenzene	-	0.001		
	Hexachlorocyclopentadiene	0.05	0.05		
	Pentachlorophenol	-	0.001		
	2,3,7,8-TCDD (Dioxin)	-	3E-08		
	Trichlorobenzene (1,2,4)	0.07	0.07		
Proposed MCLs and MCLGs for Semivolatile Organic Contaminants (Safe Drinking Water Act)					
55 Federal Register 30370 (July 25, 1990)	The following are proposed non-zero Federal maximum contaminant level goals (MCLG) and maximum contaminant levels for semivolatile organic contaminants in mg/L:			TBC	These proposed MCLs are not ARARs because they are not promulgated. The proposed MCLs have been adopted as TBCs because they represent health-based guidance for application to the GMA to ensure protectiveness of human health.
		Federal MCLG (mg/L)	Federal or Ohio MCL (mg/L)		
	Benz(a)anthracene (PAH)	-	0.0001		- = Represents a MCLG of zero. Only non-zero MCLGs are pertinent per CERCLA.
	Benzo(b)fluoranthene (PAH)	-	0.0002		
	Benzo(k)fluoranthene (PAH)	-	0.0002		
	Bromodichloromethane	-	0.1/0.08		NA = Not Available
	Butyl benzyl phthalate (PAE)	-	0.1		
	Chloroform	-	0.1/0.08		
	Chrysene (PAH)	-	0.0002		
	Dibenz(a,h)anthracene (PAH)	-	0.0003		
	Hexachlorobutadiene	0.001	NA		
	Indenol(1,2,3,-c,d)pyrene (PAH)	-	0.0004		

TABLE B.1 (Continued)
OPERABLE UNIT 5 CHEMICAL-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
MCLs and MCLGs for Pesticides/PCB Contaminants (Safe Drinking Water Act, continued...)			
EPA National Primary Drinking Water Regulations for MCLGs and MCLs 40 CFR 141.11 40 CFR 141.51 40 CFR 141.62 Ohio Drinking Water Regulations OAC 3745-81-11 OAC 3745-81-23	The following are the non-zero Federal maximum contaminant level goals (MCLG) and State of Ohio and Federal maximum contaminant levels (MCL) for pesticides/PCB contaminants in mg/L. Adipate (diethylhexyl): Federal MCLG 0.4; Federal or Ohio MCL 0.4 Arochlor: Federal MCLG -; Federal or Ohio MCL 0.002 Atrazine: Federal MCLG 0.003; Federal or Ohio MCL 0.003 Chlordane: Federal MCLG -; Federal or Ohio MCL 0.002 Endrin: Federal MCLG -; Federal or Ohio MCL 0.0002* Heptachlor: Federal MCLG -; Federal or Ohio MCL 0.0004 Heptachlor epoxide: Federal MCLG -; Federal or Ohio MCL 0.0002 Lindane: Federal MCLG 0.0002; Federal or Ohio MCL 0.0002 Methoxychlor: Federal MCLG 0.04; Federal or Ohio MCL 0.04 Polychlorinated biphenyls (PCBs): Federal MCLG -; Federal or Ohio MCL 0.0005 Toxaphene: Federal MCLG -; Federal or Ohio MCL 0.003	Relevant and Appropriate	This requirement is not applicable to OU5 activities because there are no public drinking systems involved with this remediation. The MCLs and MCLGs are considered relevant and appropriate to the GMA as it is a sole source aquifer currently used to supply drinking water to the regional area. * = Ohio Drinking Water MCL - = Represents a MCLG of zero. Only non-zero MCLGs are pertinent per CERCLA. NA = Not Available
MCLs and MCLGs for Herbicide Contaminants (Safe Drinking Water Act, continued...)			
EPA National Primary Drinking Water Regulations for MCLGs and MCLs 40 CFR 141.11 40 CFR 141.51 40 CFR 141.62 Ohio Drinking Water Regulations OAC 3745-81-11 OAC 3745-81-23	The following are the non-zero Federal maximum contaminant level goals (MCLG) and State of Ohio and Federal maximum contaminant levels (MCL) for herbicide contaminants in mg/L. 2,4-D: Federal MCLG 0.07; Federal or Ohio MCL 0.07 Dinoseb: Federal MCLG 0.007; Federal or Ohio MCL 0.007 2,4,5-TP: Federal MCLG 0.05; Federal or Ohio MCL 0.01*	Relevant and Appropriate	This requirement is not applicable to OU5 activities because there are no public drinking systems involved with this remediation. The MCLs and MCLGs are considered relevant and appropriate to the GMA as it is a sole source aquifer currently used to supply drinking water to the regional area. * = Ohio Drinking Water MCL

TABLE B.1 (Continued)
OPERABLE UNIT 5 CHEMICAL-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
MCLs and MCLGs for Inorganic Contaminants (Safe Drinking Water Act, continued...)			
EPA National Primary Drinking Water Regulations for MCLGs and MCLs 40 CFR 141.11 40 CFR 141.51 40 CFR 141.62 Ohio Drinking Water Regulations OAC 3745-81-11 OAC 3745-81-23	The following are the Federal non-zero maximum contaminant level goals (MCLG) and State of Ohio and Federal maximum contaminant levels (MCL) for inorganic contaminants in mg/L. Antimony: Federal MCLG 0.006; Federal or Ohio MCL 0.006 Barium: 2; 2 Beryllium: 0.004; 0.004 Cadmium: 0.005; 0.005 Chromium (total): 0.1; 0.05[a] Copper: 1.3; TT Lead: -; TT Mercury: 0.002; 0.002 Nickel: 0.1; 0.1 Selenium: 0.05; 0.01 Thallium: 0.0005; 0.002	Relevant and Appropriate	This requirement is not applicable to OU5 activities because there are no public drinking systems involved with this remediation. The MCLs and MCLGs are considered relevant and appropriate to the GMA as it is a sole source aquifer currently used to supply drinking water to the regional area. [a] = Ohio Drinking Water MCL TT = Copper - action level 1.3 mg/L; Lead - action level 0.015 mg/L. - = Represents a MCLG of zero. Only non-zero MCLGs are pertinent per CERCLA.
Proposed MCLs and MCLGs for Inorganic Contaminants (Safe Drinking Water Act, continued...)			
EPA National Primary Drinking Water Regulations for MCLGs and MCLs 40 CFR 141.11 40 CFR 141.51 40 CFR 141.62 Ohio Drinking Water Regulations OAC 3745-81-11 OAC 3745-81-23	The following are the proposed Federal non-zero maximum contaminant level goals (MCLG) and State of Ohio and Federal maximum contaminant levels (MCL) for inorganic contaminants in mg/L. Arsenic: Federal MCLG NA; Federal or Ohio MCL 0.05 Cyanide: 0.2; 0.2 Silver: 0.05; 0.05	Relevant and Appropriate	This requirement is not applicable to OU5 activities because there are no public drinking systems involved with this remediation. The MCLs and MCLGs are considered relevant and appropriate to the GMA as it is a sole source aquifer currently used to supply drinking water to the regional area. NA = Not Available

TABLE B.1 (Continued)
OPERABLE UNIT 5 CHEMICAL-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
MCLs for Resource Conservation and Recovery Act, Subtitle C and D			
Chemicals in Drinking Water (Solid Waste Disposal Facility) 40 CFR 257.4 Ohio Solid Waste Regulations OAC 3745-27-10(D) Chemicals in Drinking Water (Hazardous Waste Disposal Facility) 40 CFR 264.94 Ohio Hazardous Waste Regulations OAC 3745-54-94	A solid waste disposal facility shall not contaminate an underground drinking water source beyond the solid waste boundary (outermost perimeter of the waste). The concentration of chemicals shall not exceed background levels or listed MCLs, whichever is higher. A hazardous waste disposal facility must comply with the requirements specified in the facility permit for the uppermost aquifer underlying the waste management area beyond the point of compliance, which is a vertical surface located at the hydraulically downgradient limit of waste management that extends down into the uppermost aquifer underlying the regulated area. The concentration of chemicals in groundwater shall not exceed background levels or the listed maximum concentration level (MCL) of the constituent for groundwater protection, whichever is higher. **Inorganic Chemicals** — Solid Waste RCRA MCL (mg/L) / Hazardous Waste RCRA MCL (mg/L) Arsenic: 0.05 / 0.05 Barium: 1.00 / 1.00 Cadmium: 0.01 / 0.01 Chromium: 0.05 / 0.05 Lead: 0.05 / 0.05 Mercury: 0.002 / 0.002 Selenium: 0.01 / 0.01 Silver: 0.05 / 0.05 **Organic Chemicals** Benzene: .005 / NA Carbon tetrachloride: .005 / NA 1,2-Dichloroethane: .005 / NA 1,1-Dichloroethene: .007 / NA Trichloroethylene: .005 / NA **Radionuclides** Combined Ra-226 & Ra-228: 5 pCi/L Gross alpha particle activity (excluding radon & uranium): 15 pCi/L	Relevant and Appropriate	40 CFR 257.4 and 40 CFR 264.94 and their Ohio equivalents are relevant and appropriate because OU5 contains several of the chemicals listed in the regulation. Compliance with the MCLGs and MCLs under the Safe Drinking Water Act (SDWA) will assure compliance with these RCRA MCLs as discussed in the NCP. The RCRA MCLs reflect earlier versions of the SDWA but the intent is to follow the updated standards of the SDWA (Compliance With Other Laws Manual). These regulations are pertinent to remedial alternatives that involve the use of capping systems or engineered cells. On-property disposal of remediation waste might cause migration into the underlying aquifer and potentially contaminate drinking water systems as a consequence of remedial actions. NA = Not Available

TABLE B.1 (Continued)
OPERABLE UNIT 5 CHEMICAL-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
SURFACE WATER			
Discharges of Liquid Waste to Surface Waters			
Ohio Water Quality Standards OAC 3745-1-04	"Five Freedoms" for Surface Water are provided by the State of Ohio: All surface waters of the State shall be free from: • Objectionable suspended solids • Floating debris, oil and scum • Materials that create a nuisance • Toxic, harmful or lethal substances • Nutrients that create nuisance growth	Relevant and Appropriate	OAC 3745-1-04 pertains to both discharges to surface waters of the State as a result of remediation and any on-site surface waters affected by site conditions. All action alternatives involve effluent discharges to the Great Miami River. The no action alternative assumes surface water discharges to Paddys Run.
Use Designation of Surface Water			
Ohio Water Quality Standards OAC 3745-1-21	Paddys Run and the Great Miami River are designated as: • Warmwater aquatic life habitat • Agricultural and industrial water supply • Primary contact recreation	Applicable	The Great Miami River between Ross Road [River Mile (RM)95.7] to Taylorsville Dam (RM 92.6) is a state resource water and RM 130 and 118 are public water supplies. Discharges to the Great Miami River and Paddys Run must not cause a violation of applicable numeric or narrative water quality standards for these designations.

TABLE B.1 (Continued)
OPERABLE UNIT 5 CHEMICAL-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
	Warmwater Habitat Water Quality Criteria		
Ohio Water Quality Standards OAC 3745-1-07	Surface waters in the State of Ohio must comply with the maximum concentrations of each contaminant listed below for inside and outside the mixing zones of the receiving water to protect warm water aquatic habitats. "Outside Mixing Zone" shall be met after the effluent and the receiving water have been determined to be reasonably well mixed based upon information readily available to the Director. The criteria listed as "Inside Mixing Zone Maximum" shall be applicable as end-of-pipe maximum effluent limits or as criteria to be met within a short distance of the effluent pipe if it can be demonstrated that discharge-induced mixing occurs as per the definition of "area of initial mixing" in rule OAC 3745-1-02.	Applicable	OAC 3745-1-07 is applicable because the site is bordered by the Great Miami River and Paddys Run. All remedial alternatives involving remedial action involve discharges to the Great Miami River. The No Action alternative assumes surface water discharges to Paddys Run.

Parameter (µg/L or as marked)	Outside Mixing Zone Max.	Outside Mixing Zone 30-Day Avg.	Inside Mixing Zone Max.	Rationale
Antimony (total)	650	190	1,300	NA = Not Available
Arsenic	360	190	720	
Benzene	1,100	560	2,100	
Beryllium (total)	520	23	1,000	Beryllium is based on a presumed water hardness of 100 mg/L calcium carbonate $CaCO_3$.
Bis(2-ethylhexyl) phthalate	1,100	8.4	2,200	
Cadmium	5.6	1.4	11	
Carbon tetrachloride	1,800	280	3,500	
Chlordane	NA	0.01	NA	
Chlorobenzene	590	26	1,200	
Chromium	1,800	210	3,600	
Chloroform	1,800	79	3,600	
2-Chlorophenol	200	8.8	400	
Copper (total)	18	12	35	Copper is based on a presumed water hardness of 100 mg/L $CaCO_3$.
Cyanide (free)	46	12	92	
1,2 Dichloroethane	12,000	3,500	24,000	
Dieldrin	NA	0.005	NA	

TABLE B.1 (Continued)
OPERABLE UNIT 5 CHEMICAL-SPECIFIC REQUIREMENTS

Citation	Requirement				ARAR/TBC	Rationale
	Parameter (µg/L or as marked)	Outside Mixing Zone Max.	Outside Mixing Zone 30-Day Avg.	Inside Mixing Zone Max.		Lead is based on a presumed water hardness of 100 mg/L $CaCO_3$.
	Lead (total)	130	6.9	260		
	Mercury (total)	1.1	0.2	2.2		
	Methylene chloride	9,700	430	19,000		
	Nickel (total)	1,600	170	3,100		Nickel is based on a presumed water hardness of 100 mg/L $CaCO_3$.
	Pentachlorophenol	5.3	3.2	11		
	PCBs	NA	0.001	NA		
	Selenium (total)	20	5.0	40		
	Silver (total)	1.6	1.3	3.2		Silver is based on a presumed water hardness of 100 mg/L $CaCO_3$.
	Tetrachloroethylene	540	73	1,100		
	Trichloroethylene	1,700	75	3,400		
	Thallium (total)	71	16	140		
	Zinc (total)	120	110	230		Zinc is based on a presumed water hardness of 100 mg/L $CaCO_3$.

TABLE B.1 (Continued)
OPERABLE UNIT 5 CHEMICAL-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
Human Health and Agricultural Water Supply Criteria			
Ohio Water Quality Standards OAC 3745-1-07	See previous requirement for explanation of inside/outside mixing zones. The maximum (outside mixing zone) concentrations for contaminants listed below are based on the designated use of the surface water body as Human Health or Agricultural.	Applicable	OAC 3745-1-07 is applicable because the site is bordered by the Great Miami River and Paddys Run. All remedial alternatives involving remedial action involve discharges to the Great Miami River. The No Action alternative assumes surface water discharges to Paddys Run. NA = Not Available

Parameter (µg/L or as marked)	Outside Mixing Zone 30-Day Average: Human Health	Outside Mixing Zone 30-Day Average: Agricultural
Antimony (total)	4,300	NA
Arsenic	NA	100
Benzene	710	NA
Beryllium (total)	1.17	100
beta-BHC	0.55	NA
Bis(2-ethylhexyl) phthalate	59	NA
Cadmium	NA	50
Carbon tetrachloride	44	NA
Chromium (total)	3,433,000	100
Copper (total)	NA	500
1,2 Dichloroethane	990	NA
Dieldrin	0.00076	NA
Fluoride (mg/L)	NA	2.0
Lead (total)	NA	100
Mercury (total)	0.012	10
Nickel (total)	4,600	200
N-Nitrosodi-n-propylamine	12.4	NA
PCBs	0.00079	NA
PAHs	0.31	NA
Selenium (total)	NA	50
Thallium (total)	48	NA
Vinyl chloride	5,250	NA
Zinc Total	NA	25,000

TABLE B.1 (Continued)
OPERABLE UNIT 5 CHEMICAL-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
Management and Control of Radioactive Materials in Liquid Discharges DOE Order 5400.5 Chapter II, (3) Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter II (3)(a) 10 CFR 834 (PROPOSED)	In addition to the requirements to limit dose to members of the public (onsite and offsite) in accordance with the standards established in paragraphs II (1)(a) and II (1)(d), further controls are imposed on liquid releases to protect resources such as surface water. Derived Concentration Guides (DCGs) are not release limits, but rather are screening values for considering Best Available Technology (BAT) for these discharges and for making dose estimates. These requirements apply at the point of discharge from the conduit to the environment (see DCGs in DOE Order 5400.5 Chapter III (3)). The BAT is the prescribed level of treatment for liquid radioactive discharges to surface waters that would otherwise contain radioactive concentrations greater than the DCG values. Implementation of the BAT process is not required for waste streams that contain radionuclide concentrations of not more than the DCG values at the point of discharge to a surface waterway. Residual concentrations of radionuclides in water that may be ingested are listed in tabular form in DOE Order 5400.5 Chapter III . The derived concentration guides (DCGs) for the COCs are based on a committed effective dose equivalent (CEDE) of 100 mrem/yr, assuming ingestion of 2 liters/day. Note that these DCGs apply only if ingestion is the single pathway of exposure.	TBC	DOE orders are not ARARs because they are not promulgated. This DOE order is a TBC because all alternatives have the potential to result in the exposure to members of the public. 10 CFR 834 is included as a TBC because it is presently a proposed rule.
DOE Order 5400.5 Chapter II (3)(a)(5) 10 CFR 834 (PROPOSED)	The absorbed dose to native aquatic animal organisms shall not exceed 1 rad per day from exposure to the radioactive material in liquid wastes discharged to natural waterways.	TBC	DOE orders are not ARARs because they are not promulgated. This DOE order is a TBC because all alternatives have the potential to result in exposure to members of the public. 10 CFR 834 is included as a TBC because it is presently a proposed rule.

TABLE B.1 (Continued)
OPERABLE UNIT 5 CHEMICAL-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
RADIATION LIMITS			
Dose Limits for Individual Members of the Public			
Ohio General Radiation Protection Standards OAC 3701-38-15 (A)(1),(B) DOE Order 5400.5 Chapter II (1)(a) 10 CFR 834 (PROPOSED)	Operations causing air emissions shall be conducted such that: • The total effective dose equivalent to individual members of the public from the operation does not exceed 0.1 rem (100 mrem) in a year • The dose in any unrestricted area from external sources does not exceed 0.002 rem (2mrem) in any one hour	Relevant and Appropriate	This OAC standard is not applicable because it applies to radiation sources which are not regulated by the United States Atomic Energy Act authority. However, this standard is relevant and appropriate because of the potential to result in the exposure to members of the public. NESHAP 40 CFR 61.91 will assure compliance with the first bullet. The second bullet is not found in NESHAP or in DOE Orders. 10 CFR 834 is included as a TBC because it is presently a proposed rule.
Radiation Dose Limit Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter II (1) DOE Order 5400.5, Chapter II (1)(a) DOE Order 5400.5, Chapter II (1)(a)(3) 10 CFR 834 (PROPOSED)	The public dose limits include consideration of all exposure modes from all DOE activities (including remedial activities). Effective dose equivalent is the sum of the effective dose equivalent (weighted summation of doses to various organs of the body) from exposures to radiation sources external to the body during the year plus the committed effective dose equivalent from radionuclides taken into the body during the year. Medical sources, consumer products, residual fallout from past nuclear accidents and weapons tests and naturally occurring radiation sources are not included in this summation. The exposure of members of the public to radiation sources as a consequence of all routine DOE activities shall not cause, in a year, an effective dose equivalent of more than 100 mrem for all exposure pathways. If unusual circumstances affect a DOE activity in such a manner that the potential public dose could exceed an effective dose equivalent of 0.1 rem (100 mrem) in a year, DOE may authorize a temporary increase of the dose limit up to 0.5 rem (500 mrem).	TBC	DOE orders are not ARARs because they are not promulgated. This DOE order is a TBC because all alternatives have the potential to result in exposure to members of the public. 10 CFR 834 is included as a TBC because it is presently a proposed rule.

TABLE B.1 (Continued)
OPERABLE UNIT 5 CHEMICAL-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
As Low As Reasonably Achievable (ALARA) DOE Order 5400.5 Chapter II, 2. 10 CFR 834 (PROPOSED)	Field Elements shall develop a program and shall require contractors to implement an ALARA Process for DOE activities and facilities that have the potential to cause radiation exposure to the public.	TBC	DOE orders are not ARARs because they are not promulgated. This DOE order is a TBC because all alternatives have the potential to result in exposure to members of the public. 10 CFR 834 is included as a TBC because it is presently a proposed rule.
STORAGE OF RADIOACTIVE MATERIAL			
Control of Residual Radioactive Material DOE Order 5400.5 Chapter IV (6)(b) 10 CFR 834 (PROPOSED)	Interim storage must provide: 1) Control and stabilization features shall be designed to provide, to the extent reasonably achievable, an effective life of 50 years with a minimum life of at least 25 years. 2) Controls to be designed such that Radon-222 concentrations in the atmosphere above facility surfaces or openings in addition to background levels, will not exceed: (a) 100 pCi/L at any given point; (b) An annual average concentration of 30 pCi/L over the facility site; and (c) An annual average concentration of 3 pCi/L at or above any location outside the facility site. (d) Flux rates from the storage of radon producing wastes shall not exceed 20 pCi/sq.m-sec, as required by 40 CFR Part 61. 3) Controls to be designed such that concentrations of radionuclides in the groundwater and quantities of residual radioactive material will not exceed applicable Federal or State standards. 4) Access to a property and use of onsite material contaminated by residual radioactive material should be controlled through appropriate administrative and physical controls such as those described in 40 CFR Part 192. These control features should be designed to provide, to the extent reasonable, an effective life of at least 25 years.	TBC	All OU5 alternatives except the no action alternative will provide for the interim storage of contaminated materials. 10 CFR 834 is included as a TBC because it is presently a proposed rule.

TABLE B.1 (Continued)
OPERABLE UNIT 5 CHEMICAL-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
Control of Residual Radioactive Material DOE Order 5400.5 Chapter IV (6)(d) 10 CFR 834 (PROPOSED)	1) Long-term management of uranium, thorium, and their decay products must provide: (a) Control and stabilization features designed to provide, to the extent reasonably achievable, an effective life of 1,000 years with a minimum life of at least 200 years. (b) Control and stabilization features designed to limit Radon-222 emanation to the atmosphere from the wastes to less than an annual average release rate of 20 $pCi/m^2/s$ and prevent increases in the annual average Radon-222 concentration at or above any location outside the boundary of the contaminated area by more than 0.5 pCi/L. Field verification of emanation rates shall be in accordance with the requirements of 40 CFR Part 61. (c) A long-term management facility for any potentially biodegradable contaminated wastes properly conditioned so that the generation and escape of biogenic gases will not cause the requirement in paragraph IV.6d(1)(b) to be exceeded and that biodegradation within the facility will not result in premature structural failure in violation of the requirements in paragraph IV.6d(a). (d) Ground water protected in accordance with legally applicable Federal and State standards. (e) Access to a property and use of onsite material contaminated by residual radioactive material controlled through appropriate administrative and physical controls such as those described in 40 CFR Part 192 for Uranium Mill Tailings designed to be effective to the extent reasonable for at least 200 years. 2) In addition, long-term management of other radionuclides shall be in accordance with Chapters II, III, and IV of DOE 5820.2A, as applicable.	TBC	All remedial actions will provide for the long term storage of contaminated materials. Remedial alternatives under land use 2, 3, and 4 involve the long term management of radioactive materials. DOE orders are not ARARs because they are not promulgated. This DOE order is a TBC because all alternatives have the potential to result in exposure to members of the public. 10 CFR 834 is included as a TBC because it is presently a proposed rule.

TABLE B.1 (Continued)
OPERABLE UNIT 5 CHEMICAL-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
AIR			
National Emissions Standards for Emissions of Radionuclides Other than Radon From DOE Facilities			
National Emission Standards for Hazardous Air Pollutants 40 CFR §61.190, 61.192 Subpart Q	No source at a DOE facility shall emit more than 20 pCi/m²s of radon-222 as an average for the entire source, into the air.	Applicable	This requirement is applicable because the FEMP presently and/or will continue to be a storage and disposal facility for radium-bearing material. This requirement explicitly includes the FEMP in its designation of facilities.
National Emission Standards for Hazardous Air Pollutants 40 CFR §61.90, 61.91 and 61.92 - .97 Subpart H	These requirements are applicable to DOE owned and operated facilities that emit any radionuclides other than radon-222 and radon-220 into the air. Emissions of radionuclides (except radon-220 and radon-222) to the ambient air from Department of Energy facilities shall not exceed those amounts that would cause any member of the public to receive in any year an effective dose equivalent of 10 mrem/yr. To determine compliance with the standard, radionuclide emissions shall be determined and effective dose equivalent values to members of the public calculated using EPA approved sampling procedures, computer models CAP-88 or AIRDOS-PC, or other procedures for which EPA has granted prior approval.	Applicable	All remedial alternatives have the potential to release radionuclides to the atmosphere through fugitive dust and/or point source emissions.
Control of Radon Emissions			
Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings 40 CFR §192.06 (b) Subpart A 40 CFR §192.32 (b)(1)(ii) Subpart D National Emission Standards for Hazardous Air Pollutants, Radon-222 Emissions 40 CFR 61, Subpart Q	The following standards apply to the: • Control of residual radioactive materials from inactive uranium processing sites. • Management of uranium byproduct materials after closure of a disposal area. • Long-term management of uranium, thorium, and their decay products. Controls shall be designed to provide reasonable assurance that releases of radon-222 from the above materials to the atmosphere will not: • Exceed an average release rate of 20 pCi/m²/s (averaged over the entire surface of the disposal site and over at least a one year period). • Increase the annual average concentration of radon-222 in air or above any location outside the disposal site by more than 0.5 pCi/L.	Relevant and Appropriate	Radioactive materials in this operable unit are as a result of releases from uranium processing. Contaminated soil and sediment are similar in characteristic to materials addressed by these regulations. Requirements for design of controls for on-property disposal should be consistent with design for control of other residual radioactive materials such as mill tailings.

TABLE B.1 (Continued)
OPERABLE UNIT 5 CHEMICAL-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
AIR EMISSION STANDARDS			
Lead in Air EPA Regulations on National Primary and Secondary Ambient Air Quality Standards 40 CFR 50.12 Ohio Ambient Air Quality OAC 3745-17-08	Lead and its compounds measured as elemental lead should not exceed 1.5 micrograms per cubic meter, maximum arithmetic mean averaged over a calendar quarter.	Relevant and Appropriate	The Federal regulation at 40 CFR 50.12 is relevant and appropriate because it sets a standard for lead in air and lead has been identified as a contaminant of concern at OU5. All alternatives contemplating action have a potential to release quantities of lead bearing soil as fugitives during excavation and disposal operations. Additionally, lead could be a contaminant in particulate emissions from point source discharges from sludge dewatering and soil treatment/stabilization.
Definition of Derived Concentration Guides for Radionuclides DOE Order 5400.5 Chapter III 10 CFR 834 (PROPOSED)	The derived concentration guides (DCGs) are provided as reference values for conducting radiological environmental protection programs at operational DOE facilities and sites. • Ingestion of water • Inhalation of air • immersion in a gaseous cloud The DCG values for internal exposure are based on a committed effective dose equivalent of 100 mrem for the radionuclide taken into the body by ingestion or inhalation during one year. The DCG values account for only three exposure pathways (ingested water <u>or</u> inhaled air <u>or</u> air immersion) and do not include other potentially significant pathways. When more complex environmental pathways are involved, a more complete pathway analysis is required for calculating public radiation doses resulting from the operation of DOE facilities.	TBC	DOE orders are not ARARs because they are not promulgated. This DOE order is a TBC because all alternatives have the potential to result in exposure to members of the public. 10 CFR 834 is included as a TBC because it is presently a proposed rule.

TABLE B.1 (Continued)
OPERABLE UNIT 5 CHEMICAL-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter III 10 CFR 834 (PROPOSED)	Residual concentrations of radionuclides in air in an uncontrolled area are limited to the following (for known mixtures of radionuclides, the sum of the ratios of the observed concentration of each radionuclide to its corresponding limit must not exceed 1.0). Derived Concentration Guide[a] (μCi/mL) ISOTOPE — D — W — Y Actinium-227: 2 x 10^{15} — 7 x 10^{15} — 1 x 10^{14} Lead: 9 x 10^{15} — — Polonium-210: 1 x 10^{12} — 1 x 10^{12} — — Protactinium-231: — — 9 x 10^{15} — 1 x 10^{14} Radium-224: — — 4 x 10^{12} — — Radium-226: — — 1 x 10^{12} — — Radium-228: — — 3 x 10^{12} — — Technetium-99: 1 x 10^{8} — 2 x 10^{9} — — Strontium-90[c]: 5 x 10^{11} — — Thorium-228: — — 5 x 10^{14} — 4 x 10^{14} Thorium-230: — — 4 x 10^{14} — 5 x 10^{14} Thorium-232: — — 7 x 10^{15} — 1 x 10^{14} Uranium-234: 4 x 10^{12} — 2 x 10^{12} —	TBC	DOE orders are not ARARs because they are not promulgated. This DOE order is a TBC because all alternatives have the potential to result in exposure to members of the public. 10 CFR 834 is included as a TBC because it is presently a proposed rule.
Derived Concentration Guides for Radionuclides DOE Order 5400.5 Chapter III,3. 10 CFR 834 (PROPOSED)	The DCGs are given for different lung retention classes (noted as D,W, or Y, where D equals a removal half-time of 0.5 days, W equals a removal half-time of 50 days, and Y equals a removal half-time of 500 days). Derived Concentration Guide[a] ISOTOPE — D — W — Y Uranium-235: 5 x 10^{12} — 2 x 10^{12} — 1 x 10^{13} Uranium-236: 5 x 10^{12} — 2 x 10^{12} — 1 x 10^{13} Uranium-238: 5 x 10^{12} — 2 x 10^{12} — 1 x 10^{13} Exposure conditions assume an inhalation rate of 8,400 m^3 of air per year (based on an exposure over 24 hours per day, 365 days per year).	TBC	DOE orders are not ARARs because they are not promulgated. This DOE order is a TBC because all alternatives have the potential to result in exposure to members of the public. 10 CFR 834 is included as a TBC because it is presently a proposed rule.

TABLE B.1 (Continued)
OPERABLE UNIT 5 CHEMICAL-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
SOIL AND CONTAMINATED MATERIALS			
Cleanup of Soil Contaminated with Residual Radioactive Materials			
Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings 40 CFR 192.02 Subpart A 40 CFR 192.12(a) Subpart B 40 CFR 192.20 Subpart C	Remedial actions shall be conducted so as to provide reasonable assurance that, as a result of residual radioactive materials, the concentration of radium-226 in land averaged over any area of 100 m^2 shall not exceed the background level by more than: • 5 pCi/g averaged over the first 15 cm of soil below the surface, and • 15 pCi/g, averaged over 15-cm-thick layers of soil more than 15 cm below the surface. Compliance with this requirement should be shown through measurements performed within the accuracy of currently available types of field and laboratory instruments in conjunction with reasonable survey and sampling procedures.	Relevant and Appropriate	The contaminated materials associated with OU5 are similar in characteristics to uranium mill tailings (UMT). This regulation is not applicable as the FEMP is not a designated UMT facility. This standard is relevant and appropriate to all remedial alternatives.
Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings 40 CFR 192.21 (f) and 192.22 (b) Subpart C	Where radionuclides other than radium-226 and its decay product are present in sufficient quantity and concentration to constitute a significant radiation hazard from residual radioactive materials, remedial actions shall, in addition to satisfying the standards of 40 CFR 192.02, Subpart A and 192.12, Subpart B (both listed above), reduce other residual radioactivity to levels that are as low as is reasonably achievable.	Relevant and Appropriate	Contaminated material associated with OU5 are similar in characteristics to uranium mill tailings. This standard is relevant and appropriate to all remedial alternatives.
Post Closure Standards for Uranium and Thorium Mill Tailings 40 CFR 192.32 (b)(2) Subpart D	The requirements for the management of uranium byproduct materials after closure of a disposal area (40 CFR 192.32 (b)(1)) shall not apply to any portion of a disposal site which contains a concentration of radium-226 in land, averaged over areas of 100m^2, which, as a result of uranium byproduct material, does not exceed the background level by more than: • 5 pCi/g averaged over the first 15 cm of soil below the surface, and • 15 pCi/g, averaged over 15-cm-thick layers of soil more than 15 cm below the surface.	Relevant and Appropriate	Contaminated materials associated with OU5 are similar in characteristics to uranium mill tailings. This standard is relevant and appropriate to all remedial alternatives.
Management of Thorium Mill Tailings 40 CFR 192.40-192.42 Subpart E	The following are requirements for the management of thorium byproduct materials: • The provisions for the management of uranium byproduct material (40 CFR §192.32) shall apply to thorium byproduct material and: - Provisions applicable to the element uranium shall also apply to the element thorium - Provisions applicable to radon-222 shall also apply to radon-220 - Provisions applicable to radium-226 shall also apply to radium-228 With the concurrence of EPA, alternative provisions may be substituted for any of the above requirements provided the alternative provisions will provide at least an equivalent level of protection for human health and environment.	Relevant and Appropriate	Contaminated material associated with OU5 are similar in characteristics to uranium mill tailings. This standard is relevant and appropriate to all remedial alternatives.

TABLE B.1 (Continued)
OPERABLE UNIT 5 CHEMICAL-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
	Hot Spots		
Radiation Protection of the Public and the Environment in soil DOE Order 5400.5 Chapter IV (4)(a)(1) 10 CFR 834 (PROPOSED)	If the average residual concentration of radionuclides in any surface soil or below surface area less than or equal to 25 m^2, exceeds the limit or guideline by a factor of$(100/A)^{0.5}$ [where A is the area (in square meters) of the region in which the concentrations are elevated], limits for "hot spots" shall also be developed and applied. Procedures for calculating these hot spots limits, which depend on the extent of the elevated local concentrations, are given in DOE/CH-8901. In addition, reasonable efforts shall be made to remove any source of radionuclide that exceeds 30 times the appropriate limit in the soil, irrespective of the average concentration in the soil.	TBC	All OU5 alternatives involve the excavation of contaminated soil and sediment. DOE Orders provide guidance on addressing contaminated soil and sediment at DOE facilities. DOE orders are TBC rather than ARARs because they are not promulgated. 10 CFR 834 is included as a TBC because it is presently a proposed rule.
Radiation Protection of the Public and the Environment DOE Order 5400.5 Chapter IV (4)(a)(2)(3) 10 CFR 834 (PROPOSED)	The generic guidelines for residual concentrations of radium-226, radium-228, thorium-230, and thorium-232 are: • 5 pCi/g, averaged over the first 15 cm of soil below the surface; and • 15 pCi/g, averaged over 15-cm-thick layers of soil more than 15 cm below the surface. These guidelines take into account ingrowth of radium-226 from thorium-230 and of radium-228 from thorium-232, and assume secular equilibrium. If both thorium-230 and radium-226, or both thorium-232 and radium-228, are present and not in secular equilibrium, the appropriate guideline is applied as a limit for the radionuclide with the higher concentration. If other mixtures of radionuclides occur, the concentrations of individual radionuclides shall be reduced so that either the dose for the mixture will not exceed the basic dose limit or the sum of the ratios of the soil concentration of each radionuclide to the allowable limit for that radionuclide will not exceed 1. Explicit formulas for calculating residual concentrations guidelines for mixtures are given in DOE/CH-8901.	TBC	Radionuclides are Constituents of Concern for soil within the scope of OU5. All OU5 actions except the no action alternative involve excavation of soil contaminated with these Constituents of Concern. DOE orders are TBC rather than ARARs because they are not promulgated. This citation is included as a TBC as it is more restrictive than the federal standard in 40 § CFR 192, .02, .12(a), .20, .21(f), .22(b), .32(b)(2), .40-.42. 10 CFR 834 is included as a TBC because it is presently a proposed rule.
Guidelines for Residual Radioactive Material--Surface contamination DOE Order 5400.5, Chapter IV (4)(d) 10 CFR 834 (PROPOSED)	These generic surface contamination guidelines are applicable to existing structures and equipment. These guidelines are generally consistent with standards of the NRC (1982) and functionally equivalent to Section 4, "Decontamination for Release for Unrestricted Use," of Regulatory Guide 1.86, but apply to nonreactor facilities. These limits apply to both interior equipment and building components that are potentially salvageable or recoverable scrap. If a building is demolished, the guidelines in paragraph IV (6)(a) are applicable to the resulting contamination in the ground.	TBC	These criteria will be used for any process facility building built and/or used for the remedial action, including the AWWT, soil washing, soil staging, etc., structures and buildings. DOE orders are not ARARs because they are not promulgated. This DOE order is a TBC because all alternatives have the potential to result in structures and equipment containing residual radioactivity. 10 CFR 834 is included as a TBC because it is presently a proposed rule.

TABLE B.1 (Continued)
OPERABLE UNIT 5 CHEMICAL-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
Lead Soil Cleanup Standards			
Resource Conservation and Recovery Act 40 CFR 268.41	The maximum concentration of lead (5.0 mg/L) may not be exceeded whether it is the extract of a waste or waste treatment residual.	Applicable	Lead is a Constituent of Concern in soil and sediment in OU5. This requirement is applicable to all remedial alternatives.
Revised Interim Soil Lead Guidance for CERCLA Sites and RCRA Corrective Action Facilities OSWER Directive # 9355.4-12	• Screening levels of lead in soil for residential land use is proposed for 400 ppm; • Site-specific preliminary remediation goals (PRGs) at CERCLA sites and media cleanup standards (MCLs) at RCRA Corrective Action facilities for residential land use are described and, • A plan for soil lead cleanup at CERCLA sites and RCRA Corrective Action facilities that have multiple sources of lead are described.	TBC	This policy is not ARAR because it is not a promulgated regulation. This interim directive is a TBC because it establishes an approach for determining protective levels for lead in soil at CERCLA sites and RCRA facilities that are subject to corrective action under RCRA Section 3004(v) or 3008(h).
PCB Soil Cleanup Standards			
PCB Spill Cleanup Policy 40 CFR 761.125 40 CFR 761.125 (c)	PCBs at concentration of greater than 50 ppm are subject to TSCA decontamination requirements in 40 CFR 761.120 (b). Soil in non-restricted access areas contaminated by a PCB spill will be decontaminated to 10 ppm PCBs by weight, provided that the soil is excavated to a minimum depth of 10 inches. The excavated soil will be replaced with clean soil, i.e., containing less than 1 ppm PCBs, and the spill site will be restored (e.g., replacement of turf) [761.125 (c)(4)(v)]. For soils in restricted access areas, decontaminate to 25 ppm PCBs by weight [761.125(c)(3)(v)].	TBC	PCBs are a Constituent of Concern in soil for OU5. Concentrations of PCBs at OU5 are expected to be less than 50 ppm. Although published in the Code of Federal Regulations, this is a policy, not a promulgated rule, and hence a TBC. This TBC is pertinent to all remedial alternatives and will be considered relative to Operable Unit 5 PRLs for soil containing PCBs as CERCLA wastes, per the NCP.

TABLE ARAR B.2

OPERABLE UNIT 5 LOCATION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
THREATENED & ENDANGERED SPECIES			
HABITAT PROTECTION			
Procedures for Implementing the National Environmental Policy Act 40 CFR §6.302(h) 10 CFR 1021 Endangered Species Act 16 U.S.C. §1531, et. seq. Endangered and Threatened Wildlife and Plants 50 CFR §17.21, §17.31, §17.61, §17.71, and §17.94 Interagency Cooperation-Endangered Species Act 50 CFR §402.01	All Federal agencies must ensure that any action authorized, funded, or carried out by them is not likely to jeopardize the continued existence of any listed species or result in the destruction or adverse modification of the constituent elements essential to the conservation of a listed species within a defined critical habitat. Additional requirements apply if it is determined that a proposed activity could adversely affect these species or their habitat.	Applicable	In 1993 and 1994 updated surveys at the FEMP determined the presence of the state-listed Sloan's Crayfish (Orconectes sloanii) in Paddys Run. Additionally, it was determined that good habitat exists for the federally-listed endangered Indiana bat (Myotis sodalis) along Paddys Run and the storm sewer outfall ditch. Moderate and original habitat exist in a very limited area for the state-listed endangered cave salamander (Eurycea lucifuga). Surveys did not locate habitat or populations for the federally-listed endangered running buffalo clover (Trifolium stoloniferum) or the state-listed endangered mountain bindweed (Polygonum cilinode) and slender fingergrass (Digitaria filiformis). In addition, neither habitat or populations of the state-listed threatened spring coralroot (Corallorhiza wisteriana) were found on FEMP property.
Interagency Cooperation-Endangered Species Act 50 CFR §402.12 (a),(b)	A biological assessment shall evaluate the potential effects of the action on listed and proposed critical habitat and determine whether any such species or habitat are likely to be adversely affected by the action and is used in determining whether formal consultation or a conference is necessary.	Applicable	These procedures are required for Federal actions that are "major construction activities".

TABLE B.2 (Continued)
OPERABLE UNIT 5 LOCATION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
SPECIES PROTECTION			
Ohio Endangered Species Regulations ORC 1531.25	No person shall take or possess any native species of wild animal, or any eggs, or offspring thereof, that is endangered with state-wide extinction.	Applicable	Updated surveys in 1993-94 found state-listed threatened Sloan's crayfish (Orconects sloanii) populations in sections of Paddys Run. Moderate habitat for the state-listed endangered cave salamander (Eurycea lucifuga) was also determined during a 1993 survey of the FEMP.
Ohio Endangered Species Regulations ORC 1518.02 OAC 1501:18-1	No person shall root-up, injure, destroy, remove, or carry away on or from public highways, public property, or waters of the state, or on or from the property of another, without the written permission of the owner, lessee, or other person entitled to possession, any endangered plant listed in OAC 1501:18-1.	Applicable	Surveys in 1994 did not locate the federally-listed endangered running buffalo clover (Trifolium stoloniferum), the state-listed endangered mountain bindweed (Polygonum cilinode) or slender finger grass (Digitaria filiformis), or state-listed threatened spring coralroot (Corallorhiza wisteriana).
Classification of Solid Waste Disposal Facilities and Practices 40 CFR §257.3-2	Solid waste disposal facilities or practices shall not cause or contribute to the taking of any endangered or threatened species of plants, fish, or wildlife. Solid waste disposal facilities or practices shall not result in the destruction or adverse modification of the critical habitat of endangered or threatened species as identified in 50 CFR Part 17.	Applicable	This regulation is applicable to alternatives involving the use of capping systems or engineered cells.

HISTORIC AND CULTURAL RESOURCE PROTECTION

ANTIQUITY AND HISTORIC SITE PRESERVATION			
Antiquities Act of 1906 16 U.S.C. §431-433 and Historic Sites Preservation Act 16 U.S.C. §461-467	No person may appropriate, excavate, injure, or destroy any historic or prehistoric ruin or monument, or any object of antiquity situated or controlled by the Government of the United States without an applicable permit. Identification and preservation of cultural resources on federal lands is required, including natural land marks.	Applicable	Proposed areas of disturbance associated with Operable Unit 5 remedial actions will be surveyed and the Advisory Council on Historic Preservation and the State Historic Preservation Office (SHPO) will be consulted as agreed upon in a programmatic agreement with DOE, SHPO, and the Advisory Council. This regulation is applicable to all alternatives contemplating soil excavation, which include all except No Action.

TABLE B.2 (Continued)
OPERABLE UNIT 5 LOCATION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
ARCHAEOLOGICAL RESOURCE RECOVERY AND PRESERVATION			
Procedures for Implementing the National Environmental Policy Act 40 CFR §6.301 (c) Archaeological Resources Protection Act (16 USC § 47099-47011) Protection of Archaeological Resources 43 CFR §7.4(a)	No person may excavate, remove, damage, or otherwise alter or deface or attempt to excavate, remove, damage, or otherwise alter or deface any archaeological resource located on public lands unless such activity is pursuant to a permit.	Applicable	Compliance will be coordinated through Section 106 of the National Historic Preservation Act.
HISTORIC PRESERVATION			
National Historic Preservation Act 16 USC § 470C Consideration of Historic Properties 36 CFR Part 800	DOE must take into account the effect of an undertaking on Historic Properties and accord the Advisory Council on Historic Preservation a reasonable opportunity to comment. Historic properties are defined as any prehistoric or historic district, building, site, structure, or object included in or eligible for inclusion in, the National Register of Historic Places. This term includes artifacts, records, and persons released to and located within such properties. Historic properties that are to be substantially altered or demolished must be recorded for future use and reference.	Applicable	Proposed areas of disturbance associated with Operable Unit 5 remedial activities will be surveyed to determine applicable requirements and the Advisory Council will be consulted as agreed upon in a programmatic agreement with DOE, SHPO, and the Advisory Council. This requirement is applicable to all remedial alternatives except the no action alternative.
Archaeological and Historic Preservation Act 16 U.S.C. §469, §470	Upon discovery that a project may cause the irreparable loss, destruction, significant scientific finding, prehistorical finding, or loss of historical or archeological data, DOE must notify DOI in writing and provide appropriate information concerning the project. DOE must, with possible assistance from SHPO, undertake recovery, protection, and preservation of the data.	Applicable	See previous comment.

TABLE B.2 (Continued)
OPERABLE UNIT 5 LOCATION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
HISTORIC PRESERVATION (Continued)			
American Indian Religious Freedom Act, 42 U.S.C. §1996	Provides for tribal access by native peoples to grave sites and sites of cultural, symbolic, or religious significance.	Applicable	See previous comment.
Executive Order 11593, Protection and Enhancement of Cultural Environment 3 CFR 54	An inventory of a site with potential historic places is required for eligibility in the National Register of Historic Places.	Applicable	See previous comment.
Native American Graves Protection and Repatriation Act 25 U.S.C. §3001	Identification and preservation of cultural resources on federal lands is required, including natural landmarks. DOE must consult with appropriate Indian tribes prior to the intentional excavation or removal after an inadvertent discovery of Native American cultural items including human remains and objects of cultural significance.	Applicable	See previous comment.

SENSITIVE ENVIRONMENTAL LOCATIONS

FLOODPLAIN/WETLANDS			
DOE Compliance with Floodplain/Wetlands Environmental Review Requirements 10 CFR §1022.11 (a), (b), (c)	Concurrent with its review of a proposed action to determine appropriate NEPA requirements, DOE shall determine applicability of the floodplain management and wetlands protection requirements of this part. In making a floodplain determination, DOE shall utilize the Flood Insurance Rate Maps (FIRMs) or the Flood Hazard Boundary Maps (FHBMs) prepared by the Federal Insurance Administration of the Department of Housing and Urban Development to determine if a proposed action is located in the base or critical action floodplain, as appropriate. For a proposed action in an area of predominately Federal or State land holdings where FIRM or FHBM maps are not available, information shall be sought from the land administering agency (e.g., Bureau of Land Management, Soil Conservation Service, etc.) or from agencies with floodplain analysis expertise.	Applicable	Review will be conducted concurrently with NEPA determinations for proposed actions. This requirement is applicable to all remedial alternatives except the no action alternative.

TABLE B.2 (Continued)
OPERABLE UNIT 5 LOCATION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
FLOODPLAIN/WETLANDS (Continued)			
DOE Compliance with Floodplain/Wetlands Assessments 10 CFR §1022.12(a)	Prior to any proposed remedial action, DOE shall prepare a floodplain/wetlands assessment.	Applicable	Floodplain/wetland assessments will be prepared as required. This requirement is applicable to all remedial alternatives except the no action alternative.
DOE Compliance with Floodplain/Wetlands Environmental Review Requirements 10 CFR §1022.15(a)	If DOE finds that no practicable alternative to locating in the floodplain/wetland is available, consistent with the policy set forth in Executive Order 11988, DOE shall, prior to taking action, design, or modify its action in order to minimize potential harm to or within the floodplain or wetland.	Applicable	Floodplain/wetland impacts will be avoided and minimized to the maximum extent practicable. This requirement is applicable to all remedial alternatives except the no action alternative.

TABLE B.2 (Continued)
OPERABLE UNIT 5 LOCATION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
FLOODPLAIN/WETLANDS (Continued)			
DOE Compliance with Floodplain/Wetlands Environmental Review Requirements 10 CFR §1022.3(a), (b)(1),(2),(3),(5),(6),(c), (d),(e)	DOE shall exercise leadership and take action to: • Avoid to the extent possible the long- and short-term adverse impacts associated with the destruction of wetlands and the occupancy and modification of floodplain and wetlands, and avoid direct and indirect support of floodplain and wetlands development wherever there is a practicable alternative. • Incorporate floodplain management goals and wetlands protection considerations into its planning, regulatory, and decision making processes and shall to the extent practicable: - Reduce the hazard and risk of flood loss. - Minimize the impact of floods on human safety, health, and welfare. - Restore and preserve natural and beneficial values served by the floodplain. - Minimize the destruction, loss, or degradation of wetlands. - Preserve and enhance the natural and beneficial values of wetlands. • Undertake a careful evaluation of the potential effects of any DOE action taken in a floodplain and any new construction undertaken by DOE in wetlands not located in a floodplain. • Identify, evaluate, and as appropriate, implement alternative actions which may avoid or mitigate adverse floodplain/wetlands impacts. • Provide opportunity for early public review of any plans or proposals for actions in floodplain and new construction in wetlands.	Applicable	Short and long term impacts associated with Operable Unit 5 remedial activities will be avoided and minimized to the maximum extent practicable. This requirement is applicable to all remedial alternatives except the no action alternative.
DOE Compliance with Floodplain/Wetlands Environmental Review Requirements 10 CFR §1022.5(b),(h)	This part shall apply to all proposed floodplain/wetlands actions, including those sponsored jointly with other agencies, where practicable alternatives to the proposed actions are still available. The policies and procedures of this part which are applicable to floodplain actions shall apply to all proposed actions which occur in a wetlands located in a floodplain.	Applicable	Short and long term impacts associated with Operable Unit 5 remedial activities will be avoided and minimized to the maximum extent practicable. This requirement is applicable to all remedial alternatives except the no action alternative.

TABLE B.2 (Continued)
OPERABLE UNIT 5 LOCATION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
WETLANDS			
Procedure for Implementing the National Environmental Policy Act 40 CFR §6.302(a) [Executive Order 11990]	Federal agencies conducting certain activities must avoid, to the extent possible, the adverse impacts associated with the destruction or loss of wetlands and to avoid support of new construction in wetlands when a practicable alternative exists.	Applicable	Approximately 35.9 acres of jurisdictional wetlands and 8.9 acres of waters of the United States were identified on-site as a result of the 1993 FEMP Wetland Delineation. The U.S. Army Corps of Engineers officially approved the delineation on August 19, 1993. Wetland impacts associated with Operable Unit 5 remedial activities will be minimized and avoided to the maximum extent practicable. This requirement is applicable to all remedial alternatives except the no action alternative.
Executive Order 11990, Protection of Wetlands	This order requires that Federal agencies take action to avoid adversely impacting wetlands wherever possible, to minimize wetland destruction and to preserve the values of wetlands.	Applicable	Wetland impacts associated with Operable Unit 5 remedial activities will be avoided and minimized to the maximum extent practicable. This requirement is applicable to all remedial alternatives except the no action alternative.
Nationwide Permit Program, 33 CFR §330	The U.S. Army Corps of Engineers has authorized certain categories of activities involving the discharge of dredged and fill material into wetlands and waters of the U.S. under the Nationwide Permit (NWP) Program. Impacts involving the discharge of dredged and fill material will be conducted in accordance with the substantive requirements of applicable NWPs as required. Discharges not authorized by NWP will be conducted in accordance with the substantive requirements of 33 CFR 323 and 40 CFR 230.	Applicable	Approximately 35.9 acres of jurisdictional wetlands and 8.9 acres of waters of the United States have been identified on-site. Impacts to these areas will be avoided and minimized to the maximum extent practicable. Discharges of dredged and fill material authorized by NWPs will be conducted in accordance with the substantive requirements of the respective permits. This requirement is applicable to all remedial alternatives except the no action alternative.
Permits for the Discharge of Dredged and Fill Material into waters of the United States 33 CFR §323	Remedial actions involving the discharge of dredge and fill material into these areas shall meet the substantive requirements of this section and 40 CFR §230.	Applicable	Discharges of dredged and fill material not authorized by NWP will be conducted in accordance with the substantive requirements of these regulations. This requirement is applicable to all remedial alternatives except the no action alternative.

TABLE B.2 (Continued)
OPERABLE UNIT 5 LOCATION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
WETLANDS (Continued)			
Section 404(b)(1) Guidelines for Specification of Disposal Sites for Dredged and Fill Material, 40 CFR §230	40 CFR 230 sets guidelines for evaluation of discharges of dredged and fill material into wetlands and waters of the U.S. The requirements specify that no discharge of dredged or fill material shall take place unless the permit authorizing agency makes a determination of the short-term effects of the discharge on the environment of the site, and if: 1. There is no practicable alternative to the action; 2. A State Water Quality Standard will not be violated; and 3. It does not contribute to or causes the significant degradation of waters of the United States.	Applicable	Discharges of dredged and fill material associated with Operable Unit 5 remedial actions will be evaluated and conducted against the substantive requirements of these regulations. This requirement is applicable to all remedial alternatives except the no action alternative.
Section 401 State Water Quality Certifications, OAC 3745-32	Section 401 State Water Quality Certification is required to conduct dredged and fill activities within wetlands or waters of the U.S. State Water Quality Certification is granted provided: 1. The discharge does not prevent or interfere with the attainment or maintenance of applicable water quality standards; and 2. The discharge does not result in a violation of any applicable provisions of CWA.	Applicable	Discharges of dredged and fill material associated with Operable Unit 5 remedial actions will meet the substantive requirements of these regulations. This requirement is applicable to all remedial alternatives except the no action alternative.
Protection of Wetlands 40 CFR §258.12	New municipal solid waste landfill units must not be located in wetlands unless Ohio approves otherwise.	Applicable	Wetland impacts associated with Operable Unit 5 remedial actions will be avoided and minimized to the maximum extent practicable. This requirement is applicable to all remedial alternatives except the no action alternative.
Ohio Solid Waste Disposal Regulations OAC 3745-27-07 (G)(15)	A solid waste disposal facility may not be located in a floodway.	Applicable	Floodway impacts associated with Operable Unit 5 remedial activities will be avoided and minimized to the maximum extent practicable. This requirement is applicable to all remedial alternatives except the no action alternative.
Ohio Solid Waste Disposal Regulations OAC 3745-27-07 (H)(4)(d)	The limits of waste placement cannot be located within 200 feet of a stream, lake, or natural wetland, unless deemed acceptable by the Director of the OEPA.	Applicable	Wetland impacts associated with Operable Unit 5 remedial actions will be avoided and minimized to the maximum extent practicable. This requirement is applicable to all remedial alternatives except the no action alternative.

TABLE B.2 (Continued)
OPERABLE UNIT 5 LOCATION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
FLOODPLAINS			
Ohio Solid Waste Disposal Regulations OAC 3745-27-07 (G)(15)	The limits of solid waste placement and the leachate management system cannot be located in a regulatory floodplain, unless deemed acceptable by the Director of the OEPA.	Applicable	Several remedial alternatives involve the siting of a solid waste disposal facility. This requirement is applicable to all alternatives contemplating use of capping systems or engineered cells.
Ohio Solid Waste Disposal Regulations OAC 3745-29-07 (G)(15)	The limits of solid waste placement and the leachate management system cannot be located in a regulatory floodplain, unless deemed acceptable by the Director of the OEPA.	Applicable	Several remedial alternatives involve the siting of a solid waste disposal facility. This requirement is applicable to all alternatives contemplating the use of capping systems or engineered cells.
Procedures for Implementing the National Environmental Policy Act 40 CFR §6.302(b)	Federal agencies must evaluate the potential effects of actions they may take in a floodplain to avoid, to the extent possible, adverse effects associated with direct and indirect development of a floodplain.	Applicable	Floodplain impacts associated with Operable Unit 5 remedial activities will be avoided and minimized to the maximum extent practicable. This requirement is applicable to all remedial alternatives except the no action alternative.
Floodplain Management Executive Order 11988	This order requires Federal agencies undertaking actions within a floodplain to evaluate the potential action has for adverse impact on the floodplain. If it is determined that adverse impacts could occur, the effects of the action must be minimized to the extent practical.	Applicable	Floodplain impacts associated with Operable Unit 5 remedial activities will be avoided and minimized to the maximum extent practicable. This requirement is applicable to all remedial alternatives except the no action alternative.
SOLID WASTE SITING CRITERIA			
SOLE SOURCE AQUIFERS			
Siting Over a Sole Source Aquifer Safe Drinking Water Act 42 U.S.C. §1424(e)	All Federal financially assisted projects constructed in the area of a sole source aquifer and its principal recharge zone will be subject to EPA's review to insure that these projects are designed and constructed so that they do not create a significant hazard to public health.	Applicable	A notice in 53 FR 15876 (May 4, 1988) designated the Buried Valley Aquifer System of the Great Miami/ Little Miami River Basins of southwestern Ohio as a sole or principal source of drinking water. The Fernald site is located above this aquifer. This requirement is applicable to all remedial alternatives except the no action alternative.
Ohio Solid Waste Disposal Regulations OAC 3745-27-07 (H)(2)(c)	A solid waste landfill facility cannot be located above an aquifer declared by the federal government under the Safe Drinking Water Act to be a sole source aquifer.	Applicable	Several remedial alternatives involve the on-property disposal of solid waste. This requirement is applicable to all alternatives contemplating the use of capping systems or engineered cells.

TABLE B.2 (Continued)
OPERABLE UNIT 5 LOCATION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
SOLE SOURCE AQUIFERS (Continued)			
OEPA Guidance on Solid Waste Siting Criteria: GD202.101	The Director may grant an exemption to the prohibition of siting a sanitary landfill facility over a sole source aquifer (OAC 3745-27-07(H)(2)(c)) under ORC 3743.02(G). In order to grant an exemption, the Director needs to determine that no adverse impact to human health or safety or the environment will occur due to granting the exemption. The decision to grant an exemption from this rule is made on a site by site basis. Among the items that should be considered when determining if a waiver will be granted are whether a significant thickness of low permeable material exists between the sanitary landfill facility liner and the sole source aquifer and whether there is an inter-connection between the sole source aquifer and any significant saturated zones which exist above the sole source aquifer.	TBC	Several remedial alternatives involve the on-property disposal of solid waste. This requirement pertains to all alternatives contemplating the use of capping systems or engineered cells.
Ohio Solid Waste Disposal Regulations OAC 3745-27-07 (H)(2)(d)	A sanitary landfill facility cannot be located above an unconsolidated aquifer capable of sustaining a yield of 100 gallons per minute for a 24-hour period to a water supply well located within 1,000 feet of the limits of solid waste placement, unless deemed acceptable by the Director of the OEPA.	Applicable	Several remedial alternatives involve the on-property disposal of solid waste. This requirement is applicable to all alternatives contemplating the use of capping systems or engineered cells.

TABLE B.2 (Continued)
OPERABLE UNIT 5 LOCATION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
SOLE SOURCE AQUIFERS (Continued)			
OEPA Guidance on Solid Waste Siting Criteria: 100 Gallon Per Minute Aquifer GD202.102	An exemption to the prohibition of siting a sanitary landfill facility over an unconsolidated aquifer capable of sustaining a yield of 100 gallons per minute for a 24-hour period (OAC 3745-27-07(H)(2)(d)) may be obtained by demonstrating that the thickness and lack of permeability of the sediment that exists between the bottom of the proposed sanitary landfill facility liner and the top of the unconsolidated high yield aquifer provide adequate protection to the unconsolidated high yield aquifer from the effects of a release of leachate from the sanitary landfill facility. The sediment should prevent leachate from migrating from the bottom of the sanitary landfill facility liner to the high yield aquifer in a time period equal to the active life of the facility including the post-closure care period.	TBC	This guidance is a TBC rather than a ARAR because it is not promulgated. This guidance is a TBC for all alternatives contemplating the use of capping systems or engineered cells.
OTHER SOLID WASTE SITING LIMITATIONS			
Distance from a Public Water Supply Ohio Solid Waste Disposal Regulations OAC 3745-27-07 (H)(3)(a)	A sanitary landfill facility may not be located within the surface and subsurface areas surrounding a public water supply well through which contaminants may move toward and may reach the public water supply well within a period of five (5) years.	Applicable	Several remedial alternatives involve the on-property disposal of solid waste. This requirement is applicable to all alternatives contemplating the use of capping systems or engineered cells.
Ohio Solid Waste Disposal Regulations OAC 3745-27-07 (G)(16)	Limit of solid waste placement and leachate management system are not located within 200 feet of fault that has displacement in Holocene time.	Applicable	Several remedial alternatives involve the on-property disposal of solid waste. This requirement is applicable to all alternatives contemplating the use of capping systems or engineered cells.

TABLE B.2 (Continued)
OPERABLE UNIT 5 LOCATION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
OTHER SOLID WASTE SITING LIMITATIONS (Continued)			
Ohio Solid Waste Disposal Regulations OAC 3745-27-07 (H)(3)(c)	The limits of solid waste placement cannot be located within 1,000 feet of a water supply well or developed spring unless it is deemed acceptable by the Director of the OEPA or it is: • Controlled by the applicant, is needed as a source of nonpotable water, no other reasonable alternate water source is available, and the well is constructed to prevent contamination of the groundwater, or • Located at least 500 feet hydrogeologically upgradient from the limits of solid waste placement, or • Separated from the limits of solid waste placement by a hydrogeologic barrier, or • Constructed and used solely for monitoring groundwater quality.	Applicable	Several remedial alternatives involve the on-property disposal of solid waste. This requirement is applicable to all alternatives contemplating the use of capping systems or engineered cells.
Ohio Solid Waste Disposal Regulations OAC 3745-27-07 (H)(4)(b)	The limits of waste placement cannot be located within 300 feet of the sanitary landfill facility's property line, unless deemed acceptable by the Director of the OEPA.	Applicable	Several remedial alternatives involve the on-property disposal of solid waste. This requirement is applicable to all alternatives contemplating the use of capping systems or engineered cells.
Ohio Solid Waste Disposal Regulations OAC 3745-27-07 (H)(4)(c)	The limits of solid waste placement cannot be located within 1,000 feet of a domicile whose owner has not consented in writing to the location of the sanitary landfill facility.	Applicable	Several remedial alternatives involve the on-property disposal of solid waste. This requirement is applicable to all alternatives contemplating the use of capping systems or engineered cells.
Ohio Solid Waste Disposal Regulations OAC 3745-27-07 (H)(2)(e)	The isolation distance between the uppermost aquifer system and the bottom of the recompacted soil liner of a sanitary landfill system cannot be less than 15 feet of in situ or added geologic material deemed acceptable by the Director of the OEPA.	Applicable	Several remedial alternatives involve the on-property disposal of solid waste. This requirement is applicable to all alternatives contemplating the use of capping systems or engineered cells.

TABLE B.2 (Continued)
OPERABLE UNIT 5 LOCATION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
OTHER SOLID WASTE SITING LIMITATIONS (Continued)			
OEPA Guidance on Solid Waste Siting Criteria: Minimum Distance From a Public Water Supply Well GD202.105	The minimum distance to a public water supply well (OAC 3745-27-07 (H)(3)(c)) will be considered by the application of this criteria: - The five year time of travel shall be calculated between the boundary of the solid waste landfill facility and the closest public water supply. A period of no less than 5 years will be required before ground water flowing in a downgradient direction from the facility can intersect with a public water supply well screen. - To be considered for an exemption from this rule, the following will need to be demonstrated: - That there is at least 50 feet of separation between the bottom of the solid waste landfill facility liner and the aquifer system in which the public water supply well is screened. - That any release of leachate shall be detected prior to reaching the aquifer system in which the public water supply well is screened. - That once leachate is released below the liner, the leachate shall not reach the aquifer system in which the public water supply well is screened within a time span of 100 years plus the anticipated life of the solid waste landfill facility which shall include the 30 year post-closure care period.	TBC	Several remedial alternatives involve the on-property disposal of solid waste. This guidance is a TBC rather than a ARAR because it is not promulgated. This guidance is a TBC for all alternatives contemplating the use of capping systems or engineered cells. A public water supply exists outside of the 5-year time of travel from the FEMP property boundary. In addition, this public water supply system will be removed in the near future.
OEPA Guidance on Solid Waste Siting Criteria: Minimum Isolation Distances to Wells and Developed Springs GD0202.103	This guidance clarifies when exceptions to the required 1,000 foot isolation distance from water supply wells and developed springs (OAC 3745-27-07 (H)(3)(c)) apply and when a situation contrary to the rule can be deemed acceptable to the Director of the OEPA.	TBC	This guidance is a TBC rather than a ARAR because it is not promulgated. This guidance is a TBC for all alternatives contemplating the use of capping systems or engineered cells.

TABLE B.2 (Continued)
OPERABLE UNIT 5 LOCATION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
OTHER SOLID WASTE SITING LIMITATIONS (Continued)			
OEPA Guidance on Solid Waste Siting Criteria: Material Acceptable to the Director GD202.104	For geologic material to be deemed acceptable to the Director of the OEPA as added fill under OAC Rule 3745-27-07 (H)(2)(e), it must be able to meet the following criteria: • The geologic material must be impermeable enough so it will not store, transmit or yield a significant amount of water to a well or spring • The geologic material must be able to impede both physically and chemically, the flow of leachate constituents through it In order to meet both criteria listed above, the added geologic material should: • Be classified as CL, SC, GC, CL-ML, or CH under the Unified Soil Classification System (USCS) • Be composed of particles of which at least 25% by dry weight will pass through a No. 200 (75 μm) sieve • Be composed of no more than 25% by dry weight particles which will not pass through a No. 4 sieve • No particle should be greater than 8 inches in diameter • Have a final permeability of no more than 1×10^{-5} cm/sec • Be recompacted in a manner that when the landfill is constructed on it, no damage to the landfill liner will occur due to settling of the added material	TBC	This guidance is a TBC rather than a ARAR because it is not promulgated. This guidance is a TBC for all alternatives contemplating the use of capping systems or engineered cells.

TABLE B.2 (Continued)
OPERABLE UNIT 5 LOCATION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Rationale
HAZARDOUS WASTE			
LOCATION OF HAZARDOUS WASTE FACILITIES			
Hazardous Waste Facility Environmental Impact OAC 3745.05(D)(6)(c)	A hazardous waste facility installation and operation permit shall not be approved unless it proves that the facility represents the minimum adverse environmental impact, considering the state of available technology, the nature and economics of various alternatives and other pertinent considerations	Applicable	This requirement is applicable for several alternatives which consider treatment, storage, or disposal of hazardous wastes if HWMUs are to be constructed during remediation. This requirement may serve as a siting criteria.
Hazardous Waste Facility Minimum Risk OAC 3745.05(D)(6)(d)	A hazardous waste facility installation and operation permit shall not be approved unless it proves that the facility represents the minimum risk of all the following: 1) contamination of groundwater and surface waters; 2) fires or explosions from treatment, storage, or disposal methods; 3) accident during transportation; 4) impact to public health and safety; 5) air pollution; and 6) soil contamination	Applicable	Use of any existing or potential HWMUs for remediation where hazardous wastes may be stored, treated, or disposed must meet these substantive requirements. This requirement may serve as a siting criteria.

TABLE B.3

OPERABLE UNIT 5 ACTION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Remarks
HAZARDOUS WASTES			
HAZARDOUS WASTE STORAGE			
Empty Containers OAC 3745-51-07 (A) and (B) RCRA 40 CFR 261.7 Subpart A	Any hazardous waste remaining in either an empty container or an inner liner removed from an empty container is not subject to regulation under 40 CFR Parts 261 through 265 (RCRA requirements). A container is empty if: 1) All wastes have been removed that can be removed using the practices commonly employed to remove materials from that type of container (e.g., pouring, pumping, and aspirating); and 2) No more than 2.5 cm (1 inch) of residue remain on bottom of the container or inner liner; or 3) No more than 3% by weight of the total capacity of the container remains in the container or inner liner if the container is less than or equal to 110 gal in size, or no more than 0.3% by weight of the total capacity of the container remains in the container or inner liner if the container is greater than 110 gal in size.	Relevant and Appropriate	This requirement is relevant and appropriate when containerizing soils contaminated by RCRA waste. This requirement would also be relevant and appropriate for containerizing any treatment residues exhibiting RCRA characteristics including Advanced Wastewater Treatment (AWWT) sludges and soil decontamination residues. OEPA has the overriding authority for on-site management of RCRA wastes.
Condition of Containers OAC 3745-66-71 through 74, 76 and 77 RCRA 40 CFR 265.171 through .174, .176 and .177 Subpart I	If a container holding hazardous waste is not in good condition (e.g., severe rusting, apparent structural defects) or it begins to leak, the owner or operator must transfer the hazardous waste from this container to a container that is in good condition or manage the waste in some other way that complies with this requirement.	Relevant and Appropriate	This requirement is relevant and appropriate to handling containers holding environmental media contaminated with RCRA waste. OEPA has the overriding authority for on-site management of RCRA wastes.

TABLE ARAR B-3 (Continued)
OPERABLE UNIT 5 ACTION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Remarks
Waste Storage Piles OAC 3745-56-51, 54, and 58 40 CFR 264.251 through .259	A waste pile used to store or treat hazardous waste must have: 1) A liner that is designed, constructed, and installed to prevent any migration of waste out of the pile into the adjacent subsurface soil or groundwater or surface water at any time during the active life (including the closure period) of the waste pile, and 2) A leachate collection and removal system immediately above the liner that is designed, constructed, maintained, and operated to collect and remove leachate from the pile. The owner/operator must design, construct, operate, and maintain a run-on control system capable of preventing flow onto the active portion of the pile during peak discharge from at least a 25-yr storm and manage a runoff management system to collect and control at least the water volume resulting from a 24-hr, 25-yr storm. Collection and holding facilities associated with run-on and run-off control system must be inspected weekly and be emptied or otherwise managed expeditiously after storms to maintain design capacity of the system. If the pile contains any particulate matter which may be subject to wind dispersal, the owner or operator must cover or otherwise manage the pile to control wind disposal. During construction or installation, liners and cover systems must be inspected for uniformity, damage, and imperfections. At closure, the owner/operator must remove or decontaminate all waste residues, contaminated containment system components, contaminated subsoils, and structures and equipment contaminated with waste and leachate, and manage them as hazardous waste unless OAC 3745-51-03(D) applies. If after, removing or decontaminating all residues and making all reasonable effort to effect removal or decontamination of contaminated components, subsoils, structures, and equipment, the owner/operator finds that not all contaminated subsoils can be practically removed or decontaminated, he must close the facility and perform post-closure care in accordance with OAC 3745-57-10.	Relevant and Appropriate	This requirement is relevant and appropriate for on-site hazardous waste piles used for longer than 90 days unless the CAMU Rule is applied.

TABLE ARAR B-3 (Continued)
OPERABLE UNIT 5 ACTION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Remarks
Containment OAC 3745-55-75 RCRA 40 CFR 265.175(a) through (c) Subpart I	A containment system for RCRA containment storage areas must be designed and operated to provide: 1) A sufficiently impervious base, which is sloped to collect any leaking liquids. 2) Sufficient capacity to contain liquids. 3) Prevention of run-on into the containment system. 4) A sump to prevent overflow of the collection system. Storage areas for containers holding only wastes that do not contain free liquids need not have a containment system provided that: 1) The storage area is sloped or is otherwise designed and operated to drain and remove liquid resulting from precipitation, or 2) The containers are elevated or are otherwise protected from contact with accumulated liquid.	Relevant and Appropriate	This requirement is relevant and appropriate to handling soil contaminated with listed or characteristic RCRA waste. A Part B Permit Application for RCRA storage has been submitted to the OEPA.
Containment Building RCRA 40 CFR 264.1100 through .1102 Subpart DD 57 FR 37194 8/18/92	The owner or operator is not subject to the definition of land disposal in RCRA section 3004(k) provided that the unit: 1) Is a completely enclosed, self-supporting structure that is designed and constructed of manmade materials of sufficient strength and thickness to support themselves, the waste contents, and any personnel and heavy equipment that operate within the unit, and to prevent failure due to pressure gradients, settlement, compression, or uplift, physical contact with the hazardous wastes to which they are exposed, climatic conditions, and the stresses of daily operation, including the movement of heavy equipment within the unit and contact of such equipment with containment walls; 2 Has a primary barrier for management of solids, in addition to a liquid collection system and secondary containment for management of liquids. 3) Has controls sufficient to prevent fugitive dust emissions to meet the no visible emission standard in Sec. 264.1101(c)(1)(iv); and 4) Is designed and operated to ensure containment and prevent the tracking of materials from the unit by personnel or equipment. At closure, the owner or operator must remove or decontaminate all waste residues, contaminated containment system components, contaminated subsoils, and structures and equipment contaminated with waste and leachate, and handle them as a hazardous waste.	Relevant and Appropriate	This requirement is not applicable because the facility is currently in interim status; 40 CFR 264 requirements only apply to facilities with a Part B Permit. Excavated RCRA soils and sediments may require temporary storage during the remedial action.

TABLE ARAR B-3 (Continued)
OPERABLE UNIT 5 ACTION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Remarks
HAZARDOUS WASTE MANAGEMENT AND DISPOSAL			
Preparing and Transporting Hazardous Waste Off-site RCRA 40 CFR 262.20 through .23, .30 and .33 Subparts B and C OAC 3745-53-20 through 31 OAC 3745-52-30 and 33	General Requirements for transporting hazardous waste for off-site disposal require a Manifest. Pre-transporting requirements include appropriate packaging, labeling, marking, and placarding.	Applicable	Any residues determined to be RCRA hazardous waste destined for off-site disposal are subject to manifest requirements. Remedial actions involving off-site disposal of RCRA wastes will be subject to this requirement.
Landfill Design RCRA 40 CFR 265.301(a) OAC 3745-68-011	Construction of a landfill must include two (2) or more liners and a leachate collection and removal system above and between such liners.	Applicable	If on-site disposal is selected for Operable Unit 5 low-level mixed wastes then this requirement will be applicable.
Land Disposal Restrictions RCRA 40 CFR 268.40 through .44 Subpart D OAC 3745-59	A restricted hazardous waste may be land disposed only if: 1) An extract of the waste or of the treatment residue of the waste does not exceed the value shown in 40 CFR 268.41. 2) It is treated using a technology specified in 40 CFR 268.42(a) or an equivalent treatment method. 3) [illegible] constituent concentrations in the waste or treatment residue of the waste do not [illegible]ed the value shown in 40 CFR 268.43.	Applicable	This requirement is applicable to those RCRA listed hazardous wastes that will be disposed of off-site. Land disposal restrictions will not apply to on-property disposal within a CAMU under the CAMU Rule.

TABLE ARAR B-3 (Continued)
OPERABLE UNIT 5 ACTION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Remarks
HAZARDOUS WASTE MANAGEMENT AND DISPOSAL (Continued)			
Contaminated Debris RCRA 40 CFR 268.2 Subpart A 40 CFR 268.45 Subpart D 40 CFR 261.3 Subpart A	Debris means solid material exceeding a 60 mm particle size that is intended for disposal and that is a manufactured object, plant or animal matter, or natural geologic material. Hazardous debris means debris that contains a listed hazardous waste, or that exhibits a characteristic of hazardous waste. Hazardous debris must be treated prior to land disposal unless the EPA determines that the debris is no longer contaminated with hazardous waste or the debris is treated to the waste-specific treatment standard for the waste contaminating the debris. Provided the debris does not exhibit a RCRA characteristic it is not subject to regulation under 40 CFR parts 260, 261 to 266, 268, or 270 if: 1) The hazardous debris has been treated using one of the required extraction or destruction technologies specified in 40 CFR 268.45 or 2) The debris, considering the extent of contamination, is determined to no longer be contaminated with hazardous waste.	Applicable	This requirement is applicable to hazardous debris that will be disposed of off site. Land disposal restrictions will not apply to on-property disposal within a CAMU.
GENERAL FACILITY STANDARDS			
Hazardous Waste Determination RCRA 40 CFR 262.11 Subpart A OAC 3745-52-11 (A) through (F)	A person who generates a solid waste must determine if that waste is a hazardous waste using the following method: 1) He should first determine if the waste is not a solid waste (40 CFR 261.4). 2) He must then determine if the waste is listed as a hazardous waste in Subpart D of 40 CFR Part 261. 3) For purposes of compliance with 40 CFR Part 268, or if the waste is not listed in subpart D of 40 CFR part 261, the generator must then determine whether the waste is identified in subpart C [characteristic] of 40 CFR part 261.	Relevant and Appropriate	This requirement is relevant and appropriate for soils contaminated with a RCRA listed waste, or a RCRA characteristic waste, and for residues from treatment of soil contaminated with RCRA listed waste, if the waste is to be managed or stored on-property within a CAMU. This requirement would further apply to waste sludges generated by the AWWT or the soil decontamination process where RCRA constituents may be present. A hazardous waste determination will be applicable for any RCRA regulated waste destined for off-site disposal.

TABLE ARAR B-3 (Continued)
OPERABLE UNIT 5 ACTION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Remarks
GENERAL FACILITY STANDARDS (Continued)			
Treatment, Storage, and Disposal General Facility Standards RCRA 40 CFR 265.13 through .16 Subpart B OAC 3745-65-13 through 16	General facility standards require that operators of a facility must obtain chemical and physical analyses of a representative sample of each hazardous waste to be treated, stored, or disposed of at the facility prior to treatment, storage, or disposal. The analysis may include existing published or documented data on the hazardous waste or on hazardous waste generated from similar processes. The operator of facility must also provide controlled access for the facility. In addition, the operator must maintain and inspect all monitoring equipment, safety and emergency equipment, security devices and operating and structural equipment that are important to preventing human health hazards. Operators must train personnel for procedures relevant to their emergency response training.	Relevant and Appropriate	These standards are relevant and appropriate where RCRA wastes are managed on site. All alternatives must meet compliance if they require action that involves storage and treatment of soil containing listed waste.
Treatment, Storage, and Disposal Facility Preparedness and Prevention RCRA 40 CFR 265.31 through .35, .37 Subpart C OAC 3745-65-31 through 35, 37	TSD operators must design, construct, maintain and operate facilities to minimize the possibility of fire, explosion or any unplanned sudden or nonsudden release of hazardous waste to air, soil, or surface water which might threaten human health or the environment.	Relevant and Appropriate	This requirement is relevant and appropriate for all alternatives involving the storage and treatment of RCRA listed waste. RCRA listed waste or characteristic waste may be disposed in an on-property disposal facility.
Treatment, Storage, and Disposal Facility Contingency Plan and Emergency Procedures RCRA 40 CFR 265.51, .52, and .55 through .56, Subpart D OAC 3745-65-51, 52, and 55 through 56	Each facility operator must have a contingency plan designed to minimize hazards to human health and the environment due to fires, explosions, or any unplanned releases of hazardous waste constituents to air, soil or surface/groundwater.	Relevant and Appropriate	This requirement is relevant and appropriate for all alternatives involving the storage and treatment of RCRA listed waste. RCRA listed waste or characteristic waste may be disposed in an on-property disposal facility.

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TABLE ARAR B-3 (Continued)
OPERABLE UNIT 5 ACTION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Remarks
GENERAL FACILITY STANDARDS (Continued)			
Treatment, Storage, and Disposal of Hazardous Waste in Miscellaneous Units OAC 3745-57-91 through 93 40 CFR 264.601 through .603	Prevention of any release that may have adverse effects on human health or the environment includes, but is not limited to: A. Migration of waste constituents in the groundwater or subsurface environment. B. Migration of waste constituents in surface water, or wetlands or on the soil surface. C. Migration of waste constituents in the air. Monitoring, tests, analytical data, inspections, response, and reporting procedures and frequencies must ensure compliance portions of the OAC. A miscellaneous unit that is a disposal unit must be maintained in a manner that complies with OAC 3745-57-91 during the post closure care period. If a treatment or storage unit has contaminated soils or groundwater that can not be completely removed or decontaminated during closure, the unit must also meet the requirements of OAC 3745-57-91 during the post-closure care. The post-closure plan under OAC 3745-55-18 must specify the procedures that will be used to satisfy this requirement.	Relevant and Appropriate	These requirements are relevant and appropriate to on-site facilities that treat, store, or dispose of hazardous waste in miscellaneous units unless the CAMU Rule is applied.
GROUNDWATER MONITORING			
Groundwater Monitoring Program RCRA 40 CFR 265.90 Subpart F OAC 3745-65-90	The owner or operator of a surface impoundment, landfill, or land treatment facility which is used to manage hazardous waste must implement a ground-water monitoring program capable of determining the facility's impact on the quality of ground water in the uppermost aquifer underlying the facility.	Applicable	This requirement is applicable to all interim-status RCRA land-based units and to select remedial alternatives that involve the disposal of soil containing listed hazardous waste. The Ohio EPA Director's Final Findings and Orders (DFOs) signed September 10, 1993, provides an alternate groundwater monitoring program from 40 CFR 265.92, Subpart F, to integrate the RCRA program with the CERCLA response actions.

TABLE ARAR B-3 (Continued)
OPERABLE UNIT 5 ACTION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Remarks
GROUNDWATER MONITORING (Continued)			
Groundwater Protection Standard RCRA 40 CFR 264.92 through .100 Subpart F OAC 3745-54-92 through 100	The owner or operator must ensure that hazardous constituents detected in the groundwater from a regulated unit do not exceed the concentration limits for MCLs in the uppermost aquifer underlying the waste management area beyond the point of compliance during the compliance period. The groundwater monitoring requirements include procedures for detection, compliance, and corrective action monitoring programs.	Relevant and Appropriate	This requirement is relevant and appropriate to land-based units, which would include any alternatives using on-site disposal facility and/or a consolidation area. However, the FEMP is currently an interim status facility with a Part B Permit application pending.
CLOSURE UNDER RCRA			
Closure Performance Standard for HWMUs RCRA 40 CFR 265.111 Subpart G OAC 3745-66-11	The owner or operator must close a facility in a manner that: 1) Minimizes the need for further maintenance; and 2) Controls, minimizes or eliminates, to the extent necessary to protect human health and the environment, post-closure escape of hazardous waste, hazardous constituents, leachate, contaminated run-off, or hazardous waste decomposition products to the ground or surface waters or to the atmosphere; and 3) Complies with these closure requirements.	Applicable	This requirement is applicable to HWMU closures occurring during the remedial action. This requirement is relevant and appropriate, not applicable, to alternatives involving disposal in an on-property disposal facility and/or consolidation area.
Closure Performance Standard RCRA 40 CFR 265.114 Subpart G OAC 3745-66-14	During the partial and final closure periods, all contaminated equipment, structures, and soils must be clean closed, have risk-based closure, or be closed in place. If the owner or operator demonstrates that not all contaminated soils can be practically removed or decontaminated then the owner or operator must close the tank system and perform post-closure care in accordance with the closure and post-closure care requirements that apply to landfills (40 CFR 264.310)	Applicable	This requirement is applicable to actions involving removal, treatment or storage of soils contaminated by RCRA constituents from HWMUs.
Storage Area Closure RCRA 40 CFR 264.178 Subpart I OAC 3745-55-78	At closure, all hazardous waste and hazardous waste residues must be removed from the containment system. Remaining containers, liners, bases, and soil containing, or contaminated with hazardous waste, or hazardous waste residues must be decontaminated or removed. If the owner or operator demonstrates that not all contaminated soils can be practically removed or decontaminated then the owner or operator must close the tank system and perform post-closure care in accordance with the closure and post-closure care requirements that apply to landfills (40 CFR 264.310)	Relevant and Appropriate	This requirement is relevant and appropriate to Operable Unit 5 for handling hazardous waste or environmental media. This requirement is not applicable because the FEMP is currently in interim status; 40 CFR 264 requirements only apply to facilities with a Part B Permit.

TABLE ARAR B-3 (Continued)
OPERABLE UNIT 5 ACTION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Remarks
CLOSURE UNDER RCRA (Continued)			
Closure of Tank Systems RCRA 40 CFR 265.197 Subpart J OAC 3745-66-97	At closure of a tank system, the owner or operator must remove or decontaminate all waste residues, contaminated containment system components (liners, etc), contaminated soils, and structures and equipment contaminated with waste, and manage them as hazardous waste. If the owner or operator demonstrates that not all contaminated soils can be practicably removed or decontaminated then the owner or operator must close the tank system and perform post-closure care in accordance with the closure and post-closure care requirements that apply to landfills (40 CFR 264.310).	Relevant and Appropriate	This requirement is relevant and appropriate to RCRA wastes contained in tanks that will be used by Operable Unit 5 during remedial actions.
Contained-In Policy RCRA 58 FR 48092 9/14/93 Proposed rule. 58 FR 59976 11/12/93 Notice to extend comment. 59 FR 10778 3/8/93 Clarification, partial withdrawal.	Hazardous soil means soil that contains RCRA hazardous waste(s) listed in 40 CFR part 261, subpart D, or that exhibits one or more of the characteristics of a hazardous waste as defined in 40 CFR part 261, subpart C. This proposed rule recommends contained-in determinations for hazardous debris, hazardous soil and other environmental media. Any person may petition the Regional Administrator to exclude, under 261.(f)(2) or 261.3(g) of this chapter, hazardous debris and hazardous soil or other environmental media, including but not limited to, ground water, surface water, and sediments, from regulation as hazardous waste. The petition for a contained-in determination must include information sufficient to demonstrate that specific constituent concentrations in the hazardous debris, hazardous soil, or other environmental media to be excluded do not pose a hazard to human health and the environment at that site. (Such a petition is not necessary for remedial actions conducted pursuant to RCRA or CERCLA authorities provided that a similar determination is made by the Regional Administrator based on information substantially equivalent to the information listed below including public notice and comment requirements).	TBC	Policies are not promulgated and therefore cannot be ARARs. This policy will be considered for managing treated soils that are contaminated with RCRA waste.
Risk-Based Remediation Standards Ohio EPA Closure Plan Review Guidance for RCRA Facilities. Interim Final. 9/1/93	Federal regulations of May 2, 1986 (50 FR 16422) and March 19, 1987 (52 FR 8704) modified the closure performance standard such that risk assessment, or what constitutes "decontamination" of a site, may be considered by the EPA as a closure option. The Ohio EPA adopted the equivalent of the EPA's March 19, 1987, regulations on December 8, 1988 (see OAC 3745-67-28), clarifying that risk assessment may be an option. It is Ohio EPA and DHWM practice to consider risk assessment as a possible third option for closure for all types of units.	TBC	The use of risk-based closures is to be considered for closing HWMUs with media contamination as integrated with the CERCLA remedial action.

TABLE ARAR B-3 (Continued)
OPERABLE UNIT 5 ACTION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Remarks
LANDFILL CLOSURE AND CORRECTIVE ACTION			
Corrective Action Management Unit RCRA 40 CFR 264.552 Subpart S 58 FR 865829 2/16/93	Corrective action management unit or CAMU means an area within a facility that is designated by the Regional Administrator under part 264 subpart S, for the purpose of implementing corrective action requirements under Sec. 264.101 and RCRA section 3008(h). A CAMU shall only be used for the management of remediation wastes pursuant to implementing such corrective action requirements at the facility. For the purpose of implementing remedies under Sec. 264.101 or RCRA Section 3008(h), the Regional Administrator may designate an area at the facility as a corrective action management unit, as defined above. One or more CAMUs may be designated at a facility under the following conditions: 1) Emplacement of remediation wastes into or within a CAMU does not constitute land disposal of hazardous wastes. 2) Consolidation or emplacement of remediation wastes into or within a CAMU does not constitute creation of a unit subject to minimum technology requirements. The owner/operator shall provide sufficient information to enable the Regional Administrator to designate a CAMU in accordance with the criteria in Sec. 264.552. **Note:** RCRA regulated units (HWMUs) within a CAMU are fully subject to RCRA Closure regulations.	Applicable	All action alternatives involve the excavation and handling of soil containing hazardous waste, therefore the CAMU concept is applicable to the remedial action for RCRA wastes. "Placement" as defined in HSWA does not occur in a CAMU. Therefore, land disposal restrictions (LDRs) and minimum technology requirements (MTRs) are not "triggered" as ARARs during and after the remedial activity within the boundaries of the CAMU.
Post-Closure Care RCRA 40 CFR 265.117 Subpart G OAC 3745-66-17	Post-closure care for each hazardous waste management unit must begin after completion of closure of the unit and continue for 30 years after that date and must consist of at least the following: 1) Monitoring and reporting in accordance with the requirements of Subparts F,K,L,M,N, and X of this part; and 2) Maintenance and monitoring of waste containment systems in accordance with the requirements of Subparts F,K,L,M,N, and X of this part. Post-closure use of property on or in which hazardous wastes remain after partial or final closure must never be allowed to disturb the integrity of the final cover, liner(s), or any other component of the containment system, or the function of the facility's monitoring systems. If clean closure is performed then post closure care is not required.	Applicable	This requirement is applicable to all alternatives, except the no action alternative, involving the closure of existing HWMUs.

TABLE ARAR B-3 (Continued)
OPERABLE UNIT 5 ACTION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Remarks
LANDFILL CLOSURE AND CORRECTIVE ACTION (Continued)			
Minimum RCRA Landfill Design Requirements for Closure RCRA 40 CFR 265.310 Subpart N OAC 3745-68-10	At final closure of the landfill or upon closure of any cell, the owner or operator must cover the landfill or cell with a final cover designed and constructed to: 1) Provide long-term minimization of migration of liquids through the closed landfill; 2) Function with minimum maintenance; 3) Promote drainage and minimize erosion or abrasion of the cover; 4) Accommodate settling and subsidence so that the cover's integrity is maintained; and 5) Have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present. After final closure, the owner of operator must comply with all post-closure requirements, including maintenance and monitoring throughout the post-closure care period. The owner or operator must: 1) Maintain the integrity and effectiveness of the final cover, including making repairs to the cap as necessary to correct the effects of settling, subsidence, erosion, or other events; 2) Continue to operate the leachate collection and removal system until leachate is no longer detected; 3) Maintain and monitor the leak detection system; 4) Maintain and monitor the ground-water monitoring system; 5) Prevent run-on and run-off from eroding or otherwise damaging the final cover; and 6) Protect and maintain surveyed benchmarks.	Relevant and Appropriate	This requirement is relevant and appropriate for on-property consolidation, capping, and/or disposal that may contain RCRA waste. This requirement is not applicable because the FEMP is currently in interim status; 40 CFR 264 requirements only apply to facilities with a Part B Permit.

RADIOACTIVE WASTES

MANAGEMENT AND DISPOSAL OF URANIUM MILL TAILINGS			
Landfill Requirements AEA/UMTRCA 40 CFR 192.02(a) Subpart A	Control of residual radioactive material shall be designed to: Be effective for up to 1000 years, to the extent reasonably achievable, and in any case, for at least 200 years, and provide protection of groundwater.	Relevant and Appropriate	The requirement is relevant and appropriate for residual radioactive materials because they are sufficiently similar to contaminated soils and sediments being addressed by Operable Unit 5. This requirement will be met as a general performance standard for all alternatives requiring on-property or off-site disposal.

TABLE ARAR B-3 (Continued)
OPERABLE UNIT 5 ACTION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Remarks
MANAGEMENT AND DISPOSAL OF URANIUM MILL TAILINGS (Continued)			
Implementation of Standards in 40 CFR 192, Subparts A and B AEA/UMTRCA 40 CFR 192.20 Subpart C	Implementing agencies shall establish methods and procedures to provide reasonable assurance that the provisions of Subparts A (above) and B (Table B.1) are satisfied. This should be done through use of analytical models and site specific analyses for Subpart A, and through measurements performed within the accuracy of currently available types of field and laboratory instruments along with reasonable survey and sampling procedures. This includes measuring the flow rate of uranium and groundwater.	Relevant and appropriate	This requirement is relevant and appropriate for ensuring compliance with 40 CFR 192 Subparts A and B. Note that Subpart B is listed as an ARAR in the chemical-specific ARAR table, B.1.
Management of Uranium By-Product Materials AEA/UMTRCA 40 CFR 192.30 through .34 Subpart D	This subpart applies to the management of uranium byproduct materials under section 84 of the Atomic Energy Act of 1954, as amended, during and following processing of uranium ores, and to restoration of disposal sites following any use of such sites under section 83(b)(1)(B) of the Act. Uranium byproduct materials shall be managed to conform with groundwater protection, which includes detection monitoring. Subpart D(iv) allows for alternate concentration limits of uranium to be established, as described in 264.95 and 264.94(b)	Relevant and Appropriate	This requirement is for disposal areas at active uranium mill tailing sites, and is a relevant and appropriate requirement for the engineered disposal cell and capping systems.
LOW LEVEL RADIOACTIVE WASTE DISPOSAL			
Performance Objectives DOE Order 5820.2A, Chapter III (3)(a)	Performance objectives must: 1) Protect public health and safety in accordance with standards specified in applicable EH Orders and other DOE Orders. 2) Assure that external exposure to the waste and concentrations of radioactive material which may be released into surface water, groundwater, soil, plants and animals results in an effective dose equivalent that does not exceed 25 mrem/yr to any member of the public. Releases to the atmosphere shall meet the requirements of 40 CFR 61. Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment ALARA. 3) Assure that the committed effective dose equivalents received by individuals who inadvertently may intrude into the facility after the loss of active institutional control (100 years) will not exceed 100 mrem/yr for continuous exposure or 500 mrem for a single acute exposure. 4) Protect groundwater resources, consistent with federal, state, and local requirements.	TBC	Soils contain radioactive materials consistent with low level wastes. All alternatives contemplate leaving residual radioactivity at the site above background and could result in exposures to members of the public.
Disposal Methods DOE Order 5820.2A, Chapter III, (3)(i)(1)-(6)	Low level radioactive waste shall be disposed by methods appropriate to achieve the performance standard objectives in (3)(a) above, consistent with the radiation dose limits in paragraph (3)(b)	TBC	Alternatives involving on-site disposal facilities will handle materials consistent with low level waste.

TABLE ARAR B-3 (Continued)
OPERABLE UNIT 5 ACTION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Remarks
LOW LEVEL RADIOACTIVE WASTE DISPOSAL (Continued)			
Disposal Facility and Disposal Site Design DOE Order 5820.2A, Chapter III (3)(i)(8)	Design criteria shall be established prior to selection of new disposal facilities, new disposal sites, or both. These design criteria shall be based on analyses of physiographic, environmental, and hydrogeologic data to assure that the policy and requirements of this Order can be met. The criteria shall be also based on assessments of projected waste volumes, waste characterizations, and facility and disposal site performance.	TBC	Alternatives involving on-site disposal facilities will handle materials consistent with low level waste.
Disposal Facility Operations DOE Order 5820.2A, Chapter III (3)(i)(9)	Operating procedures shall: protect human health and the environment, security, minimum long-term control, closure/post-closure, identify markers for excavations, training, minimum voids between containers	TBC	Alternatives involving on-site disposal facilities will handle materials consistent with low level waste.
MANAGEMENT OF LOW LEVEL RADIOACTIVE WASTE			
Low Level Radioactive Waste Generation DOE Order 5828.2A, Chapter III (3)(c)	Technical and Administrative controls shall be directed to reducing the gross volume of waste generated and/or the amount of radioactivity requiring disposal. Waste reduction efforts shall include consideration of process modification, process optimization, materials substitution, and decontamination. All DOE low level waste generators shall establish auditable programs to assure that the amount of low level waste generated and/or shipped for disposal is minimized. Each DOE low level waste generator shall separate uncontaminated waste from low level waste to facilitate cost effective treatment and disposal. Each DOE low level waste generator preparing a design for a new process or process change shall incorporate principles into the design that will minimize the generation of low level waste.	TBC	Alternatives involving on-site disposal facilities will handle materials consistent with low level waste.

TABLE ARAR B-3 (Continued)
OPERABLE UNIT 5 ACTION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Remarks
MANAGEMENT OF LOW LEVEL RADIOACTIVE WASTE (Continued)			
Waste Treatment DOE Order 5820.2A, Chapter III (3)(f)	Waste shall be treated by appropriate methods so that the disposal site can meet the performance objectives stated in DOE Order 5820.2A Chapter III (3)(a). Waste treatment techniques such as incineration, shredding, and compaction to reduce volume and provide more stable waste forms shall be implemented as necessary to meet performance requirements. Use of waste treatment techniques to increase the life of the disposal facility and improve the long-term facility performance, by improved site stability and reduction of infiltrating water, is required to the extent it is cost effective. The development of large scale waste treatment facilities shall be supported by the appropriate National Environmental Policy Act documentation. Operation of waste treatment facilities shall be supported by adequate documentation.	TBC	Alternatives using on-site disposal of low-level [illegible]ite will meet these performance objectives.
Low Level Radioactive Waste Shipment DOE Order 5820.2A, Chapter III (3)(g)	The volume of waste and number of shipments of low level waste shall be minimized and the shipments conducted based on plans developed by field organizations. Generators must receive advance approval from the receiving facility and shall certify prior to shipment that waste meets the receiving facility waste acceptance criteria (WAC). The certification program shall be auditable and able to withstand independent review.	TBC	All alternatives requiring remedial action contemplate the off-site shipment of some contaminated soils, sludges, or treatment residues.
Long-Term Storage DOE Order 5820.2A, Chapter III (3)(h)	Requires achieving performance objectives of DOE 5820.2A III (3)(a); requires records and documentation be maintained for low level waste in storage, permits storage of waste until disposal by approved methods.	TBC	All alternatives requiring remedial action involve the staging of contaminated soils prior to treatment and/or disposal.

TABLE ARAR B-3 (Continued)
OPERABLE UNIT 5 ACTION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Remarks
MANAGEMENT OF LOW LEVEL RADIOACTIVE WASTE (Continued)			
Disposal Site Closure/Post Closure DOE Order 5820.2A, Chapter III (3)(j)	Site-specific comprehensive closure plans shall be developed for new and existing operating low level waste disposal sites. The plan shall address closure of disposal sites within a 5-year period after each is filled and shall conform to the requirements of the NEPA process. Performance objectives for existing disposal sites shall be developed on a case-by-case basis as part of the NEPA process. During closure and post closure, residual radioactivity levels for surface soils shall comply with existing DOE decommissioning guidelines. Corrective measures shall be applied to new disposal sites or individual disposal units if conditions occur or are forecasted that could jeopardize attainment of the performance objectives of this Order. Inactive disposal facilities, disposal sites, and disposal units shall be managed in conformance with RCRA, CERCLA, and the Superfund Amendments and Reauthorization Act (SARA). Closure Plans for new and existing operating low level waste disposal facilities shall be reviewed and approved by the appropriate field organization. Termination of monitoring and maintenance activity at closed facilities or sites shall be based on an analysis of site performance at the end of the institutional control period.	TBC	Alternatives using on-site disposal of low-level waste will meet these performance objectives.
Environmental Monitoring DOE Order 5820.2A, Chapter III (3)(k)	Each operational or non-operational low level waste disposal facility shall be monitored by an environmental monitoring program that conforms with DOE 5484.1 and, at a minimum, meets the requirements listed below: 1) The environmental program shall be designed to measure: a) Operational effluent releases; b) Migration of radionuclides; c) Disposal units subsidence; d) Changes in disposal facility and disposal site parameters which may affect long-term site performance. 2) Based on the character of the facility monitored, the environmental monitoring program may include, but not necessarily be limited to, monitoring surface soil, air, surface water, and in the subsurface, soil and water, both in the saturated and unsaturated zones. 3) The monitoring program shall be capable of detecting changing trends in performance sufficiently in advance to allow application of any necessary corrective action prior to exceeding performance objectives. The monitoring program shall be able to ascertain whether or not effluents from each treatment, storage, or disposal facility or disposal site meets the requirements of applicable DOE Orders.	TBC	Alternatives involving on-site disposal facilities will handle materials consistent with low level waste.

TABLE ARAR B-3 (Continued)
OPERABLE UNIT 5 ACTION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Remarks
UNDERGROUND STORAGE TANKS (USTs)			
UST CLOSURE			
General Requirements RCRA 40 CFR 280.61 through .66 Subpart F OAC 1301:7-7-36	Owners and operators of petroleum or hazardous substance UST systems must, in response to a confirmed release from the UST system, comply with abatement measures, site characterization, product removal, investigations for soil and groundwater cleanup, and corrective action plans, except for USTs excluded under 280.10(b) and UST systems subject to RCRA Subtitle C corrective action requirements under section 3004(u) of the RCRA, as amended.	Applicable	Petroleum USTs will be closed as part of sitewide remedial actions.
Ohio Petroleum Contaminated Soil Policy OPEA Policy PP 01 03 200 PP.01-03-200	The basis of the "contained in" policy is that environmental media, such as soil or groundwater, are not considered to be waste material. because they are not a solid waste, the mixture rule, as set forth in OAC 3745-51-03, does not apply when they become contaminated with a listed hazardous waste but only contains the waste. The result of this policy is that if the waste constituents can be removed, the soil is no longer considered to contain a hazardous waste. Therefore, since soil is not a waste material it does not have to be de-listed in order for it to be used for its intended purpose. However, as long as the soil contains the waste material, it must be managed as a hazardous waste. If we apply this concept to petroleum-contaminated soil, the soils containing a petroleum hydrocarbon would not need to be managed as a solid waste if the contaminants were removed.	TBC	This policy allows for treated/cleaned soil to be backfilled at the excavation site. Operable Unit 5 will consider this policy for all soils treated below PRGs or PRLs to be backfilled as clean soil.

TABLE ARAR B-3 (Continued)
OPERABLE UNIT 5 ACTION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Remarks
BEST MANAGEMENT PRACTICES PROGRAM			
Best Management Practices Programs (BMP) Clean Water Act 40 CFR 125.104 Subpart K	BMP programs shall be developed in accordance with good engineering practices and: 1) Be documented in narrative form, and include any necessary plot plans, drawings or maps; 2) Establish specific objectives for the control of toxic and hazardous pollutants. (a) Each facility component or system shall be examined for its potential for causing a release of significant amounts of toxic or hazardous pollutants to waters of the United States due to equipment failure, improper operation, natural phenomena such as rain or snowfall, etc. (b) Where experience indicates a reasonable potential for equipment failure (e.g., a tank overflow or leakage), natural condition (e.g., precipitation), or other circumstances to result in significant amounts of toxic or hazardous pollutants reaching surface waters, the program should include a prediction of the direction, rate of flow and total quantity of toxic or hazardous pollutants which could be discharged from the facility as a result of each condition or circumstance; 3) Establish specific best management practices to meet the objectives identified in (2) above, addressing each component or system capable of causing a release of significant amounts of toxic or hazardous pollutants to the waters of the United States.	Applicable	Substantive requirements of this regulation are applicable to all alternatives requiring action. All action alternatives could release contaminants to waters of the United States if BMPs are not implemented.

AIR

AIR EMISSION STANDARDS FROM A STATIONARY SOURCE			
Air Emission Standards for Process Vents RCRA 40 CFR 264.1030, .1032 through .1034 Subpart AA	This subpart applies to process vents associated with distillation, fractionation, thin-film evaporation, solvent extraction, or air or steam stripping operations that manage hazardous wastes with organic concentrations of at least 10-ppm.	Applicable	This requirement is applicable for treating soils contaminated with RCRA waste.
Malfunction and Maintenance of Air Pollution Control Equipment OAC 3745-15-06 (A)(1) and (A)(2)	Scheduled maintenance must be established for pollution control equipment, as well as time periods when the pollution source must be shut-down during maintenance.	Applicable	This requirement is applicable for all alternatives that will utilize air pollution control equipment on-site.

TABLE ARAR B-3 (Continued)
OPERABLE UNIT 5 ACTION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Remarks
AIR EMISSION STANDARDS FROM A STATIONARY SOURCE (Continued)			
Stack Height Requirements OAC 3745-15-12 (B) and (C)	Stack height for air contaminant sources must be based on good engineering practices.	Applicable	All alternatives that include low-temperature thermal desorption must meet this requirement.
STATIONARY SOURCE AIR EMISSIONS			
General Provisions on Air Pollution Control OAC 3745-15-07 ORC 3704.01-.05	Measures shall be taken to adopt and maintain a program for the prevention, control, and abatement of air pollution in order to protect and enhance the quality of the state's air resource so as to promote the public health, welfare, and economic vitality of the people of the state. The emission or escape into open air from any source whatsoever of smoke ashes, dust, dirt, grime, acids, fumes, gases, vapors, odors and combinations of the above in such a manner or in such amounts as to endanger the health, safety, welfare of the public, or to cause unreasonable injury or damage to property shall be declared to be a public nuisance. It is unlawful for any person to cause, permit, or maintain any such public nuisance.	Applicable	During the remedial action, potential exists for emissions of radionuclides and toxic chemicals to air, which might endanger individuals or damage property.
Installation and Modification of Air Contaminant Sources OAC 3745-31-05(A)(3)	New or modified air contaminant sources are required to employ best available technology to control emissions	Applicable	This requirement is applicable to alternatives that involve the construction or modification of air contaminant sources.
Control of Emissions of Organic Materials form Stationary Sources OAC 3745-21-07(G)(2)	Discharges containing organic material must not exceed 40 pounds in any one day, nor eight pounds in any one hour, unless the discharge has been reduced by at least eight-five percent.	Applicable	This requirement is applicable to alternatives that involve the discharge of organic emissions.

TABLE ARAR B-3 (Continued)
OPERABLE UNIT 5 ACTION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Remarks
FUGITIVE AIR EMISSION STANDARDS			
Visible Particulates in Air EPA Regulations on National Primary and Secondary Ambient Air Quality Standards 40 CFR 50.6(a),(b),(c) Ohio Ambient Air Quality OAC 3745-17-07 (A)	The level of the national primary and secondary 24-hour ambient air quality standards for particulate matter is 150 micrograms per cubic meter, 24-hour average concentration. Visible particulate emissions from any stack may exceed 20% opacity, as a six-minute average, for not more than six consecutive minutes in any sixty minutes, but shall not exceed 60% opacity, as a six minute average at any time. The standards for national primary and secondary standards must be ≤ 50 micrograms per cubic meter, annual arithmetic average. Particulate matter shall be measured in the gradient air as PM_{10} (particles with an aerodynamic diameter less than or equal to a nominal 10 micrometers).	Applicable	The Federal standard at 40 CFR 50.6 for particulate matter in air is applicable to remedial actions at Operable Unit 5 because remedial activities may contribute, at least temporarily, to particulate matter in the air. Particulate emissions may be generated through fugitive emissions from excavations and disposal activities and point source discharges from wastewater sludge dewatering or soil treatment/stabilization. The Ohio standard for particulates in air is not an ARAR because it is not more stringent than the Federal standard at 40 CFR 50.6
Particulate Ambient Air Quality Standards OAC 3745-17-02 (C)(D)	The level of ambient air quality standards for total suspended particles is one hundred fifty micrograms per cubic meter, twenty-four-hour average concentration. The level of the primary and secondary annual standards for total suspended particulates is fifty micrograms per cubic meter.	Applicable	This requirement is applicable for all alternatives the omit or allow the escape of particulates. This includes all remedial activities that require excavation, demolition, cleaning and scrubbing.
Particulate Non-Degradation Policy OAC 3745-17-05	Degradation of Air Quality in any area where the air quality is better than required in 3745-27-02 (described above) is prohibited.	Applicable	See comment above.

TABLE ARAR B-3 (Continued)
OPERABLE UNIT 5 ACTION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Remarks
FUGITIVE AIR EMISSION STANDARDS (Continued)			
Control of Visible Particulate Emissions for Fugitive Dust OAC 3745-17-07 (B)(4),(5),(6)	There shall be no visible particulate emissions from any paved roadway or parking area except for a period of time not to exceed six minutes during any sixty-minute observation period. There shall be no visible particulate emissions from any unpaved roadway or parking area except for a period of time not to exceed thirteen minutes during any sixty-minute observation period. There shall be no visible particulate emissions from any material storage piles except for a period of time not to exceed thirteen minutes during any sixty-minute observation period.	Relevant and Appropriate	Paved and unpaved roadways, parking areas, and material storage piles will be in use during the remedial action. This requirement is not applicable as the FEMP is not located within a city or township subject to the rule, however, the requirement is relevant and appropriate for site activities during the remedial action. Grading, loading, and construction operations will occur during soil excavation, soil backfilling and during capping and construction of the disposal facility.
Ambient Air Quality Standards for Non-methane Hydrocarbons OAC 3745-21-02(C) and OAC 3745-21-03(D)	The ambient air quality guidelines for non-methane hydrocarbons is a maximum three hour arithmetic mean concentration of one hundred sixty micrograms per cubic meter not to be exceeded between the hours of six and nine am. Hourly and three-hour concentrations must be determined in accordance with prescribed methods.	Applicable	These requirements are applicable to alternatives that involve hydrocarbon emissions.
Restriction of Emission of Fugitive Dust OAC 3745-17-08 (B)	No person shall cause or permit any fugitive dust source to be operated; or any materials to be handled, transported, or stored; or a building or its appurtenances or a road to be used, constructed, altered, repaired, or demolished without taking or installing reasonably available control measures to prevent fugitive dust from becoming airborne. Such reasonably available control measures shall include, but not limited to, one or more of the following which are appropriate to minimize or eliminate visible particulate emissions of fugitive dust. - The use of water or other suitable dust suppression chemicals for the control of fugitive dust from the demolition of existing buildings or structures, construction operations, the grading of roads, or the clearing of land; or - The periodic application of asphalt, oil, water, or other suitable dust suppression chemicals on dirt or gravel roads and parking lots, and any other surfaces which may cause emissions of fugitive dust.	Relevant and Appropriate	This requirement is not applicable as the FEMP is not located within a city or township subject to the rule, however, the requirement is relevant and appropriate for site activities during the remedial action. Grading, loading, and construction operations will occur during soil excavation, soil backfilling and during capping and construction of the disposal facility.

TABLE ARAR B-3 (Continued)
OPERABLE UNIT 5 ACTION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Remarks
SOLID WASTES			
SOLID WASTE DISPOSAL			
Facility Design Criteria OAC 3745-27-08 (C)(1) through (9); (D) through (H) 40 CFR 258.40 Subpart D	Prescriptive engineering design specifications must be followed for the solid waste landfill facility, including requirements for liner specifications, leachate management systems, leachate storage, surface water control, benchmark location, access road grading, groundwater control, explosive gas monitoring systems and structures, composite and alternate cap systems, and the final cover.	Applicable	These requirements are applicable to alternatives that include the on-site disposal facility. The prescriptive requirements needed for construction of a solid waste landfill will be performed. The OAC requirements are more stringent than the Federal requirements, and therefore become the pertinent ARAR. Certification is not required as specified in OAC 3745-27-08 (A) and (B) because the FEMP is a CERCLA site. However the substantive requirements will be met.
SOLID WASTE DISPOSAL FACILITY OPERATIONS			
Facility Operations OAC 3745-27-09 (C), (D) through (F); (K) through (Q)	Sanitary landfill facility operations requirements.	Applicable	These requirements are applicable to alternatives that include the on-site disposal facility.
Daily Facility Operations OAC 3745-27-09 (C) through (E), (F)(2); (J) through (R) OAC 3745-27-19	This requirement specifies procedures for daily landfill operations maintenance and types of waste that is acceptable.	Applicable	These requirements are applicable to alternatives that include the on-site disposal facility.

TABLE ARAR B-3 (Continued)
OPERABLE UNIT 5 ACTION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Remarks
SOLID WASTE DISPOSAL FACILITY OPERATIONS (Continued)			
Required Technical Information OAC 3745-7-06 (A)(B) and (C)	The minimum technical information is required of a solid waste permit to install. Included are a hydrogeologic investigation report, leachate production and migration information, surface water discharge information, design calculations, and plan drawings.	Applicable	This paragraph presents the substantive requirements of a solid waste permit to install. This requirement is applicable for all alternatives where siting a new solid waste landfill facility is considered. This requirement is also applicable to existing areas of contamination are capped per solid waste rules. This rule establishes the minimum information required during the remedial design stage.
Ohio Solid Waste Disposal Regulations OAC 3745-27-19(N)	Section 3745-27-19(N) states the permittee shall submit to the Director of the OEPA, upon every tenth anniversary of the effective date of a permit to install that approved the initial construction of the facility, an analysis demonstrating that the design, construction and final closure plan of the sanitary landfill facility continue to constitute best available technology. If the director of the OEPA determines that the design is no longer consistent with best available technology as being applied to the sanitary landfill industry in the state of Ohio, the permittee may be required to submit a permit to install application for necessary modifications to the landfill facilities. If a permit to install is required, the director of the OEPA shall not apply the siting criteria outlined in paragraph (H) of OAC 3745-27-07, when considering the permit to install application.	Relevant and Appropriate	Several remedial alternatives involve the on-property disposal of solid waste. A permit-to-install is not required for the siting of on-property landfill at the FEMP because it is a CERCLA site. However, the substantive requirements will be met through the CERCLA 5-year review process.
SOLID WASTE DISPOSAL FACILITY CLOSURE			
Final Closure of Sanitary Landfill Facilities OAC 3745-27-11 (A),(B); (G)(1) through (3), (7)	It is the responsibility of the permittee to complete final closure of the sanitary landfill facility in a manner that minimizes the need for further maintenance and minimizes post-closure formation and release of leachate and explosive gases to air, soil, groundwater, or surface water to the extent necessary to protect human health and the environment. The adequacy of closure methods must be approved by OEPA for cap design, soil barrier layer, granular drainage layer and vegetative cover.	Applicable	These requirements are applicable to alternatives that include the on-site disposal facility.

TABLE ARAR B-3 (Continued)
OPERABLE UNIT 5 ACTION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Remarks
SOLID WASTE DISPOSAL FACILITY CLOSURE (Continued)			
Post-Closure Care of Sanitary Landfill Facilities OAC 3745-27-14 (A)(1),(2) RCRA Subtitle D	Following completion of final closure activities in accordance with rule 3745-27-11 of the Administrative Code, the owner or operator shall conduct post-closure care activities at the sanitary landfill facility for a minimum of thirty years. Post-closure care activities for all sanitary landfill facilities shall include, but are not limited to: (1) Continuing operation and maintenance of the leachate management system, the surface water management system, any explosive gas extraction and/or control system, any explosive gas monitoring system, and the ground water monitoring system; and (2) Maintaining the integrity and effectiveness of the cap system, including making repairs to the cap system as necessary to correct the effects of settling, dead vegetation, subsidence, erosion, or other events, and preventing run-on and run-off from eroding or otherwise damaging the cap system.	Applicable	These requirements are applicable to alternatives that include the on-site disposal facility.
Post-Closure Care EPA Criteria for Municipal Solid Waste Landfills 40 CFR §258.61	This requirement allows State Director to direct the owner or operator to stop managing leachate if the owner or operator demonstrates that leachate no longer poses a threat to human health and the environment.	Applicable	These requirements are applicable to alternatives that include the on-site disposal facility
WATER			
SURFACE WATER			
Ohio NPDES Permits CWA OAC 3745-33-05 ORC 6111.042 40 CFR 122.41 Subpart C	That the point source must be equipped with instrumentation to monitor and record data and other information about the operation of the point source. The permittee shall maintain in good working order and operate at optimum levels in accordance with good engineering practices any wastewater treatment facilities or control systems regardless of the quality of the effluent. The permittee shall provide adequately trained and qualified personnel to operate the wastewater treatment facility.	Applicable	The Ohio NPDES permit is applicable because these requirements are more stringent than the federal regulations under the Clean Water Act. These requirements are applicable as all alternatives involve point source discharges to the Great Miami River.

TABLE ARAR B-3 (Continued)
OPERABLE UNIT 5 ACTION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Remarks
SURFACE WATER (Continued)			
Stormwater Discharges Associated with Industrial Activity 40 CFR 122.26(a)(l)(ii) 40 CFR 122.26(b)(4) and OAC 3745-38	A discharge composed entirely of stormwater associated with industrial activity must obtain a NPDES permit. These categories of facilities are considered to be engaging in "industrial activity": • landfills, land application sites, and open dumps that receive or have received any industrial wastes (waste that is received from any of the facilities described under this subsection), including those that are subject to regulation under Subtitle D of RCRA and • construction activities including clearing, grading, and excavation that disturbs 5 acres more of total land area.	Applicable	The Ohio NPDES permit is applicable because these requirements are more stringent than the federal regulations under the Clean Water Act. These requirements are applicable as all alternatives involve point source discharges to the Great Miami River.
Antidegradation Policy OAC 3745-1-05 CWA 40 CFR 131.12	Existing instream water uses as defined in Rule 3745-1-07 of the Administrative Code and designated in Rules 3745-1-08 to 3745-1-32 of the Administrative Code, shall be maintained and protected. No further water quality degradation which would interfere with or become injurious to existing designated uses is allowable.	Applicable	This requirement is applicable for wastewater discharges to the Great Miami River. Under CERCLA, the State of Ohio has the overriding authority for the antidegradation of surface waters.
Analytical and Collection Procedures OAC 3745-01-03	Analytical methods and collection procedures for surface water discharge sampling are specified.	Applicable	This requirement is applicable to both discharges to surface waters as a result of remediation and any on-site surface waters affected by site conditions.
National Pollutant Discharge Elimination System; Wastewater Discharges Resulting From Clean-up of Response Action Sites Contaminated with Volatile Organic Compounds OEPA Policy #DSW-DERR 0100.027	Establishes response action guidelines for treatment technologies and discharge criteria for VOCs to be discharged to surface water.	TBC	This OEPA policy will provide guidance for alternatives involving wastewater discharges which contain VOCs.

TABLE ARAR B-3 (Continued)
OPERABLE UNIT 5 ACTION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Remarks
GROUNDWATER MONITORING			
Monitoring Well System OAC 3745-27-10 (A) and (B)	Ground water monitoring program requirements of new landfill facilities include background monitoring, detection monitoring and post-closure monitoring. The groundwater monitoring system will consist of a sufficient number of wells installed at appropriate locations and depths to yield ground water samples form both the uppermost aquifer system and any significant zones of saturation.	Applicable	These requirements are applicable to alternatives that include the on-site disposal facility.
Groundwater Monitoring Program OAC 3745-27-10 (C) and (D)	Sampling and analyses procedures must be designed to provide accurate representation of groundwater quality at the background and downgradient wells. Sampling and analysis procedures must be documented in a written plan. If the landfill facility owner deviates from the monitoring parameters listed in OAC 3745-27-10 (D)(3) to (D)(6), then an alternate list may be proposed to the Director. In addition, a written Quality Assessment Program must be prepared.	Applicable	These requirements are applicable to alternatives that include the on-site disposal cell. An alternate list of monitoring parameters will be required from those specified in OAC 3745-27-10(D)(3) to (D)(6).
Groundwater Quality Assessment Program OAC 3745-27-10 (E) and (P)	If a statistically significant change from background levels is identified for each parameter or constituent being monitored, then the landfill owner must submit a Quality Assessment program within 15 days. The plan must determine: (1) If leachate or leachate-derived constituents have entered the groundwater; (2) The rate and extent of migration of leachate or leachate-derived waste in the groundwater (3) The concentrations of leachate or leachate-derived waste in groundwater.	Applicable	These requirements are applicable to alternatives that include the on-site disposal facility.
Corrective Measures Study 3745-24-19(F)	After 180 days of determining that contaminants have leached from the landfill a corrective measures study must be submitted to OEPA. Remediation must include meeting MCLs in groundwater for a risk-level of 1×10^{-6} for a cumulative lifetime risk to an individual.	Applicable	These requirements are applicable to alternatives that include the on-site disposal facility.
GROUNDWATER WELLS			
INJECTION			
Underground Injection Control Program OAC 3745-34-01 OAC 3745-34-13	Injection into existing and new Class V wells is authorized by rule pursuant to section 6111.043 of the Ohio Revised Code until further requirements under future rules become applicable, unless injection is of sewage, industrial wastes or other wastes, as defined in Section 6111.01 of the Ohio Revised Code, into or above an Underground Source of Drinking Water (USDW).	Applicable	This requirement is applicable to all alternatives which involve the re-injection of treated groundwater into the GMA rather than discharging it to the Great Miami River.
Injection of Wastes into Wells ORC 6111.043 ORC 6111.044 to ORC 611.049	These sections of the Ohio Revised Code establish a program for regulations of the injection of sewage, industrial waste, hazardous waste, and other wastes into wells in order to control pollution of the waters of the state, to prevent contamination of underground sources of drinking water, and to satisfy all requirements of the "Safe Drinking Water Act", regarding injection wells as defined in regulations adopted under that act.	Applicable	This requirement is applicable to all alternatives which involve the re-injection of treated groundwater into the GMA rather than discharging it to the Great Miami River.

TABLE ARAR B-3 (Continued)
OPERABLE UNIT 5 ACTION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Remarks
OEPA Policy 5X26 Aquifer Remediation Projects	This OEPA policy outlines requirements for groundwater remediation via subsurface injection of fluids.	TBC	This OEPA policy will provide guidance for alternatives contemplating the re-injection of treated groundwater into the GMA.
WELL ABANDONMENT			
Abandonment of Test Holes and Wells OAC 3745-09-10	Upon completion of testing, a test hole shall be either completely filled with grout or such other material as will prevent contaminants from entering ground water.	Applicable	This requirement is applicable to all groundwater wells on the site that either will be installed or have been installed since February 15, 1975.
PCBs			
PCB DISPOSAL			
Disposal Requirements TSCA 40 CFR 761.60(a)(4) Subpart D	Any non-liquid PCBs at concentrations 50 ppm or greater in the form of contaminated soil, rags, or other debris shall be disposed of in an incinerator or in a chemical waste landfill.	Applicable	In the event soils containing PCBs above 50 ppm are excavated, this requirement is applicable. PCBs were detected in soil beneath the Fire Training Facility.
PCB TREATMENT			
TSCA 40 CFR 761.60(e) Subpart D	Any person who is required to incinerate any PCBs and PCB items under this subpart and who can demonstrate that an alternative method of destroying PCBs and PCB Items exists and that this alternative method can achieve a level of performance equivalent to 761.70 incinerators or high efficiency boilers as provided in paragraphs (a)(2)(iv) and (a)(3)(iv) of this section, may submit a written request to either the Regional Administrator or the Director, Exposure Evaluation Division for an exemption from the incineration requirements of 761.70 or 761.60. The applicant must show that his method of destroying PCBs will not present an unreasonable risk of injury to health or the environment.	Applicable	This requirement is applicable only if PCB contaminated soils are greater than 50 ppm and are treated on-property using a method besides incineration.
PCB STORAGE			
Storage for Disposal TSCA 40 CFR 761.65 Subpart D	This section applies to the design of storage areas to be used for later disposal of PCBs at concentrations of 50 ppm or greater.	Applicable	This requirement is applicable for storage of contaminated PCB soils at 50 ppm or greater.

TABLE ARAR B-3 (Continued)
OPERABLE UNIT 5 ACTION-SPECIFIC REQUIREMENTS

Citation	Requirement	ARAR/TBC	Remarks
OTHER REGULATIONS			
NOISE CONTROL			
Noise Control Act, as amended 42 USC 4901, et seq. Noise Pollution and Abatement Act 42 USC 7641	The public must be protected from noises that jeopardize health and welfare.	Applicable	Because equipment and vehicles would be involved in certain aspects of the proposed action, all substantive requirements of the act are applicable. However, appropriate engineering controls and best management practices will be implemented to reduce nuisance noise to the maximum practicable extent during conduct of the proposed actions.
HAMILTON COUNTY EARTHWORK REGULATIONS			
Erosion Control Specifications Hamilton County Earthwork Regulations	Department of Public Works -- temporary and/or permanent erosion and sediment control features and devices shall be designed and constructed in accordance with the State of Ohio Temporary Erosion Control Specifications.	TBC	All alternatives involving excavation contemplate erosion and sediment control features.

TABLE B.4.A

METHOD OF COMPLIANCE WITH CHEMICAL-SPECIFIC ARARs FOR OPERABLE UNIT 5 ALTERNATIVES

Chemical ARAR	Method of Compliance
Applicable Chemical-Specific Federal ARARs	
EPA Regulations on National Emission Standards for Hazardous Air Pollutants 40 CFR 61 National Emission Standards for Emissions of Radionuclides other than Radon from DOE Facilities Subpart H	Existing site conditions currently attain compliance with this regulation through the application of appropriate waste management and maintenance activities. Dust suppression techniques will be implemented during all phases of remedial action involving the handling of contaminated materials. Additionally, all soil treatment and wastewater treatment operations with a potential to emit radionuclides to the environment will be equipped with emission control devices (i.e., HEPA filters, etc.).
National Emission Standard for Radon Emissions from DOE Facilities 40 CFR 61 Subpart Q	The existing distribution of contaminants within the affected environmental media in Operable Unit 5 attains compliance with this requirement. The disposal facility design would accommodate sufficient barriers to ensure continued compliance.
Lead in Air 40 CFR 50.12	Compliance will be met.
Relevant and Appropriate Chemical-Specific Federal ARARs	
National Primary Drinking Water Standards, Maximum Contaminant Levels and Proposed Maximum Contaminant Levels 40 CFR 141.11, 40 CFR 141.15 and 40 CFR 141.16	The existing conditions exhibit concentrations of contaminants in the aquifer exceeding MCL or proposed MCL concentrations. Affected groundwater in the glacial till (1 gpm sustained yield) and GMA exhibiting greater than MCL or proposed MCL concentrations will be extracted with recovery wells. The pumping/excavation operation is anticipated to reduce contaminant concentrations to less than the MCLs or proposed MCLs at all points in the aquifer system at and beyond the point of compliance.
Federal non-zero Maximum Contaminant Level Goals for Organic and Inorganic Chemicals 40 CFR 141.12, 40 CFR 141.50 and 40 CFR 141.51	See comment above

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TABLE B.4.A (Continued)
METHOD OF COMPLIANCE FOR OPERABLE UNIT 5 ALTERNATIVES WITH CHEMICAL-SPECIFIC ARARs

Chemical ARAR	Method of Compliance
Relevant and Appropriate Chemical-Specific Federal ARARs (Continued)	
The National Primary Drinking Water Standards, Maximum Contaminant Levels for Organic and Inorganic Chemicals 40 CFR 141.61 and 40 CFR 141.62	See comment above
Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings 40 CFR 192.02, Subpart A; 192.12(a), Subpart B; 192.20, Subpart C; 192.21(f) and 192.22(b), Subpart C; 192.32(b)(2), Subpart D; 192.40-192.42, Subpart E	Select portions of the site exhibit existing concentrations exceeding these requirements. Soil excavation efforts for radioactive environmental media will reduce the concentration of radium-226/radium-228/thorium-230to required levels, in addition to reducing other residual radioactivity levels to attain FRLs.
Chemicals in Drinking Water for a Solid Waste Disposal Facility 40 CFR 257.4	Waste generated from remedial activities may be disposed of in an on-property disposal facility. The disposal facility would be designed and the WAC established as to ensure the continued protection of the underlying regional aquifer system. Through the engineering design, complemented by the WAC, this standard would be attained.
Chemicals in Drinking Water for a Hazardous Waste Disposal Facility 40 CFR 264.94	See comment above
Lead Soil Cleanup Standards (Resource Conservation and Recovery Act) 40 CFR 268.41	Soil exceeding these standards would be excavated and placed in the on-property disposal facility.
Applicable Chemical-Specific Ohio ARARs	
Ohio Water Quality Standards for Surface Water OAC 3745-1-04 and OAC 3745-1-07	All discharges to surface water will be controlled to the Great Miami River (permitted under NPDES) and to Paddys Run during the time period of active remediation. Stormwater, process wastewaters, sanitary sewage, and recovered groundwater will be managed to ensure the water quality standards are attained. The AWWT system and a new expansion of this facility will be employed to treat wastewater, stormwater, and recovered groundwater, as required, to ensure compliance with the standards.
Relevant and Appropriate Chemical-Specific Ohio ARARs	
General Radiation Protection Standards OAC 3701-38-15(A)(1),(B)	Compliance will be met.

TABLE B.4.B

METHOD OF COMPLIANCE WITH LOCATION-SPECIFIC ARARs FOR OPERABLE UNIT 5 ALTERNATIVES

Location ARAR	Method of Compliance
Applicable Location-Specific Federal ARARs	
16 U.S.C. 470, National Historic Preservation Act and 36 CFR 60, 60.4, 63, 800	Prior to remedial activities, surveys will be conducted to determine the presence of any cultural resources. Identification of cultural resources identified will be either avoided or managed consistently with this requirement as agreed upon with DOE, SHPO, the Advisory Council in a signed programmatic agreement. Compliance will be met.
16 U.S.C. 1531, et seq., Endangered Species Act 50 CFR 402.01, 402.12, Interagency Cooperation- Endangered Species Act	Studies are being conducted to determine the presence of individuals and potential habitat of federally and state-listed animal and plant species. If habitat or individuals are found, appropriate mitigative measures would be implemented. Compliance will be met.
Archeological Resources Protection Act (16 USC § 47099 -47011) 43 CFR 7.4 (a), Protection of Archeological Resources	Compliance will be coordinated through Section 106 of the National Historic Preservation Act.
16 U.S.C. 431-433, Antiquities Act of 1906	Compliance will be coordinated through Section 106 of the National Historic Preservation Act.
16 U.S.C. 461-467, 469, and 470 Historic Sites Preservation Act	Compliance will be coordinated through Section 106 of the National Historic Preservation Act.
25 U.S.C. 3001, Native American Graves Protection and Repatriation Act	Compliance will be coordinated through Section 106 of the National Historic Preservation Act.
42 U.S.C. 1996, American Indian Religious Freedom Act	Prior to remedial activities, surveys will be conducted to determine the presence of these cultural resources. Cultural resources identified will be either avoided or managed consistently with this requirement. Compliance will be met.
42 U.S.C. 1424(e), Safe Drinking Water Act	Operable Unit 5 overlies a sole source aquifer (Great Miami Aquifer), which has been contaminated by site process activities. Contaminants will be removed to health protective levels during remedial activities. Compliance will be met.

TABLE B.4.B (Continued)
METHOD OF COMPLIANCE FOR OPERABLE UNIT 5 ALTERNATIVES WITH LOCATION-SPECIFIC ARARs

Location ARAR	Method of Compliance
Applicable Location-Specific Ohio ARARs (Continued)	
DOE Compliance with Flood Plain/Wetlands Review Requirements 10 CFR 1022.3(a), (b)(1), (2), (3), (5), (6), (c), (d), (e): .5(b), (h), 11(a), (b), (c), .12(a), .15(a)	A wetland delineation has identified freshwater wetlands within the 1050 acre FEMP property boundary. Remedial activities relative to wetland impacts will be handled through the U.S. Army Corps of Engineers Nationwide Permit (NWP) Program where possible. When not covered by a NWP, the action will meet requirements mandated by individual permits per 33 CFR 323. Compliance will be met.
Dredge and Fill 33 CFR 323, 330, 40 CFR 230	See above comment.
Procedure for Implementing the National Environmental Policy Act 40 CFR 6.301(c)	Substantive requirements will be met through the revised secretarial policy on NEPA. Compliance will be met.
Executive Order 11990, Protection of Wetlands 40 CFR 6.302(a)	Remedial design will minimize impacts to wetlands. Any unavoidable impacts will be undertaken in accordance with 33 CFR 323 or 330. Any potentially impacted wetlands will be mitigated. Compliance will be met.
Executive Order 11988, Protection of Floodplains	Remedial activities will minimize impacts to Floodplains. Impacted Floodplain areas would be backfilled with clean soil and regraded to avoid alteration of flow patterns or uses of the Floodplain.
Procedure for Implementing the National Environmental Policy Act 40 CFR 6.302(h)	Substantive requirements will be met through the revised secretarial policy on NEPA. Compliance will be met.
Location of Solid Waste Disposal Facilities 40 CFR 257.3-2 40 CFR 258.12	Any planned disposal facility will be located so at to attain these statutory requirements.

TABLE B.4.B (Continued)
METHOD OF COMPLIANCE FOR OPERABLE UNIT 5 ALTERNATIVES WITH LOCATION-SPECIFIC ARARs

Location ARAR	Method of Compliance
[illegible] and Location-Specific Ohio ARARs (Co[illegible])	
Protection of Endangered and Threatened Wildlife and Plants 50 CFR 17.21, 17.31, 17.61, 17.71, and 17.94	All Federal agencies must ensure that any action authorized, funded, or carried out by them is not likely to jeopardize the continued existence of any listed species or result in the destruction or adverse modification of the constituent elements essential to the conservation of a listed species within a defined critical habitat. Additional requirements apply if it is determined that a proposed activity could adversely affect these species or their habitat. Compliance will be met.
Protection and Enhancement of Cultural Environment Executive Order 11593 3 CFR 154	Compliance will be met for identification and preservation of cultural resources on Federal land, including natural landmarks.
[illegible] and Appropriate Location-Specific Federal ARARs	
None Identified	
[illegible] Applicable Location-Specific Ohio ARARs	
Ohio Endangered Species Regulations OAC 1501: 18-1 ORC 1518.02 and ORC 1531.25	Compliance will be met.
Hazardous Waste Facility Environmental Impact OAC 3734.05 (D)(6)(c)	Compliance will be met.
Hazardous Waste Facility Minimum Risk OAC 3734.05 (D)(6)(d)	Compliance will be met.

TABLE B.4.B (Continued)
METHOD OF COMPLIANCE FOR OPERABLE UNIT 5 ALTERNATIVES WITH LOCATION-SPECIFIC ARARs

Location ARAR	Method of Compliance
Applicable Location-Specific Ohio ARARs (Continued)	
Water use for Southwestern Ohio Tributaries OAC 3745-01-17 and OAC 3745-01-21	Compliance will be met.
Ohio Solid Waste Regulations OAC 3745-27-07(A) and (B) and OAC 3745-27-09(Y)	Any proposed disposal facility will be sited such that the facility and any associated leachate collection system will be located out of a floodway or floodplain.
State Water Quality Certifications OAC 3745-32-02	Required certifications would be attained prior to completing excavation or backfill operations within wetlands or waters of the United States. Compliance will be attained.
Relevant and Appropriate Location-Specific Ohio ARARs	
None Identified	

TABLE B.4.C

METHOD OF COMPLIANCE WITH ACTION-SPECIFIC ARARs FOR OPERABLE UNIT 5 ALTERNATIVES

Action-Specific ARAR	Method of Compliance
Applicable Action-Specific Federal ARARs	
Preparing and Transporting Hazardous Waste Off-site 40 CFR 262.20 through 262.23, .30 and .33 Subparts B and C OAC 3745-53-20 through 31 OAC 3745-52-30 and 33	Hazardous waste that will be disposed of off site will comply with all substantive and administrative requirements.
Groundwater Monitoring Program 40 CFR 265.90(d) Subpart F OAC 3745-65-90(d)	This requirement is being met via the September 10, 1993, Ohio EPA Director's Final Findings and Orders (DFOs). These requirements will be considered during the development of a long-term monitoring program during RD/RA.
Corrective Action Management Unit 40 CFR 264.552 Subpart S	A CAMU is designated at the FEMP to include the area within the FEMP property boundaries for remedial action. Releases of contaminants that originated from the FEMP and have reached off-property areas will also be managed within the CAMU. The CAMU also includes the on-property disposal facility.
Air Emission Standards for Process Vents 40 CFR 264.1030, 264.1032 through 264.1034 Subpart AA	Units that treat soils and wastes contaminated with organic compounds will comply with air emission standards by employing control devices and monitoring.
Land Disposal Restrictions and Contaminated Debris 40 CFR 268.40 through 268.44, 268.45 Subpart D OAC 3745-59	Hazardous waste and associated debris will be treated to treatment standards for off-site disposal. On-property disposal will not require land-disposal treatment standards because of management under the CAMU Rule.

TABLE B.4.C. (Continued)
METHOD OF COMPLIANCE FOR OPERABLE UNIT 5 ALTERNATIVES WITH ACTION-SPECIFIC ARARs

Action-Specific ARAR	Method of Compliance
Applicable Action-Specific Federal ARARs (Continued)	
Post Closure Care 40 CFR 265.117 Subpart G OAC 3745-66-17	Post-closure care requirements will be met for residual contaminants at the site which exceed risk-based cleanup values (i.e., the on-property disposal facility). The requirement will be satisfied by including such monitoring and maintenance requirements into the operations & maintenance phase and long-term monitoring program of the CERCLA response action.
Underground Storage Tank (UST) Closure 40 CFR 280.60 through 280.66 Subpart F OAC 1301:7-7-36	All USTs and related petroleum-contaminated soils will undergo full closure per the requirements during the CERCLA remedial action.
Best Management Practices Programs (BMP) 40 CFR 125.104 Subpart K	The BMP requirements will be met via conducting the FEMP's BMP. The BMP Plan will be progressively updated to accommodate changing site activities during the conduct of CERCLA remedial actions.
PCB Disposal, Treatment, and Storage 40 CFR 761.60(a)(4), (e), and 761.65 Subpart D	Soil containing PCBs will be excavated to attain the FRLs. Excavated soil will be dispositioned consistent with the WAC.
Noise Control 42 USC 4901 42 USC 7641	Engineering controls and best management practices will be implemented to reduce noise to the maximum extent practicable during the remedial action.
Particulate Air Emissions 40 CFR 50.6 (a), (b), (c)	Compliance will be met.
Empty Containers of Hazardous Waste 40 CFR 261.7 Subpart A OAC 3745-51-07	Containers that have held hazardous wastes will be considered empty if the requirements in the rule are met.

TABLE B.4.C. (Continued)
METHOD OF COMPLIANCE FOR OPERABLE UNIT 5 ALTERNATIVES WITH ACTION-SPECIFIC ARARs

Action-Specific ARAR	Method of Compliance
Relevant and Appropriate Action-Specific Federal ARARs	
Hazardous Waste Determination 40 CFR 262.11 Subpart A OAC 3745-52-11	Soil exceeding the WAC will be treated for on-property disposal or dispositioned off-site. Materials destined to off-site disposal will be properly characterized to complete the necessary hazardous waste determination.
Groundwater Protection Standard 40 CFR 264.92 through 246.100 Subpart F OAC 3745-54-92 through 100	Groundwater monitoring for the on-property disposal facility will comply with the substantive requirements.
Storage Area Closure 40 CFR 264.178 Subpart I OAC 3745-55-78	Substantive closure requirements for container storage areas involving hazardous wastes will be met after the storage area is no longer needed for the CERCLA remedial action.
Minimum RCRA Landfill Design Requirements for Closure 40 CFR 264.310 Subpart N OAC 3745-68-10	The final closure substantive requirements will be met in the on-property disposal facility design.
Containment Building 40 CFR 264.1100 through .1102 Subpart DD	Design and operation of the containment building(s) will comply with the design, operation, and closure and post-closure care substantive requirements unless provisions of the CAMU rule are applied.

TABLE B.4.C. (Continued)
METHOD OF COMPLIANCE FOR OPERABLE UNIT 5 ALTERNATIVES WITH ACTION-SPECIFIC ARARs

Action-Specific ARAR	Method of Compliance
Relevant and Appropriate Action-Specific Federal ARARs (Continued)	
Treatment, Storage, and Disposal General Facility Standards 40 CFR 265.13 through 265.16 Subpart B OAC 3745-65-13 through 16 Treatment, Storage, and Disposal Facility Preparedness and Prevention 40 CFR 265.31 through 265.35, 265.37 Subpart C OAC 3745-65-31 through 35, 37 Treatment, Storage, and Disposal Facility Contingency Plan and Emergency Procedures 40 CFR 265.51 and 265.52, 265.55 and 265.56 Subpart D OAC 3745-65-51 and 52, 55 and 56	All general RCRA facility standards will be met during the CERCLA remedial action as necessary for activities involving the management of hazardous waste.
Closure Performance Standard for HWMUs 40 CFR 265.111, 265.114 Subpart G OAC 3745-66-11 and 14	All HWMUs will be closed clean or closed with the CERCLA process. The HWMU structures and contaminated soils will be fully addressed by decontamination and dismantlement under OU3, and excavation, treatment, and on- or off-site disposal of soil under OU5.
Condition of Containers 40 CFR 265.171 through 265.174, 265.175(a)-(c), 265.176, and 265.177 Subpart I OAC 3745-66-71 through 74, 76, 77 OAC 3745-55-75	Container storage requirements for hazardous wastes will be complied with by following the FEMP drum management plan as required by the SACD. Container storage areas for hazardous waste will meet the requirements for containment systems.

TABLE B.4.C. (Continued)
METHOD OF COMPLIANCE FOR OPERABLE UNIT 5 ALTERNATIVES WITH ACTION-SPECIFIC ARARs

Action-Specific ARAR	Method of Compliance
Relevant and Appropriate Action-Specific Federal ARARs (Continued)	
Closure of Tank Systems 40 CFR 265.197 Subpart J OAC 3745-66-97	Existing tank and container storage HWMUs are proposed to be closed through an integrated RCRA/CERCLA process. The affected soil associated with these HWMUs will be removed to attain FRLs for each COC to fulfill RCRA closure requirements. Any new tank system or container storage facilities installed to facilitate CERCLA remedial actions will be "closed" consistent with these substantive requirements.
Control of Residual Radioactive Materials 40 CFR 192.02(a) Subpart A	The control standards will be met in the design and operation of the on-property disposal facility multi-layered capping system.
Implementation 40 CFR 192.20 Subpart C	Compliance with the implementation requirements is met through the use of a verification and certification sampling program and the use of groundwater models for evaluating the long-term effectiveness.
Management of Uranium Byproduct Materials 40 CFR 192.30 through 34 Subpart D	The design of the on-property disposal facility capping system will attain these standards.
Solid Waste Disposal Facility Design Criteria 40 CFR 258.40 Subpart D	The on-property disposal facility design will, at a minimum, comply with the federal design standards for municipal solid waste landfills.
PCB Cleanup Policy 40 CFR 761.120, .125, .130 Subpart G	Soil containing PCBs will be excavated as necessary to attain FRLs. Removed soil will be dispositioned consistent with the WAC.

TABLE B.4.C. (Continued)
METHOD OF COMPLIANCE FOR OPERABLE UNIT 5 ALTERNATIVES WITH ACTION-SPECIFIC ARARs

Action-Specific ARAR	Method of Compliance
Applicable Action-Specific Ohio ARARs	
Analytical and Collection Procedures OAC 3745-01-03	The analytical methods and collection procedures specified in this requirement will be utilized to the extent necessary for surface water discharges.
Antidegradation Policy OAC 3745-01-05 40 CFR 131.12	The remedial action will ensure that existing in stream water uses of Paddys Run and the Great Miami River will be maintained as health protective.
Abandonment of Test Holes and Wells OAC 3745-09-10	Existing FEMP water supply wells and all wells used in support of the RI/FS, removal actions, remedial actions, and RCRA groundwater monitoring will be properly plugged and abandoned in accordance with abandonment requirements after they are no longer needed.
Malfunction and Maintenance of Air Pollution Control Equipment OAC 3745-15-06 (A)(1) and (A)(2)	Scheduled maintenance will be established for pollution control equipment, as well as time periods when the pollution source will be shut-down during maintenance.
General Provisions on Air Pollution Control OAC 3745-15-07	Air pollution nuisance prohibitions will be met by employing best management practices such as dust control and air monitoring during the CERCLA remedial action.
Stack Height Requirements OAC 3745-15-12 (B) and (C)	The stack height requirements will be met for alternatives using low-temperature thermal desorption units.
Restriction on Particulate Emissions from Industrial Processes OAC 3745-17-11	Emission restrictions will be met during stabilization, and any treatment by using proper operations, maintenance, management, and monitoring.

TABLE B.4.C. (Continued)
METHOD OF COMPLIANCE FOR OPERABLE UNIT 5 ALTERNATIVES WITH ACTION-SPECIFIC ARARs

Action-Specific ARAR	Method of Compliance
Applicable Action-Specific Ohio ARARs (Continued)	
Particulate Ambient Air Quality Standards OAC 3745-17-02 (C)(D)	Compliance will be met.
Particulate Ambient Air Quality Standards OAC 3745-17-05	Compliance will be met.
Solid Waste Disposal Facility Construction Requirements OAC 3745-27-08(C)(1) through (9), (D) through (H)	The on-property disposal facility construction design will meet the sanitary landfill substantive design requirements.
Solid Waste Disposal Facility Operations OAC 3745-27-09(D) through (F), (K) through (Q) OAC 3745-27-19	The on-property disposal facility operations will meet these requirements.
Groundwater Monitoring OAC 3745-27-10	Groundwater monitoring for the on-property disposal facility will fulfill these requirements.
Solid Waste Disposal Facility Closure OAC 3745-27-11(B);(G)(1) through (3), (7)	Final "closure" of the on-property disposal facility will meet these requirements.
Solid Waste Disposal Facility Post Closure OAC 3745-27-14	Substantive requirements for post-closure care of the on-property disposal facility will be included in the operations and maintenance phase of the CERCLA response action.
Underground Injection Control Program OAC 3745-34-01 OAC 3745-34-13	The re-injection of treated groundwater into the GMA will comply with substantive requirements.

TABLE B.4.C. (Continued)
METHOD OF COMPLIANCE FOR OPERABLE UNIT 5 ALTERNATIVES WITH ACTION-SPECIFIC ARARs

Action-Specific ARAR	Method of Compliance
Applicable Action-Specific Ohio ARARs (Continued)	
Injection of Wastes into Wells ORC 6111.043 ORC 6111.044 to ORC 6111.049	The re-injection of treated groundwater into the GMA will comply with substantive requirements.
Relevant and Appropriate Action-Specific Ohio ARARs	
Abandonment of Test Holes and Wells OAC 3745-09-10	All monitoring wells, piezometers and lysimeters will be plugged and abandoned per these requirements after they are no longer needed.
Quality Standards, Particulate in Air OAC 3745-17-07, (B)(4), (5), (6)	Appropriate mitigative measures will be applied to all excavations and material movement activities to reduce fugitive emissions. All point sources associated with a remedial alternative (i.e., sludge dewatering, etc) will employ best available emissions control technologies to mitigate particulates emissions.
Restriction of Emission of Fugitive Dust OAC 3745-17-08	Fugitive dust control will be achieved by employing control measures during grading, loading, and construction operations while soil is handled.
Ohio NPDES Permits OAC 3745-33-05 40 CFR 122.41 Subpart C	Compliance with general permit conditions for wastewater discharges will be met by employing proper operation and maintenance and monitoring during the operations and maintenance phase of the CERCLA response action.

APPENDIX E

APPENDIX E

FERMCO BASELINE OSDF COST ESTIMATE

Fernald Environmental
FERMCO
Restoration Management Corporation

INTEROFFICE MEMORANDUM

To:	Greg N. Jones, MS51-2	Date:	March 10, 1995
Location:	Fernald	Reference:	N/A
From:	Douglas L. Holmes, MS50	FERMCO #:	M:PIC:(ES):95-0023
Location:	Fernald	Client:	DOE DE-AC24-92OR21972
Extension:	738-9484	Subject:	Sitewide Onsite Disposal Facility PRELIMINARY

c: K. G. Kepler, FERMCO, MS50
C. S. Martin, FERMCO, MS50
File Record Storage Copy 106.4.6.7

Attached are two (2) copies of the estimate for the Sitewide Onsite Disposal Facility, dated March 10, 1995.

To request an additional copy of the Estimate or for any questions, please call Ken Kepler on extension 6140

DLH:CSM:tjh
Attachments (2)

PRELIMINARY

FERMCO
PROJECT & CONFIGURATION CONTROL
ESTIMATING SERVICES

10 MARCH 95

BASIS OF ESTIMATE

PROJECT DESCRIPTION:	SITEWIDE ONSITE DISPOSAL FACILITY
WBS NUMBER:	1.1.1.1.2.3.7
PROJECT LOCATION:	FERNALD, OHIO
PROJECT ENGINEER:	GREG JONES
ESTIMATOR:	KEN KEPLER
ESTIMATE NUMBER:	C2950204 (REV.01)
TASK ID:	2CC1

SUPPORTING DOCUMENTATION:

Verbal Scope	X	P & ID's		Work Plan	
Drawings		Equipment List		Site Walk	
Sketch	X	Specifications		Eng Mtg	X
Flow Diagrams		Site H & S Plan		Price Quotes	X

TYPE OF ESTIMATE:

Plan/Feasbl	X	Budg/Concpt	X	Title I Des	
Title II Des		Government		Independent	
Construction		Baseline	X		

BASIS OF ESTIMATE:

This Basis of Estimate represents costs to construct an onsite disposal facility to accept 2,500,000 CY's of waste/disposable material from OU2 waste units as well as OU3 and OU5. It is assumed that all waste will be delivered to the facility pre-treated to a predetermined waste acceptance criteria. All common soil or clay to be used in the construction of the liner and cap, as well as the intermediate cover, will be onsite borrow and all other materials will be offsite borrow.

These estimates are considered to be within a -30% to +50% range of accuracy (including Risk Budget), based on the level of information provided at this time.

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ESTIMATING SERVICES

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ESTIMATE ASSUMPTIONS

PROJECT DESCRIPTION:	SITEWIDE ONSITE DISPOSAL FACILITY
WBS NUMBER:	1.1.1.1.2.3.7
PROJECT LOCATION:	FERNALD, OHIO
PROJECT ENGINEER:	GREG JONES
ESTIMATOR:	KEN KEPLER
ESTIMATE NUMBER:	C2950204 (REV.O1)
TASK ID:	2CC1

EXECUTION:

This project is estimated to be performed by a subcontractor working a 40-hour week, 10 hours a day, no overtime or holidays. Construction start and finish dates are indicated in Appendix D (Construction Activity Duration).

WAGE RATES:

Wage rates within the estimates are based on the current rates furnished by the local Craft Labor Board and developed into a craft mix. All Labor Dollars are considered constant 1995 dollars.

ENGINEERING:

Engineering Title I/II costs to support this project are included in WBS No.1.1.1.1.2.3.6, 2CCD.
Engineering Title III costs are included in WBS No.1.1.1.1.2.3.7, 2CT1.

PRODUCTIVITY:

A site specific factor of 1.29 has been applied to Net Chart manhours. See Appendices A and B for development and application.
Task-specific factors were applied as necessary when identified.
PPE-specific factors were applied based on level identified. See Appendix B.
An allowance for delays caused by monitoring and radiation checking is included. See Appendix C, Health Physics.
No exposure/burnout rates have been identified for this work.

NOTE: All references to "See Appendix" refer to cost estimate Appendices only.

ESCALATION:

Escalation has been excluded from these estimates. Costs are considered to be constant 1995 dollars.

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TASK ID:	2CC1

DE-ESCALATION:

Page 2 of the estimate summary represents a de-escalated cost from the current year estimate (FY95) to a 1993 cost value for input into the microframe cost system.

UNIT RATES:

In general, the unit manhours, subcontract dollars, equipment dollars, and material dollars were based on 1993 MEANS. In most cases, a site productivity factor of 1.29 was applied to the Net chart unit manhours. The unit material and subcontract dollars were escalated 6% to arrive at 1995 constant dollars.

UNIT QUANTITIES:

All quantities, volumes, sizes, etc., were provided by CRU2 Engineering. All volumes of waste were considered bank cubic yards (BCY) at 10^{-6} risk level.

SWELL, DENSITY & SHRINKAGE FACTORS:

A swell or shrinkage factor was applied to the BCYs provided by CRU2 Engineering when applicable, resulting in loose cubic yards (LCY) or in-place or compacted cubic yards (ICY). Factors used are estimators judgement based on data provided in 'Fundamentals of Earthmoving' by Caterpillar Tractor Co. Density factors used are estimator's judgment based on 'Weights and Specific Gravities' in the American Institute of Steel Construction book. Weights are for bulk, heaped, or loose materials. The following factors were used:

MAT'L.	SWELL	DENSITY	SHRINKAGE
EARTH	1.25	1.275	1.2
CLAY	1.23	1.25	1.18
GRAVEL	1.12	1.275	1.075
SAND	1.12	1.275	1.075
GEN.WASTE	1.15	2.00	1.15

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ESTIMATE ASSUMPTIONS

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ESTIMATOR:	KEN KEPLER
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TASK ID:	2CC1

HEALTH PHYSICS: (See Appendix C)

All workers at the site will participate in the Medical Monitoring & Surveillance Program and the FEMP Radiation In-Vivo & Bioassay Testing Program. Costs are for the workers' time to participate in these programs based on the Number of Workers and the Duration of Construction Activity information.
Material dollars are included in this section to provide PPEs for the worker when required. Disposable PPE's are to be provided by the subcontractor. Washable PPE's will be provided by the subcontractor for the initial changeout for each required worker, with subsequent changeouts and cost for washing and decontamination provided by FERMCO. Labor dollars are included in this section for work delays caused by rad checking.

NUMBER OF WORKERS:

Calculation: Total Direct Manhours Div. By 1813 Hours (1 Man Year) x 1.25 (attrition) Div. By the Duration of Construction in Months x 12 = number of workers per year.

(Use number of workers per year to determine CERCLA/SAT and Health Physics costs.)

G&A (Home Office Expense):

G&A are excluded from the target estimate. The G&A costs are calculated within the Micro-Frame computer system according to the plan for rebaselining.

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ESTIMATING SERVICES

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ESTIMATE ASSUMPTIONS

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TASK ID:	2CC1

RISK BUDGET:

A cost element, based on a risk analysis calculated for this estimate to cover a statistical probability of a 50% chance of overrun/underrun to the project. The target estimate is the sum of the base estimate and the risk budget. The target estimate is the basis for the Performance Baseline. The risk budget for these projects will vary according to the results of the analysis. See the Risk Analysis at the end of each estimated alternative and refer to the Estimate Summary Sheets.

CONTINGENCY:

An amount budgeted to cover costs that may result from incomplete design, unforeseen and unpredictable conditions, or uncertainties. The amount of the contingency will depend on the status of design, procurement, construction, and the complexity and uncertainties of the component parts of the project. Contingency is not to be used to avoid making an accurate assessment of expected costs.

Contingency is calculated as the delta between the 50% chance of overrun and the 5% chance of overrun, indicated on the risk analysis. Contingency for these alternatives will vary based on the results of the risk analysis. See the risk analysis at the end of each estimated alternative and refer to the Estimate Summary Sheets.

FERMCO
PROJECT & CONFIGURATION CONTROL
ESTIMATING SERVICES

10 MARCH 95

SCOPE OF WORK

PROJECT DESCRIPTION:	SITEWIDE ONSITE DISPOSAL FACILITY
WBS NUMBER:	1.1.1.1.2.3.7
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PROJECT ENGINEER:	GREG JONES
ESTIMATOR:	KEN KEPLER
ESTIMATE NUMBER:	C2950204 (REV.01)

INCLUSIONS:

Costs have been included in the Field Directs for:

SITE PREPARATION
- Construction Survey
- Excavate 6" topsoil, stock for use in cell
- Access road - 6000 LF
- Storage area #1, 365' x 365', 9"thk. concrete pad
- Decon. trailer purchase
- Clear and grub surrounding area - 105 acres
- Temporary fencing - 10,000 linear feet
- Decontamination facilities - equipment - 25' x 60'
- Decontamination facilities - personnel - 11' x 11'

EROSION and SEDIMENT CONTROL
- Silt fence
- Diversion Berm
- Diversion Ditches
- Hay Bales

NORTH INTERCEPTOR TRENCH
- Excavate trench
- Riprap

CONSTRUCT LINER -
- Subgrade preparation - remove top soil, grade/compact
- Construct liner w/borrow materials
- Install leachate collection system
- Install leak detection system
- Install leachate discharge system to AWWT
- Backfill and compact - impacted cushion layer 12" thick
- Backfill and compact - remaining impacted fill
- Backfill and compact - level mD impacted fill
- Backfill generated waste
- Berm - On-site borrow

FERMCO
PROJECT & CONFIGURATION CONTROL
ESTIMATING SERVICES

10 MARCH 95

SCOPE OF WORK

PROJECT DESCRIPTION:	SITEWIDE ONSITE DISPOSAL FACILITY
WBS NUMBER:	1.1.1.1.2.3.7
PROJECT LOCATION:	FERNALD, OHIO
PROJECT ENGINEER:	GREG JONES
ESTIMATOR:	KEN KEPLER
ESTIMATE NUMBER:	C2950204 (REV.01)

CONSTRUCT CAP
- Construct cap w/borrow materials
- Top soil - 6" thick
- Grass cover - seed, mulch
- Security fence

GENERATED WASTE REMOVAL
- Construction equip. decon. facility
- Personnel decon. facility
- Temporary construction fence
- Storage area No. 1

SITE RESTORATION
- Borrowed common soil for backfill
- Borrowed top soil
- Grass cover, seed, fertilize, mulch

MONITORING WELLS
- Abandon (17) existing wells
- Install (50) pair of wells

Costs have been included in the Indirect Field Costs for:
- Contractor supervision
- Small tools and consumables
- Equipment rental
- Temporary construction facilities
- Temporary utilities and hook-up
- Job clean-up
- Safety
- Health Physics
- CERCLA and site access training
- Bond
- Subcontractor overhead and profit
- Subcontractor payroll burdens and benefits

FERMCO
PROJECT & CONFIGURATION CONTROL
ESTIMATING SERVICES

10 MARCH 95

SCOPE OF WORK

PROJECT DESCRIPTION:	SITEWIDE ONSITE DISPOSAL FACILITY
WBS NUMBER:	1.1.1.1.2.3.7
PROJECT LOCATION:	FERNALD, OHIO
PROJECT ENGINEER:	GREG JONES
ESTIMATOR:	KEN KEPLER
ESTIMATE NUMBER:	C2950204 (REV.01)

Costs for FERMCO Field Support are included in other WBS or CA's.

- Screening and confirmatory testing
- FERMCO construction management

Costs for Engineering are included in other WBS or CA's.

- Titles I,II and III (Includes cultural resource surveys, Phases I and II)

Costs have been included for Ohio State sales tax

- Subcontract material dollars at 6%

Costs have been included for Risk Budget.

Costs have been included for Contingency.

ALL OF THE ABOVE REPRESENTS SCOPE FOR THE CAPITAL COST FOR THE ALTERNATIVES.

EXCLUSIONS:

- Permits and fees
- Landlord costs
- Escalation
- G&A (home office expense)

EST FILE #: C2950204

CLIENT: US DOE

PROJECT TITLE: SITEWIDE ON-SITE DISPOSAL FACILITY - BUDGET

WBS#: 1.1.1.1.2.3.7

FERMCO ESTIMATING SERVICES

SUMMARY SHEET

DATE: 09-Mar-95

ESTIMATOR: KEN KEPLER

LOCATION: FERNALD

TASK#: 2CC1

	CODE	ITEM DESCRIPTION	M/H	RATE	LABOR $	S/C $ / OTHERS	MAT'L $	TOTAL $
1		SITE PREP for LINER	8,242		149,600	1,048,800	30,600	$1,229,000
2		EROSION and SEDIMENT CONTROL	4,354		79,000		14,600	$93,600
3		NORTH INTERCEPTOR TRENCH	9,088		164,900		87,600	$252,500
4		CONSTRUCT LINER	113,082		2,052,400	10,623,000	4,563,100	$17,238,500
5		AWWT PIPING SYSTEM	8,204		145,700		349,600	$495,300
6		PLACEMENT OF WASTE	239,856		4,353,400			$4,353,400
7		CONSTRUCT CAP	81,420		1,477,600	20,026,300	2,813,000	$24,317,100
8		GENERATED WASTE REMOVAL	21,872		397,000			$397,000
9		SITE RESTORATION	13		200	900	100	$1,200
10		MONITORING WELLS				1,371,000		$1,371,000
				AVG				
	DIRECT FIELD COSTS		486,131	$18.10	$8,820,000	$33,070,000	$7,858,300	$49,748,300
11	SUPERVISION - CONTRACTOR		82,840		$1,499,400			$1,499,400
12	SM TOOLS/CONSM'BLS						$132,300	$132,300
13	EQUIPMENT RENTAL						$10,958,200	$10,958,200
14	TEMP. FACILITIES		3,166		$57,300		$30,900	$88,200
15	TEMP UTL'S HOOK-UP		3,166		$57,300		$30,900	$88,200
16	JOB CLEAN-UP		4,751		$86,000		$46,300	$132,300
17	SAFETY		9,503		$172,000		$92,600	$264,600
18	HEALTH PHYSICS S/C		15,779		$285,600		$10,300	$295,900
19	CERCLA/SAT	20 HR'S/YR. AVG. x 40 WKRS. x 10	8,127		$147,100			$147,100
20	BOND					$497,500		$497,500
21	OVERHEAD & PROFIT					$3,246,200		$3,246,200
22	PAYRL BRD.&BENFT.				$5,784,800			$5,784,[illegible]
	INDIRECT FIELD COSTS		127,331		$8,089,500	$3,743,700	$11,301,500	$23,134,700
	DIRECT & INDIRECT FIELD COSTS		613,462		$16,909,500	$36,813,700	$19,159,800	$72,883,000
23	PURCHASE WASTE CONTAINERS (RSO)							
24	CERTIFICATION/TRANSPORTATION (RSO)							
25	BURIAL FEE (Envirocare)							
26	RECYCLING COSTS (RSO)							
27	STORAGE COSTS (RSO)							
	WASTE MANAGEMENT COSTS							
28	SOIL/WATER/AIR TESTING							
29	PROJ.MGMT-FERMCO - OU2							
30	CONSTR MGMT-FERMCO (WBS NO. 1.1.1.1.2.3.7, CA#2CM1)							
	FERMCO FIELD SUPPORT COSTS							
31	ENGINEERING, DESIGN, INSPECTION	A/E (WBS NO. 1.1.1.1.2.3.6,CA#2CCD)			FERMCO (WBS NO. 1.1.1.1.2.3.7,CA#2CT1)			
	ENGINEERING COSTS							
32	SALES TAX - SUBCONTRACT	$1,149,600	SALES TAX - FERMCO					$1,149,600
	SUB-TOTAL (BASE ESTIMATE)							$74,032,600
33	G&A-FERMCO (SEE EXCLUSION COMMENTS)							
34	ESCALATION (SEE EXCLUSION COMMENTS)							
35	RISK BUDGET	18.0%						$13,325,900
	TARGET ESTIMATE (BASE ESTIMATE PLUS RISK BUDGET)							$87,358,500
36	CONTINGENCY	10.5%						$7,773,400

FY 95 DOLLARS

F:\LOTUS31\SW\BUDCELL\INDSUM1.WK3

FERMCO ESTIMATING SERVICES

SUMMARY SHEET

EST FILE #: C2950204 | DATE: 09-Mar-95

CLIENT: US DOE | ESTIMATOR: KEN KEPLER

PROJECT TITLE: SITEWIDE ON-SITE DISPOSAL FACILITY - BUDGET | LOCATION: FERNALD

WBS#: 1.1.1.1.2.3.7 | TASK#: 2CC1

	CODE	ITEM DESCRIPTION	M/H	RATE	LABOR $	S/C $ / OTHERS	MAT'L $	TOTAL $
1		SITE PREP for LINER	8,242		$140,205	$982,935	$28,116	$1,151,256
2		EROSION and SEDIMENT CONTROL	4,354		$74,039		$13,683	$87,722
3		NORTH INTERCEPTOR TRENCH	9,088		$154,544		$82,380	$236,924
4		CONSTRUCT LINER	113,082		$1,923,509	$9,955,876	$4,276,537	$16,155,922
5		AWWT PIPING SYSTEM	8,204		$136,550		$327,645	$464,195
6		PLACEMENT OF WASTE	239,856		$4,080,006			$4,080,006
7		CONSTRUCT CAP	81,420		$1,384,994	$18,768,648	$2,636,344	$22,759,986
8		GENERATED WASTE REMOVAL	21,872		$372,068			$372,068
9		SITE RESTORATION	13		$187	$843	$94	$1,125
10		MONITORING WELLS				$1,284,901		$1,284,901
				AVG				
	DIRECT FIELD COSTS		486,131	17.00	$8,266,104	$30,993,204	$7,364,799	$46,624,107
11	SUPERVISION - CONTRACTOR		82,840		$1,405,238			$1,405,238
12	SM TOOLS/CONSM'BLS						$123,992	$123,992
13	EQUIPMENT RENTAL						$10,270,025	$10,270,025
14	TEMP. FACILITIES		3,166		$53,702		$28,959	$82,661
15	TEMP UTL'S HOOK-UP		3,166		$53,702		$28,959	$82,661
16	JOB CLEAN-UP		4,751		$80,599		$43,392	$123,992
17	SAFETY		9,503		$161,198		$86,785	$247,983
18	HEALTH PHYSICS S/C		15,779		$267,664		$9,653	$277,317
19	CERCLA	20 HR'S/YR AVG. x 40 WKRS. x	8,127		$137,862			$137,862
20	BOND					$466,257		$466,257
21	OVERHEAD & PROFIT					$3,042,339		$3,042,339
22	PAYRL BRD.&BENFT.				$5,421,515			$5,421,515
	INDIRECT FIELD COSTS		127,331		$7,581,479	$3,508,596	$10,591,766	$21,681,841
	DIRECT & INDIRECT FIELD COSTS		613,462		$15,847,583	$34,501,800	$17,956,565	$68,305,948
23	PURCHASE WASTE CONTAINERS (RSO)							
24	CERTIFICATION/TRANSPORTATION (RSO)							
25	BURIAL FEE (Envirocare)							
26	RECYCLING COSTS (RSO)							
27	STORAGE COSTS (RSO)							
	WASTE MANAGEMENT COSTS							
28	SOIL/WATER/AIR TESTING							
29	PROJ.MGMT-FERMCO - OU2							
30	CONSTR MGMT-FERMCO (WBS NO. 1.1.1.1.2.3.7, CA#2CM1)							
	FERMCO FIELD SUPPORT COSTS							
31	ENGINEERING, DESIGN, INSPECTION	A/E (WBS NO. 1.1.1.1.2.3.6,CA#2CCD)			FERMCO (WBS NO. 1.1.1.1.2.3.7,CA#2CT1)			
	ENGINEERING COSTS							
32	SALES TAX - SUBCONTRACT	$1,077,405	SALES TAX - FERMCO					$1,077,405
	SUB-TOTAL (BASE ESTIMATE)							$69,383,353
33	G&A-FERMCO (SEE EXCLUSION COMMENTS)							
34	ESCALATION (SEE EXCLUSION COMMENTS)							
35	RISK BUDGET	18.0%						$12,489,033
	TARGET ESTIMATE (BASE ESTIMATE PLUS RISK BUDGET)							$81,872,386
36	CONTINGENCY	10.5%						$7,285,230

DE-ESCALATED TO FY93 DOLLARS

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THIS SUMMARY SHEET IS ONLY FOR INPUT INTO MICROFRAME

PROJECT – SITE WIDE ON–SITE DISPOSAL FACILITY (2,500,000 CY) SITE SPECIFIC
PROJ.LOCATION: FERNALD PLANT EFFICIENCY / MULTIPLIER ANALYSIS WBS NO. : 1.1.1.1.2.3.7 EST.NO.: C2950204
ESTIMATOR : KEN KEPLER TASK I.D. :2CC1 DATE : 09–Mar–95

	PERCENT OF INFLUENCE ON CHART MANHOURS						CHART MANHOURS			% OF	WT'D	PROD.
	40%	50%	60%	70%	80%	90%	100%	105%	110%	INFLUENCE	VALUE	RESULT
CRAFT SKILL (NOTE 1)	POOR			FAIR			STD	V.GOOD	EXCELLENT	80.00%	12.0%	9.60%
CRAFT AVAIL (NOTE 1)		POOR		FAIR			STD			90.00%	8.0%	7.20%
CLIMATE (NOTE 2)	SEVERE	ICE/SNOW			RAIN		+40 TO +85			60.00%	20.0%	12.00%
PLANT ELEVATION		OVER 10,000FT			5,000' TO 10,000 FT		UNDER 5,000 FT			100.00%	5.0%	5.00%
WORK SPACE	<---- MULTIPLE SHIFTS–			200 SF	250 SF	300 SF	350 SF			70.00%	10.0%	7.00%
WORK WEEK							4–10s / 5–8s			100.00%	15.0%	15.00%
50 HOUR WORK WEEK	//// MULTIPLE–SHIFT ////			OVER 7 WEEKS	3 TO 7 WEEKS	UP TO 3 WEEKS						
60 HOUR WORK WEEK			OVER 7 WEEKS	3 TO 7 WEEKS	UP TO 3 WEEKS							
SHIFTWORK												
2ND SHIFT					2ND SHIFT		ONE SHIFT ONLY			100.00%	3.0%	3.00%
3RD SHIFT			3RD SHIFT							100.00%	5.0%	5.00%
PROJECT SIZE					400M MH AND UP	300M TO 400M MH	200M TO 300M MH	200M MH OR LESS		105.00%	4.0%	4.20%
PLANT TYPE				REVAMP ONLY	REVAMP & NEW	NEW IN EXIST PLT	GRASS ROOTS			70.00%	8.0%	5.60%
AREA/UNION INFLUENCE	STRONG		MILD		SOME		NONE			40.00%	10.0%	4.00%
											100.0%	77.6%

NOTES.....

1. TURNOVER HAS BEEN CONSIDERED
2. FOR EXTERIOR WORK ONLY

EFFICIENCY (AS A % OFF CHART MANHOURS) 77.6%

MULTIPLIER – (TO BE APPLIED TO CHART M.H.'S TO OBTAIN SITE M.H.'S) 1.29

000365

EFFICIENCY FACTORS

CONTRACT NO. :	4424321
PROJECT DESC. :	SITEWIDE ON-SITE DISPOSAL FACILITY - BUDGET
PROJECT CONTROLS :	CRU2
PROJ. LOCATION :	LOCATION:
PROJ. ENGINEER :	GREG JONES
ESTIMATOR :	KEN KEPLER
ESTIMATE NO. :	C2950204
WBS NO. :	1.1.1.1.2.3.7
TASK I.D. :	2CC1

EXAMPLE:

STANDARD CHART MANHOURS =	NET	100	
EFFICIENCY FACTORS:			
*SITE SPECIFIC (SEE APPENDIX A)	29%	29	
S/T = BASE UNIT MANHOURS		129	
*TASK SPECIFIC (BASED ON LABOR CHARTS OR EST.KNOWLEDGE)			
SEE DETAIL SHEETS or M.H.CHARTS	0%	0	N/A
S/T = NEW BASE UNIT MANHOURS		129	

*PPE SPECIFIC (BASED ON CURRENT DATA & EST. KNOWLEDGE)	LEVEL	D	Mod.'D'		C		B	
PRODUCTIVITY HOURS (AS ADDER TO BASE MH's)	0	0	1.1	142	1.5	194	1.75	226
TOTAL HOURS WITH PRODUCTIVITY		129	2.1	271	2.5	323	2.75	355

NOTE : Use a Default Productivity Factor of 2.1 for working in a contaminated area if Safety Level cannot be determined.
(SEE FERMCO ESTIMATING SERVICES REFERENCE MANUAL IM-6006 8.10)

Total hours with productivity divided by 10 hour working days = (PPE) ManDays to determine material cost of PPE's. (SEE APPENDIX C -HEALTH PHYSICS)

27 MD	32 MD	36 MD

THESE EFFICIENCY FACTORS WERE APPLIED INDIVIDUALLY THROUGHOUT THE ESTIMATE AT A TASK SPECIFIC LEVEL TO OBTAIN A MORE ACCURATE ACCOUNT OF OVERALL EFFICIENCY IMPACT DUE TO PPE REQUIREMENTS IN HANDLING CONTAMINATED AND HAZARDOUS WASTE.

DATE: 09-Mar-95

PROJECT TITLE:

HEALTH PHYSICS

SITEWIDE ON-SITE DISPOSAL FACILITY - BUDGET
WBS#:
1.1.1.1.2.3.7

EST.NO.: C2950204
EST. : KEN KEPLER
TASK I.D. : 2CC1

PPE'S - PERSONAL PROTECTIVE EQUIPMENT

DESCRIPTION	UNIT	UNIT COST $'s	• NO. OF CHANGE OUTS PER WORKER PER DAY	MD : MAN DAYS (TOTAL HOURS DIV. 10 HR. DAYS) MD	MAT'L.$'s	LEVEL
FULL/HALF FACE MASK w/RESPIRATOR & CARTRIDGES						
TYVEK SUIT - DISPOSABLE	EA	3.20	4	0	$0	C/B
TYVEK HOOD - DISPOSABLE	EA	6.00	4	0	$0	C/B
TYVEK BOOT COVER - DISPOSABLE	EA	1.30	4	0	$0	C/B
GLOVE LINER - DISPOSABLE	PR	1.40	4	0	$0	C/B
GLOVE, LASTEX - DISPOSABLE	PR	1.50	4	0	$0	C/B
GLOVE, WORK - DISPOSABLE	PR	0.90	4	0	$0	C/B
APR CARTRIDGES - DISPOSABLE	PR	17.50	4	0	$0	C/B
SUB-TOTAL		31.80	4		$0	
					$0.00	UNIT COST PER MAN DAY
FULL DRESS w/ FACE SHIELD						Modified
TYVEK SUIT - DISPOSABLE	EA	3.20	4	169	$2,160	D
TYVEK HOOD - DISPOSABLE	EA	6.00	4	169	$4,060	D
TYVEK BOOT COVER - DISPOSABLE	EA	1.30	4	169	$880	D
GLOVE LINER - DISPOSABLE	PR	1.40	4	169	$950	D
GLOVE, LASTEX - DISPOSABLE	PR	1.50	4	169	$1,010	D
GLOVE, WORK - DISPOSABLE	PR	0.90	4	169	$610	D
SUB-TOTAL		14.30	4		$9,670	
					$57.20	UNIT COST PER MAN DAY
OTHER EQUIPMENT			WKR			
RUBBER BOOT COVERS-(1)PR.PER WORKER	PR	12.70	3		$40	D/C/B
APR w/HALF FACE MASK - (1) PER WORKER	EA	22.30	3		$70	C
APR w/FULL FACE MASK - (1) PER WORKER	EA	174.00	3		$520	C
SCBA	EA	1894.00	0		$0	B
COOL VESTS	EA	137.50	0		$0	C/B
THERMO STRIPS	EA	50.00	0		$0	C/B
SUB-TOTAL					$600	
TOTAL PPE's (FORWARD TO PAGE 2 OF 2)					$10,300	

OTHER PPE's SUCH AS HARD HAT, SAFETY GLASSES/GOGGLES, STEEL TOED SAFETY SHOES, HEARING PROTECTION, ARE CONSIDERED THE SUBCONTRACTORS RESPONSIBILITY AND ARE COVERED IN HIS OVERHEAD EXPENSE. COSTS OF FERMCO SUPPLIED PPE's, SUCH AS COTTON COVERALLS, EXCHANGE OF RUBBER BOOT COVERS AND RESPIRATORS FOR CHANGEOUTS AND CLEANING OF SAME IS INCURRED BY FERMCO AND COSTS ARE NOT INCLUDED AS PART OF PROJECT COSTS AT THIS TIME.

DATE: 09-Mar-95

PROJECT TITLE:

HEALTH PHYSICS

SITEWIDE ON-SITE DISPOSAL FACILITY - BUDGET
WBS#:
1.1.1.1.2.3.7

EST.NO.: C2950204
EST. : KEN KEPLER
TASK I.D. : 2CC1

MEDICAL MONITORING - IN-VIVO & BIOASSAY SURVEILLANCE

MEDICAL MONITORING & SURVIELLANCE - LOST WORKER TIME

DESC.	QTY	HRS	WKR	TOTAL HOURS	AVG. LABOR RATE	TOTAL LABOR $		
BASELINE PHYSICALS	1	4	40.3	161	$18.10	$2,920		
ANNUAL PHYSICALS	10	3	40.3	1208	$18.10	$21,860		
EXIT (TERMINATION) PHYSICALS	1	4	40.3	161	$18.10	$2,920		
SUB-TOTAL						$27,700		

FEMP RADIATION IN-VIVO & BIOASSAY SURVEILLANCE - LOST WORKER TIME

DESC.	QTY	HRS	WKR	TOTAL HOURS	AVG. LABOR RATE	TOTAL LABOR $		
MONTHLY BIOASSAY	0	1	40.3	0	$18.10	$0		
YEARLY IN-VIVO	10	4	40.3	1611	$18.10	$29,160		
EXIT (END OF PROJECT / TERMINATION)	1	4	40.3	161	$18.10	$2,920		
SUB-TOTAL						$32,080		
	WKRS	TESTS	HRS	TOTAL HOURS				
RANDOM DRUG TESTING	18	331	2	662	$18.10	$12,000		
	NO. OF WKRS. TESTED	TESTING DAYS PER YR.	AVG. NO. OF TEST PER DAY	CHANCE PER DAY FOR TEST	NO. OF WKRS. FOR THIS ESTIMATE	CHANCES PER DAY FOR TEST FOR PROJECT	CONSTRUCTION WORKING DAYS	
	4000	226	18	0.0045	40.3	0.1812263	1829	
WORK DELAYS CAUSED BY RAD CHECKING	2%				$10,692,000	$213,800		

	TOTAL LABOR $'s	TOTAL MAT'L.$'s	TOTAL DOLLARS
TOTAL HEALTH PHYSICS - FORWARD TO ESTIMATE SUMMARY SHEET	$285,600	$10,300	$295,900

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CONSTRUCTION ACTIVITY DURATION

CONT.NO. – 4424321
PROJECT – SITE WIDE ON-SITE DISPOSAL FACILITY (2,500,000 CY)
CONTROLS – CRU2
LOCATION-LOCATION:
TASK I.D. – TASK#:

WBS NO. – 1.1.1.1.2.3.7
EST. NO. – C2950204
BY – K. KEPLER
DATE – 03/09/95

ACTIVITY	EST. DATE	START DATE	MID POINT	COMPL. DATE	ACTIVITY	DURATION
CONSTRUCTION	24-Feb-95	01-Mar-97	16-Mar-2002	31-Mar-2007	121	MONTHS

EST.DATE TO MID-POINT OF ACTIVITY	
85	MONTHS

ACTIVITY DURATION IS USED IN DETERMINING NO. OF WORKERS FOR CERCLA/SAT AND HEALTH PHYSICS COSTS.

CONTR.NO.- [redacted]21
CLIENT - [redacted]DEPT. OF ENERGY
PROJECT - SITE WIDE ON-SITE DISPOSAL FACILITY (2,500,000 CY)
LOCATION - FERNALD, OHIO
PROJ.CTL. - OU2
WBS NO. - 1.1.1.1.2.3.7

P[redacted]NARY

BUDGET ESTIMATE DETAILS

[redacted] 05:01 PM
CONTR.N[redacted] 4424321
EST. NO. C2950204
BY: KEN KEPLER
DATE: 03/09/95
TASK I.D.: 2CC1

DESCRIPTION	QUAN	UNIT	MANHOURS UNIT	MANHOURS TOTAL	FY95 RATE AVG	COST/UNIT LABOR	COST/UNIT SUB	COST/UNIT EQUIP.	COST/UNIT MAT'L	LABOR FY95	S/C	EQUIP.	MATERIAL	TOTAL
CONSTRUCTION ACTIVITY SUMMARY														
ON-SITE DISPOSAL FACILITY														
SITE PREP for LINER	1	LS		8,242						$149,600	$1,048,800	$395,700	$30,000	$1,624,100
EROSION and SEDIMENT CONTROL	1	LS		4,354						$79,000		$14,700	$14,600	$108,300
NORTH INTERCEPTOR TRENCH	1	LS		9,088						$164,900		$83,800	$87,900	$336,600
CONSTRUCT LINER	1	LS		113,082						$2,052,400	$10,623,000	$3,029,000	$4,563,100	$20,267,500
AWWT PIPING SYSTEM	1	LS		8,204						$145,700		$85,600	$349,600	$580,900
PLACEMENT OF WASTE Receive, place and compact waste. Intermediate cover	1	LS		239,856						$4,353,400		$5,466,900		$9,820,300
CONSTRUCT CAP Construct cap. On-Site borrow of clay/soil. Off-site borrow top soil, etc.	1	LS		81,420						$1,477,800	$20,026,300	$1,691,600	$2,813,000	$26,008,700
GENERATED WASTE REMOVAL Demolish disposal support facilities and place in Disposal Facility.	1	LS		21,872						$397,000		$190,500		$587,500
SITE RESTORATION At on-site disposal facility.	1	LS		13						$200	$900	$400	$100	$1,600
MONITORING WELLS	1	LS									$1,371,000			$1,371,000
TOTAL (DIRECT FIELD COSTS)	1	LS		486,131	$18.14					$8,820,000	$33,070,000	$10,958,200	$7,858,300	$60,706,500

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Site Wide On-Site Disposal Facility - SUMMARY

000370

186

CONTR.NO. – 4 ,21
CLIENT – U.S. DEPT. OF ENERGY
PROJECT – SITE WIDE ON-SITE DISPOSAL FACILITY (2,500,000 CY)
LOCATION – FERNALD, OHIO
PROJ.CTL. – OU2
WBS NO. – 1.1.1.1.2.3.7

PR .INARY

BUDGET ESTIMATE DETAILS

05:01 PM
CONTR.NO. 4424321
EST. NO. C2950204
BY: KEN KEPLER
DATE: 03/09/95
TASK I.D.: 2CC1

DESCRIPTION	QUAN	UNIT	MANHOURS UNIT	MANHOURS TOTAL	FY95 RATE	COST/UNIT LABOR	COST/UNIT SUB	COST/UNIT EQUIP.	COST/UNIT MAT'L	LABOR FY95	S/C	EQUIP.	MATERIAL	TOTAL
SITE PREP for LINER														
a. Construction Survey	105	AC					250.00				$26,250			$26,250
b. Clear and Grubb i. On-site Facility & Surrounding area	105	AC					1500.00				$157,500			$157,500
c. Excavate 6" Top Soil, stockpile (84700 cy) (to be placed in disposal facility as waste)	508200	SY	0.010	6785	18.15			0.72		$123,150		$390,280		$513,430
d. Access Road – 15' wide – 6" gravel	6000	LF	0.08	619	18.15			0.33	2.18	$11,230		$2,100	$13,860	$27,190
e. Temporary Construction Fencing i. Temp. fencing ii. 20 ft. wide swing gates	 10000 2	 LF EA					 2.32 200.00				 $23,200 $400			 $23,200 $400
f. Storage Area # I – 365' x 365' Conc. 9" thk Includes Compacted Sub-Grade Re-Inforced Hypalon, Geotextile Fabric, Crushed Rock, W6 x W6 6 x 6	14803	SY					50.00				$740,150			$740,150
g. Decon Trailer –	1	LS					100000.00				$100,000			$100,000
h. Const.Equipment Decon. Facility 25 ft x 60 ft	1	LS	730.00	730	18.05		1160.00	2900.00	11980.00	$13,180	$1,160	$2,900	$11,980	$29,220
i. Personnel Decon. Facility 11'x 11'	1	LS	108.00	108	18.89		100.00	360.00	4120.00	$2,040	$100	$380	$4,120	$6,640
TOTAL (SITE PREP for LINER)	1	LOT		8242						$149,600	$1,048,800	$395,700	$30,000	$1,624,100

Site Prep for Liner Details

000011

CONTR.NO. – 4[illegible]21
CLIENT – U.S. DEPT. OF ENERGY
PROJECT – SITE WIDE ON-SITE DISPOSAL FACILITY (2,500,000 CY)
LOCATION – FERNALD, OHIO
PROJ.CTL. – OU2
WBS NO. – 1.1.1.1.2.3.7

PRELIMINARY

BUDGET ESTIMATE DETAILS

05:01 PM
CONTR.NO. 4424321
EST. NO. C2950204
BY: KEN KEPLER
DATE: 03/09/95
TASK I.D.: 2CC1

DESCRIPTION	QUAN	UNIT	MANHOURS UNIT	MANHOURS TOTAL	FY95 RATE	COST/UNIT LABOR	COST/UNIT SUB	COST/UNIT EQUIP.	COST/UNIT MAT'L	LABOR FY95	S/C	EQUIP.	MATERIAL	TOTAL
EROSION and SEDIMENT CONTROL														
a. Silt Fence	15000	LF	0.017	329	18.15			0.06	0.65	$5,970		$950	$10,340	$17,260
b. Diversion Berm	5000	CY	0.24	1548	18.15			0.84		$28,100		$4,450		$32,550
c. Diversion Ditches	5000	CY	0.24	1548	18.15			0.84		$28,100		$4,450		$32,550
d. Hay Bales	3000	EA	0.24	929	18.15			1.53	1.35	$16,860		$4,870	$4,290	$26,020
TOTAL (EROSION and SEDIMENT CONTROL)	1	LOT		4354						$79,000		$14,700	$14,600	$108,300

000322

186

CONTR.NO.– 121
CLIENT – U.S. DEPT. OF ENERGY
PROJECT – SITE WIDE ON-SITE DISPOSAL FACILITY (2,500,000 CY)
LOCATION – FERNALD, OHIO
PROJ.CTL. – OU2
WBS NO. – 1.1.1.1.2.3.7

PRELIMINARY

BUDGET ESTIMATE DETAILS

05:01 PM
CONTR.NO. 4424321
EST. NO. C2950204
BY: KEN KEPLER
DATE: 03/09/95
TASK I.D.: 2CC1

DESCRIPTION	QUAN	UNIT	MANHOURS UNIT	MANHOURS TOTAL	FY95 RATE	COST/UNIT LABOR	COST/UNIT SUB	COST/UNIT EQUIP.	COST/UNIT MAT'L	LABOR FY95	S/C	EQUIP.	MATERIAL	TOTAL
NORTH INTERCEPTOR TRENCH														
a. Excavate Trench	20000	CY	0.24	6192	18.15			0.84		$112,380		$17,810		$130,190
b. Riprap	8700	CY	0.26	2896	18.15			7.15	10.10	$52,560		$65,940	$87,870	$206,370
TOTAL (NORTH INTERCEPTOR TRENCH)	1	LOT		9088						$164,900		$83,800	$87,900	$336,600

North Interceptor Trench Details

000373

CONTR.NO. - [redacted]21
CLIENT - U.S. DEPT. OF ENERGY
PROJECT - SITE WIDE ON-SITE DISPOSAL FACILITY (2,500,000 CY)
LOCATION - FERNALD, OHIO
PROJ.CTL. - OU2
WBS NO. - 1.1.1.1.2.3.7

F[redacted]MINARY

BUDGET ESTIMATE DETAILS

05:01 PM
CONTR.NO. 4424321
EST. NO. C2950204
BY: KEN KEPLER
DATE: 03/09/95
TASK I.D.: 2CC1

DESCRIPTION	QUAN	UNIT	MANHOURS UNIT	MANHOURS TOTAL	FY95 RATE	COST/UNIT LABOR	COST/UNIT SUB	COST/UNIT EQUIP.	COST/UNIT MAT'L	LABOR FY95	S/C	EQUIP.	MATERIAL	TOTAL
CONSTRUCT LINER Layers of Liner include: Borrow, Load, Haul, 300 ft, Place & Compact. (Soil/Clay = On-site Borrow) (Topsoil & other mat'l. = Off-Site Borrow)														
a. Subgrade Preparation														
i. Excavation of liner area 4'd x 1290' x 2390'	502431	BCY	0.037	23981	18.15			2.56		$435,260		$1,363,400		$1,798,660
ii. Disking and compaction	342567	SY	0.010	4419	18.15			0.72		$80,200		$261,450		$341,650
b. Clay - (No Bentonite) 36" Thk BCY 342567	404229	ICY	0.060	31287	18.15			2.18		$567,860		$934,090		$1,501,950
c. Geocomposite Liner	342567	SY					7.38				$2,528,140			$2,528,140
d. HDPE Liner 60 mil	342567	SY					4.75				$1,627,190			$1,627,190
e. Geotextile Fabric	342567	SY					2.25				$770,780			$770,780
f. Pea Gravel 12" Thk; In-place 114189	122753	ICY	0.11	17419	18.15			0.77	17.00	$316,150		$100,190	$2,212,010	$2,628,350
g. Composite Clay Liner	342567	SY					7.38				$2,528,140			$2,528,140
h. HDPE Liner 60 mil	342567	SY					4.75				$1,627,190			$1,627,190
i. Geotextile Fabric	342567	SY					2.25				$770,780			$770,780
j. Pea Gravel 12" Thk; In-place BCY 114189	122753	ICY	0.11	17419	18.15			0.77	17.00	$316,150		$100,190	$2,212,010	$2,628,350
k. Geotextile Fabric	342567	SY					2.25				$770,780			$770,780
l. HDPE Perforated Pipe - leachate collection 6" Dia.	10000	LF	0.30	3870	18.15			1.05	6.56	$70,240		$11,130	$69,540	$150,910
m. HDPE Perforated Pipe - leak detection 6" Dia.	10000	LF	0.30	3870	18.15			1.05	6.56	$70,240		$11,130	$69,540	$150,910
n. Berm - Common soil BCY 130000 (To accommodate ou2 waste placement for 5 YR plan)	139750	ICY	0.06	10817	18.15			1.67		$196,330		$247,390		$443,720
TOTAL (CONSTRUCT LINER)	1	LOT		113,082						$2,052,400	$10,623,000	$3,029,000	$4,563,100	$20,267,500

Construct Liner Details

000324

18c

CONTR.NO. – 4 1
CLIENT – U. DEPT. OF ENERGY
PROJECT – SITE WIDE ON-SITE DISPOSAL FACILITY (2,500,000 CY)
LOCATION – FERNALD, OHIO
PROJ.CTL. – OU2
WBS NO. – 1.1.1.1.2.3.7

PR INARY

BUDGET ESTIMATE DETAILS

05:01 PM
CONTR.NO 4424321
EST. NO. C2950204
BY: KEN KEPLER
DATE: 03/09/95
TASK I.D.: 2CC1

DESCRIPTION	QUAN	UNIT	MANHOURS UNIT	MANHOURS TOTAL	FY95 RATE	COST/UNIT LABOR	COST/UNIT SUB	COST/UNIT EQUIP.	COST/UNIT MAT'L	LABOR FY95	S/C	EQUIP.	MATERIAL	TOTAL
AWWT PIPING SYSTEM														
a. Leachate Discharge Piping														
i. HDPE Carrier & containment Pipe 6" x 10' Trench Excav/Backfill,sand bed.,comp.	7000	LF	0.86	7766	18.15			11.37	22.33	$140,950		$84,370	$165,690	$391,010
ii. 50gpm Pump, controls., elec.	3	EA	60.00	232	18.15			210.00	2500.00	$4,210		$670	$7,950	$12,830
iii. HDPE Manhole – 4' dia. x 8' deep	20	EA	8.00	206	18.15			28.00	8300.00	530.00		$590	$175,960	$177,080
TOTAL (AWWT PIPING SYSTEM)	1	LOT		8,204						$145,700		$85,600	$349,600	$580,900

AWWT Piping System Details

522000

CONTR.NO.– [redacted]
CLIENT – U.S. DEPT. OF ENERGY
PROJECT – SITE WIDE ON-SITE DISPOSAL FACILITY (2,500,000 CY)
LOCATION – FERNALD, OHIO
PROJ.CTL. – OU2
WBS NO. – 1.1.1.1.2.3.7

PI[redacted]ARY

BUDGET ESTIMATE DETAILS

[redacted]05:01 PM
CONTR.NO. 4424321
EST. NO. C2950204
BY: KEN KEPLER
DATE: 03/09/95
TASK I.D.: 2CC1

DESCRIPTION	QUAN	UNIT	MANHOURS UNIT	MANHOURS TOTAL	FY95 RATE	COST/UNIT LABOR	SUB	EQUIP.	MAT'L	LABOR FY95	S/C	EQUIP.	MATERIAL	TOTAL
PLACEMENT OF WASTE (2,500,000 BCY) Receive waste, place and compact.														
a. Impacted Fill–Cusion Layer 12" Thk BCY 114189	142736	LCY	0.06	11048	18.15			1.67		$200,520		$252,670		$453,190
b. Impacted Fill–Spread and Compact BCY 2197511	2746889	LCY	0.06	212609	18.15			1.67		$3,858,850		$4,862,540		$8,721,390
c. Intermediate Cover – Spread and Compact 150000	187500	LCY	0.06	14513	18.15			1.67		$263,410		$331,910		$595,320
PPE Allowance is added to the following:														
d. Impacted fill BCY 8300	10375	LCY	0.06	803	18.15			1.67		$14,570		$18,370		$32,940
OU2 Quantity = 8300 BCY														
Other OU's Quantity = N/A BCY														
**PPE PRODUCTIVITY ALLOWANCE – LEVEL mD	803	HRS	110%	883	18.15			1.67		$16,030		$1,420		$17,450
			S/T	1686										
MD = Man Day (No. of Hours worked in PPE's Divided by a 10 Hour Day)	169	MD												
(SEE APPENDIX C)														
TOTAL (WASTE PLACEMENT)	1	LOT		239,856						$4,353,400		$5,466,900		$9,820,300

Waste Placement Details

000376

186

CONTR.NO.– 4 21
CLIENT – U.S. DEPT. OF ENERGY
PROJECT – SITE WIDE ON-SITE DISPOSAL FACILITY (2,500,000 CY)
LOCATION – FERNALD, OHIO
PROJ.CTL. – OU2
WBS NO. – 1.1.1.1.2.3.7

PR NARY

BUDGET ESTIMATE DETAILS

05:01 PM
CONTR.NO. 4424321
EST. NO. C2950204
BY: KEN KEPLER
DATE: 03/09/95
TASK I.D.: 2CC1

DESCRIPTION		QUAN	UNIT	MANHOURS UNIT	MANHOURS TOTAL	FY95 RATE	COST/UNIT LABOR	COST/UNIT SUB	COST/UNIT EQUIP.	COST/UNIT MAT'L	LABOR FY95	S/C	EQUIP.	MATERIAL	TOTAL
CONSTRUCT CAP															
a. Contouring Layer 18" Thk.	BCY 172746	207295	ICY	0.06	16045	18.15			1.67		$291,220		$366,950		$658,170
b. Clay – (NO Bentonite) 24" Thk	BCY 230327	271786	ICY	0.060	21036	18.15			2.18		$381,800		$628,040		$1,009,840
c. Geocomposite Liner		345491	SY					7.38				$2,549,720			$2,549,720
d. Geotextile Fabric		345491	SY					2.25				$777,350			$777,350
e. Pea gravel 12" Thk, In-place	BCY 115164	123801	ICY	0.11	17567	18.15			0.77	17.00	$318,840		$101,050	$2,230,900	$2,650,790
f. Geotextile Fabric		345491	SY					2.25				$777,350			$777,350
g. Cobbels 36" Thk; In-place	BCY 345491	371403	ICY					35.52				$13,192,230			$13,192,230
h. Geotextile Fabric		345491	SY					2.25				$777,350			$777,350
i. Sand Layer 6" Thk; In-place	BCY 57593	61912	ICY	0.052	4153	18.15			1.76	5.00	$75,380		$115,500	$328,140	$519,020
j. Geotextile Fabric		345491	SY					2.25				$777,350			$777,350
k. Common Soil 21" Thk; In-place	BCY 201525	241830	ICY	0.06	18718	18.15			1.67		$339,730		$428,090		$767,820
l. Top Soil 6" Thk; In-place	BCY 57593	69112	ICY					17.00				$1,174,900			$1,174,900
m. Grass Cover – Seed, Fertilize, Mulch Utility Mix – Hydro/Air Seeding	SY 345491	3109	MSF	0.30	1203	18.15			6.75	25.00	$21,830		$22,240	$82,390	$126,460
n. Security Fence – 8' tall w/ 3-strands wire 6 ga. Aluminized		12000	LF	0.17	2632	18.15			2.28	13.40	$47,800		$29,000	$170,400	$247,200
iii. Double swing gates 20' opening		2	PR	25.60	66	18.15			340.00	560.00	$1,200		$700	$1,200	$3,100
TOTAL (CONSTRUCT CAP)		1	LOT		81,420						$1,477,800	$20,026,300	$1,691,600	$2,813,000	$26,008,700

Construct Cap Details

CONTR.NO. – 4[illegible]
CLIENT – U.S. DEPT. OF ENERGY
PROJECT – SITE WIDE ON-SITE DISPOSAL FACILITY (2,500,000 CY)
LOCATION – FERNALD, OHIO
PROJ.CTL. – OU2
WBS NO. – 1.1.1.1.2.3.7

PRI[illegible]ARY

BUDGET ESTIMATE DETAILS

05:01 PM
CONTR.NO [illegible] 4424321
EST. NO. C2950204
BY: KEN KEPLER
DATE: 03/09/95
TASK I.D.: 2CC1

DESCRIPTION		QUAN	UNIT	MANHOURS UNIT	MANHOURS TOTAL	FY95 RATE	COST/UNIT LABOR	COST/UNIT SUB	COST/UNIT EQUIP.	COST/UNIT MAT'L	LABOR FY95	S/C	EQUIP.	MATERIAL	TOTAL
GENERATED WASTE REMOVAL TO ONSITE DISPOSAL FACILITY															
	LCY														
a. Const.Equip.Decon.Facil. @ Onsite Disp.Fac.															
Demo/Remove Concrete	62.5	50.0	BCY	2.56	165	18.15			36.50		$2,990		$1,930		$4,920
Excavate, Load :															
Sub-grade Stone	35.0	28	BCY	0.292	11	18.15			9.16		$200		$270		$470
Geo-Fabric & Liner	208.8	167	SY	0.010	2	18.15			0.10		$40		$20		$60
Posts – 4" x 4" x 9'-6"	1.3	27	EA	0.48	17	18.15			1.68		$310		$50		$360
Splash Guard	11.0	702	SF	0.04	36	18.15			0.03		$650		$20		$670
* Haul & Dump Rubble	318.6	318.6	LCY	0.30	123	18.15			2.51		$2,230		$850		$3,080
b. Personnel Decon. Facil.@ Onsite Disp. Fac.															
Demo/Remove Concrete	2.8	2.20	BCY	2.56	7	18.15			36.50		$130		$90		$220
Demo/Remove Decon Trailer	400.0	10800	CF	0.003	42	18.15			0.10		$760		$1,140		$1,900
Excavate, Load :															
Sub-grade Stone	3.0	2.40	BCY	0.292	1	18.15			9.16		$20		$20		$40
Geo-Fabric & Liner	1.2	14.00	SY	0.010		18.15			0.10						
Posts – 4" x 4" x 9'-6"	0.3	6.00	EA	0.48	4	18.15			1.68		$70		$10		$80
Splash Guard	3.0	132.00	SF	0.04	7	18.15			0.03		$130				$130
* Haul & Dump Rubble	410.3	410.25	LCY	0.30	159	18.15			2.51		$2,890		$1,090		$3,980
c. Temporary Construction Fencing @ Fac.															
Remove temporary construction fencing	1482.0	10000	LF	0.052	671	18.15					$12,180				$12,180
20' wide Temporary Gates @ Fac.	6.0	2.00	EA	12.75	33	18.15			340.00		$600		$720		$1,320
* Haul & Dump Rubble	1488.0	1488	LCY	0.30	576	18.15			2.51		$10,450		$3,960		$14,410
d. Storage Area #I @ On-Site Disposal Fac.															
Demo/Remove Concrete	4626.3	3701	BCY	2.56	12222	18.15			36.50		$221,830		$143,190		$365,020
Demo/Remove Crushed rock	3084	2468	BCY	1.2	3820	18.15			3.62		$69,330		$9,470		$78,800
Excavate, Load :															
Geo-Fabric & Liner	1971	17763	SY	0.010	229	18.15			0.10		$4,160		$1,880		$6,040
* Haul & Dump Rubble	9681	9681	LCY	0.30	3747	18.15			2.51		$68,010		$25,760		$93,770
	LCY														
TOTAL GENERATED WASTE	11898														
TOTAL (GENERATED WASTE REMOVAL)		1	LOT		21,872						$397,000		$190,500		$587,500

000378

Generated Waste Removal Details

CONTR.NO. – 4 21
CLIENT – U.S. DEPT. OF ENERGY
PROJECT – SITE WIDE ON-SITE DISPOSAL FACILITY (2,500,000 CY)
LOCATION – FERNALD, OHIO
PROJ.CTL. – OU2
WBS NO. – 1.1.1.1.2.3.7

PR INARY

BUDGET ESTIMATE DETAILS

05:01 PM
CONTR.NO. 4424321
EST. NO. C2950204
BY: KEN KEPLER
DATE: 03/09/95
TASK I.D.: 2CC1

DESCRIPTION		QUAN	UNIT	MANHOURS UNIT	MANHOURS TOTAL	FY95 RATE	COST/UNIT LABOR	COST/UNIT SUB	COST/UNIT EQUIP.	COST/UNIT MAT'L	LABOR FY95	S/C	EQUIP.	MATERIAL	TOTAL
SITE RESTORATION															
a. Onsite Borrow Common Soil, Backfill	BCY														
Decon.Facil.– Const.Equip.@ Fac.	78	94	ICY												
Decon.Facil.– Personnel @ Fac.	7	8	ICY												
	S/T	102.0	ICY	0.09	12	18.15			3.21		$220		$350		$570
b. Offsite Borrow Top Soil 6"Thk., Spread															
Decon.Facil.– Const.Equip.@ Fac.	167	200	SY												
Decon.Facil.– Personnel @ Fac.	14	17	SY												
	S/T	217.2	SY					4.04				$930			$930
c. Grass Cover – Seed, Fertilize, Mulc	SY														
Utility Mix – Hydro/Air Seeding															
Decon.Facil.– Const.Equip.@ Fac.	167	1.80	MSF												
Decon.Facil.– Personnel @ Fac.	14	0.15	MSF												
	S/T	2.0	MSF	0.30	1	18.15			6.75	25.00	$20		$10	$50	$80
TOTAL (SITE RESTORATION)		1	LOT		13						$200	$900	$400	$100	$1,600

Site Restoration Details

000349

CONTR.NO.– 4[illegible]1
CLIENT – U.S. DEPT. OF ENERGY
PROJECT – SITE WIDE ON–SITE DISPOSAL FACILITY (2,500,000 CY)
LOCATION – FERNALD, OHIO
PROJ.CTL. – OU2
WBS NO. – 1.1.1.1.2.3.7

PR[illegible]ARY

BUDGET ESTIMATE DETAILS

05:01 PM
CONTR.NO. 4424321
EST. NO. C2950204
BY: KEN KEPLER
DATE: 03/09/95
TASK I.D.: 2CC1

DESCRIPTION	QUAN	UNIT	MANHOURS UNIT	MANHOURS TOTAL	FY95 RATE	COST/UNIT LABOR	COST/UNIT SUB	COST/UNIT EQUIP.	COST/UNIT MAT'L	LABOR FY95	S/C	EQUIP.	MATERIAL	TOTAL
MONITORING WELLS – MW														
Each Pair of MW includes 40 ft. deep Type I MW and 80 ft. deep Type II MW														
a. Abandon MW at On–Site Disposal Facility	17	EA					13000.00				$221,000			$221,000
b. MW at On–Site Disposal Facility Prorated based on waste volume to be disposed at the disposal facility MW 1 Pair x 120 ft/pair	50	PR					23000.00				$1,150,000			$1,150,000
TOTAL (MONITORING WELLS)	1	LOT									$1,371,000			$1,371,000

000380

Monitoring Wells Details

FERMCO RISK BUDGET ESTIMATING
INPUT DATA TABLE

PROJECT: SITEWIDE ONSITE DISPOSAL FACILITY-BUDGET
CLIENT: DOE
CONTRACT: C2-95-02-04

ACCOUNT NO.	ITEM DESCRIPTION	ESTIMATE BASE$	LOW%	LOW$	HIGH%	HIGH$	DIST. TYPE	RELA-TIONS	RANGE FACTOR
1	SITE PREP FOR LINER LABOR	149,600	-10%	$134,640	40%	$209,440	U		20%
2	SITE PREP FOR LINER S/C	1,048,800	-10%	943,920	40%	1,468,320	U		20%
3	SITE PREP FOR LINER MAT'L	30,000	-10%	27,000	25%	37,500	U		29%
4	EROSION AND SEDI. CNTRL LABOR	79,000	-10%	71,100	40%	110,600	U		20%
5	EROSION AND SEDI. CNTRL MAT'L	14,600	-10%	13,140	25%	18,250	U		29%
6	NORTH INTERCEPTOR TRNCH LABOR	164,900	-10%	148,410	40%	230,860	U		20%
7	NORTH INTERCEPTOR TRNCH MAT'L	87,900	-15%	74,715	30%	114,270	U		33%
8	CONSTRUCT LINER LABOR	2,052,400	-10%	1,847,160	40%	2,873,360	U		20%
9	CONSTRUCT LINER S/C	10,623,000	-10%	9,560,700	40%	14,872,200	U		20%
10	CONSTRUCT LINER MAT'L	4,563,100	-10%	4,106,790	30%	5,932,030	U		25%
11	AWWT PIPING SYSTEM LABOR	145,700	-10%	131,130	60%	233,120	U		14%
12	AWWT PIPING SYSTEM MAT'L	349,600	-10%	314,640	50%	524,400	U		17%
13	PLACEMENT OF WASTE LABOR	4,353,400	-10%	3,918,060	100%	8,706,800	U		9%
14	CONSTRUCT CAP LABOR	1,477,800	-10%	1,330,020	50%	2,216,700	U		17%
15	CONSTRUCT CAP S/C	20,026,300	-10%	18,023,670	50%	30,039,450	U		17%
16	CONSTRUCT CAP MAT'L	2,813,000	-10%	2,531,700	40%	3,938,200	U		20%
17	GENERATED WSTE REMOVAL LABOR	397,000	-10%	357,300	70%	674,900	U		13%
18	SITE RESTORATION LABOR	200	-10%	180	80%	360	U		11%
19	SITE RESTORATION S/C	900	-10%	810	80%	1,620	U		11%
20	SITE RESTORATION MAT'L	100	-10%	90	70%	170	U		13%
21	MONITORING WELLS S/C	1,371,000	-10%	1,233,900	40%	1,919,400	U		20%
22	INDIRECT FIELD COSTS LABOR	8,089,500	-10%	7,280,550	50%	12,134,250	U		17%
23	INDIRECT FIELD COSTS S/C	3,743,700	-10%	3,369,330	50%	5,615,550	U		17%
24	INDIRECT FIELD COSTS MAT'L	11,301,500	-10%	10,171,350	30%	14,691,950	U		25%
25	SALES TAX SUBCONTRACT MAT'L	1,149,600	-6%	1,080,624	21%	1,391,016	U		22%
26				0		0			0%
27				0		0			0%
28				0		0			0%
29				0		0			0%
30				0		0			0%
31				0		0			0%
32				0		0			0%
33				0		0			0%
34				0		0			0%
35				0		0			0%
36				0		0			0%
37				0		0			0%
38				0		0			0%
39				0		0			0%
40				0		0			0%
41				0		0			0%
42				0		0			0%
43				0		0			0%
44				0		0			0%
45				0		0			0%
		$74,032,600		$66,670,929		$107,954,716			

000351

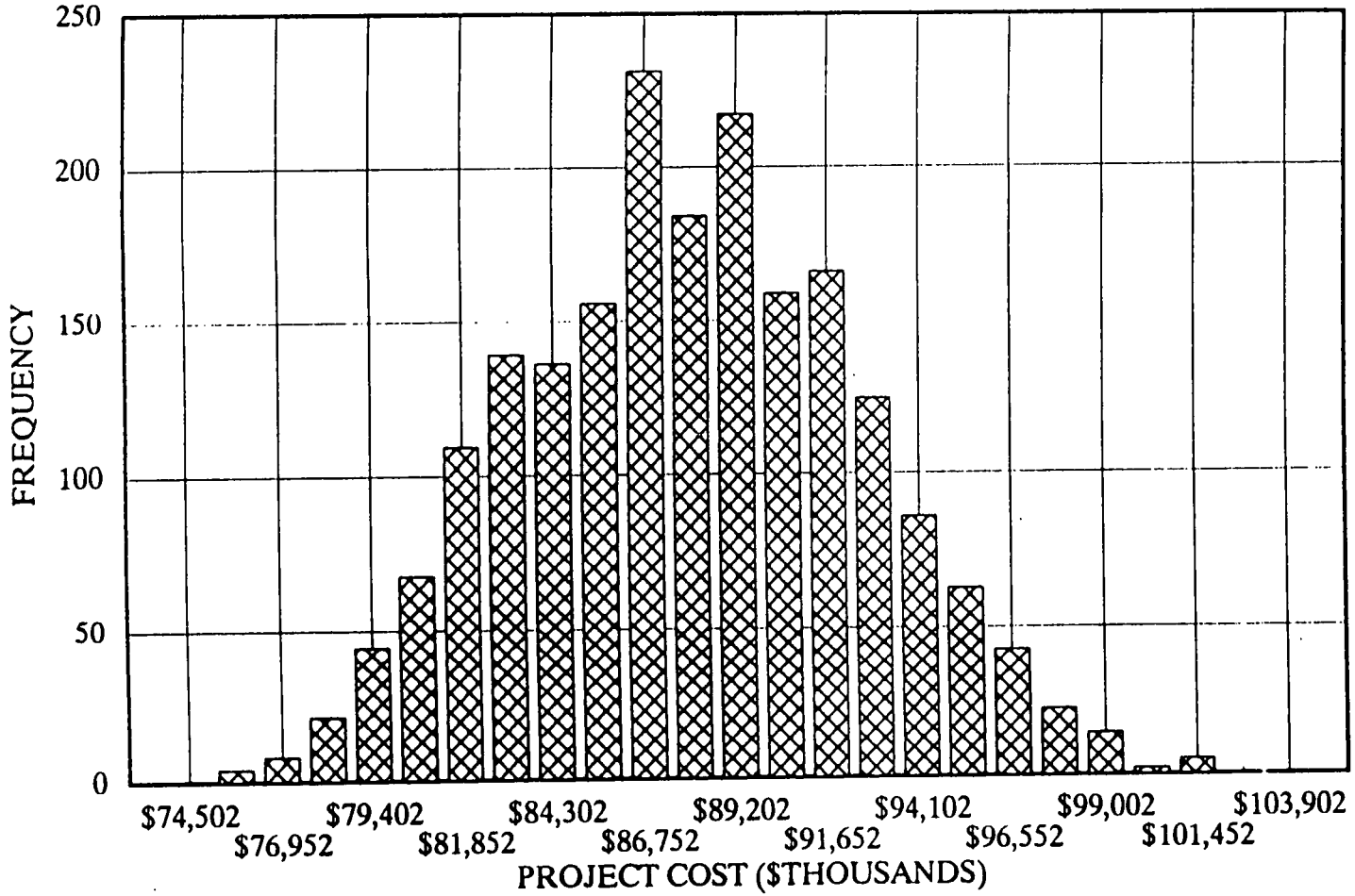
RISK BUDGET/OVERRUN ANALYSIS OUTPUT

PROJECT: SITEWIDE ONSITE DISPOSAL FACILITY–BUDGET
CLIENT: DOE DATE: 10–Mar–95
CONTRACT: C2–95–02–04 BASE ESTIMATE: $74,032,600

CHANCES OF OVERRUN	PROJECT COST W/RISK BUDGET	RISK BUDGET ADDED TO BASE ESTIMATE	%RISK BUDGET OF BASE ESTIMATE
0.00%	$107,954,716	$33,922,116	45.8%
0.05%	$100,667,592	$26,634,992	36.0%
5.00%	$95,017,181	$20,984,581	***28.3%***
10.00%	$93,275,332	$19,242,732	26.0%
15.00%	$92,159,824	$18,127,224	24.5%
20.00%	$91,382,365	$17,349,765	23.4%
25.00%	$90,587,621	$16,555,021	22.4%
30.00%	$89,898,856	$15,866,256	21.4%
35.00%	$89,122,763	$15,090,163	20.4%
40.00%	$88,522,389	$14,489,789	19.6%
45.00%	$87,986,109	$13,953,509	18.8%
50.00%	$87,326,166	$13,293,566	***18.0%***
55.00%	$86,661,142	$12,628,542	17.1%
60.00%	$86,126,143	$12,093,543	16.3%
65.00%	$85,603,264	$11,570,664	15.6%
70.00%	$84,863,656	$10,831,056	14.6%
75.00%	$84,005,129	$9,972,529	13.5%
80.00%	$83,134,469	$9,101,869	12.3%
85.00%	$82,292,906	$8,260,306	11.2%
90.00%	$81,391,821	$7,359,221	9.9%
95.00%	$79,775,203	$5,742,603	7.8%
99.95%	$74,851,501	$818,901	1.1%
100.00%	$66,670,929	($7,361,671)	–9.9%

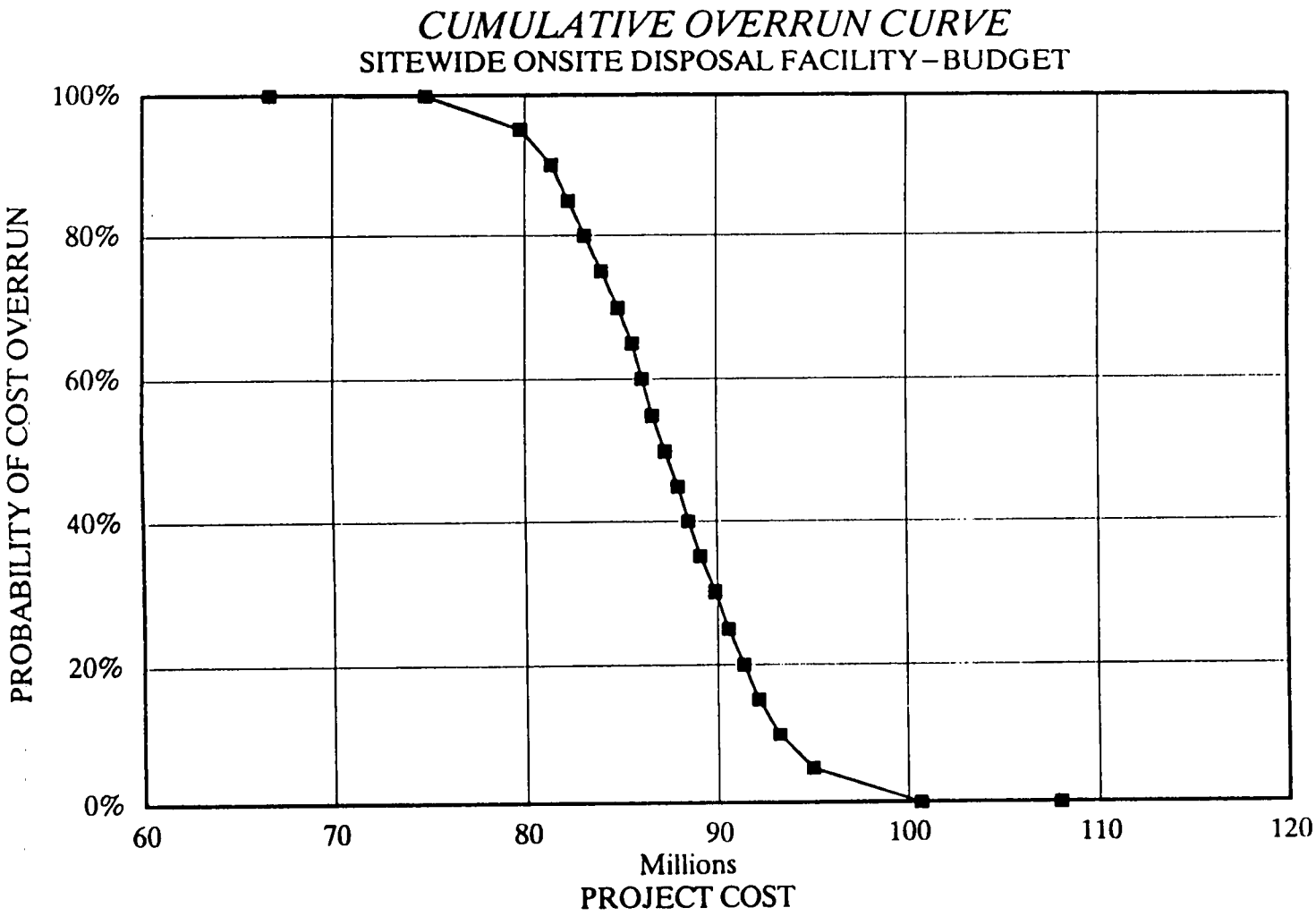
DISTRIBUTION OF 2,000 SAMPLES

SITEWIDE ONSITE DISPOSAL FACILITY – BUDGET



AVERAGE
$87,343,437

000053



BASE ESTIMATE:
$74,032,600

REQUESTOR: GREG JONES
CLIENT: U.S. DEPARTMENT OF ENERGY
PROJECT: SITEWIDE ON-SITE DISPOSAL FACILITY - BUDGET
LOCATION: FERNALD, OHIO
WBS # : 1.1.1.1.2.3.7

COST IMPACT MATRIX

EST. NO: C2950204
DATE: 03/09/95
BY: KEN KEPLER
TASK # : 2CC1

COST IMPACT MATRIX TOTAL	SITE PREP for LINER LABOR $'s		SITE PREP for LINER S/C $'s		SITE PREP for LINER MAT'L. $'s		EROSION and SEDIMENT CONTRO LABOR $'s		EROSION and SEDIMENT CONTRO S/C $'s		EROSION and SEDIMENT CONTROL MAT'L. $'s	
$74,032,600	BASE EST:	$149,600	BASE EST:	$1,048,800	BASE EST:	$30,000	BASE EST:	$79,000	BASE EST:	$0	BASE EST:	$14,600
COST DRIVER %	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH
LABOR EFFICIENCY	-5%	30%					-5%	30%				
MATERIAL PRICING			-5%	30%	-5%	15%					-5%	15%
CLASS OF CONTAMINATION												
NEW TECHNOLOGY												
NEW LAWS/REG'S												
QUANTITY VARIATION												
PROJECT DEFINITION	-5%	10%	-5%	10%	-5%	10%	-5%	10%			-5%	10%
(OTHER)												
TOTAL %	-10%	40%	-10%	40%	-10%	25%	-10%	40%	0%	0%	-10%	25%
TOTAL $	$134,640	$209,440	$943,920	$1,468,320	$27,000	$37,500	$71,100	$110,600	$0	$0	$13,140	$18,250

RISK PROFILE & CORRELATION FOR EACH COST ELEMENT	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP
	U		U		U		U		U		U	

000385

COST IMPACT MATRIX

EST. NO: C2950204
DATE: 03/09/95
BY: KEN KEPLER
TASK # : 2CC1

REQUESTOR: GREG JONES
CLIENT: U.S. DEPARTMENT OF ENERGY
PROJECT: SITEWIDE ON-SITE DISPOSAL FACILITY – BUDGET
LOCATION: FERNALD, OHIO
WBS # : 1.1.1.1.2.3.7

	NORTH INTERCEPTOR TRENCH LABOR $'s		NORTH INTERCEPTOR TRENCH S/C $'s		NORTH INTERCEPTOR TRENCH MAT'L. $'s		CONSTRUCT LINER LABOR $'s		CONSTRUCT LINER S/C $'s		CONSTRUCT LINER MAT'L. $'s	
	BASE EST:	$164,900	BASE EST:	$0	BASE EST:	$87,900	BASE EST:	$2,052,400	BASE EST:	$10,823,000	BASE EST:	$4,563,100
COST DRIVER %	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH
LABOR EFFICIENCY	-5%	30%					-5%	30%				
MATERIAL PRICING					-10%	20%			-5%	30%	-5%	20%
CLASS OF CONTAMINATION												
NEW TECHNOLOGY												
NEW LAWS/REG'S												
QUANTITY VARIATION												
PROJECT DEFINITION	-5%	10%			-5%	10%	-5%	10%	-5%	10%	-5%	10%
(OTHER)												
TOTAL %	-10%	40%	0%	0%	-15%	30%	-10%	40%	-10%	40%	-10%	30%
TOTAL $	$148,410	$230,860	$0	$0	$74,715	$114,270	$1,847,160	$2,873,360	$9,560,700	$14,872,200	$4,106,790	$5,932,030
RISK PROFILE & CORRELATION FOR EACH COST ELEMENT	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP
	U		U		U		U		U		U	

000386

189

REQUESTOR: GREG JONES
CLIENT: U.S. DEPARTMENT OF ENERGY
PROJECT: SITEWIDE ON-SITE DISPOSAL FACILITY - BUDGET
LOCATION: FERNALD, OHIO
WBS # : 1.1.1.1.2.3.7

COST IMPACT MATRIX

EST. NO: C2950204
DATE: 03/09/95
BY: KEN KEPLER
TASK # : 2CC1

	AWWT PIPING SYSTEM LABOR $'s		AWWT PIPING SYSTEM S/C $'s		AWWT PIPING SYSTEM MAT'L. $'s		PLACEMENT OF WASTE LABOR $'s		PLACEMENT OF WASTE S/C $'s		PLACEMENT OF WASTE MAT'L. $'s	
	BASE EST:	$145,700	BASE EST:	$0	BASE EST:	$349,600	BASE EST:	$4,353,400	BASE EST:	$0	BASE EST:	$0
COST DRIVER %	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH
LABOR EFFICIENCY	-5%	30%					-5%	50%				
MATERIAL PRICING					-5%	20%						
CLASS OF CONTAMINATION												
NEW TECHNOLOGY												
NEW LAWS/REG'S												
QUANTITY VARIATION												
PROJECT DEFINITION	-5%	30%			-5%	30%	-5%	50%				
(OTHER)												
TOTAL %	-10%	60%	0%	0%	-10%	50%	-10%	100%	0%	0%	0%	0%
TOTAL $	$131,130	$233,120	$0	$0	$314,640	$524,400	$3,918,060	$8,706,800	$0	$0	$0	$0

RISK PROFILE & CORRELATION FOR EACH COST ELEMENT	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP
	U		U		U		U		U		U	

000382

REQUESTOR: GREG JONES
CLIENT: U.S. DEPARTMENT OF ENERGY
PROJECT: SITEWIDE ON-SITE DISPOSAL FACILITY – BUDGET
LOCATION: FERNALD, OHIO
WBS # : 1.1.1.1.2.3.7

COST IMPACT MATRIX

EST. NO: C2950204
DATE: 03/09/95
BY: KEN KEPLER
TASK # : 2CC1

	CONSTRUCT CAP LABOR $'s		CONSTRUCT CAP S/C $'s		CONSTRUCT CAP MAT'L. $'s		GENERATED WASTE REMOVAL LABOR $'s		GENERATED WASTE REMOVAL S/C $'s		GENERATED WASTE REMOVAL MAT'L. $'s	
	BASE EST:	$1,477,800	BASE EST:	$20,026,300	BASE EST:	$2,813,000	BASE EST:	$397,000	BASE EST:	$0	BASE EST:	$0
COST DRIVER %	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH
LABOR EFFICIENCY	-5%	30%					-5%	50%				
MATERIAL PRICING			-5%	30%	-5%	20%						
CLASS OF CONTAMINATION												
NEW TECHNOLOGY												
NEW LAWS/REG'S												
QUANTITY VARIATION												
PROJECT DEFINITION	-5%	20%	-5%	20%	-5%	20%	-5%	20%				
(OTHER)												
TOTAL %	-10%	50%	-10%	50%	-10%	40%	-10%	70%	0%	0%	0%	0%
TOTAL $	$1,330,020	$2,216,700	$18,023,670	$30,039,450	$2,531,700	$3,938,200	$357,300	$674,900	$0	$0	$0	$0

RISK PROFILE & CORRELATION FOR EACH COST ELEMENT	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP
	U		U		U		U		U		U	

000388

180

REQUESTOR: GREG JONES
CLIENT: U.S. DEPARTMENT OF ENERGY
PROJECT: SITEWIDE ON-SITE DISPOSAL FACILITY – BUDGET
LOCATION: FERNALD, OHIO
WBS # : 1.1,1,1,2,3,7

COST IMPACT MATRIX

EST. NO: C2950204
DATE: 03/09/95
BY: KEN KEPLER
TASK # : 2CC1

	SITE RESTORATION LABOR $'s		SITE RESTORATION S/C $'s		SITE RESTORATION MAT'L. $'s		MONITORING WELLS LABOR $'s		MONITORING WELLS S/C $'s		MONITORING WELLS MAT'L. $'s	
	BASE EST:	$200	BASE EST:	$900	BASE EST:	$100	BASE EST:	$0	BASE EST:	$1,371,000	BASE EST:	$0
COST DRIVER %	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH
LABOR EFFICIENCY	-5%	30%										
MATERIAL PRICING			-5%	30%	-5%	20%			-5%	20%		
CLASS OF CONTAMINATION												
NEW TECHNOLOGY												
NEW LAWS/REG'S												
QUANTITY VARIATION												
PROJECT DEFINITION	-5%	50%	-5%	50%	-5%	50%			-5%	20%		
(OTHER)												
TOTAL %	-10%	80%	-10%	80%	-10%	70%	0%	0%	-10%	40%	0%	0%
TOTAL $	$180	$360	$810	$1,620	$90	$170	$0	$0	$1,233,900	$1,919,400	$0	$0

RISK PROFILE & CORRELATION FOR EACH COST ELEMENT	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP
	U		U		U		U		U		U	

000389

REQUESTOR: GREG JONES
CLIENT: U.S. DEPARTMENT OF ENERGY
PROJECT: SITEWIDE ON-SITE DISPOSAL FACILITY – BUDGET
LOCATION: FERNALD, OHIO
WBS # : 1.1.1.1.2.3.7

COST IMPACT MATRIX

EST. NO: C2950204
DATE: 03/09/95
BY: KEN KEPLER
TASK # : 2CC1

	INDIRECT FIELD COSTS LABOR $'s		INDIRECT FIELD COSTS S/C $'s		INDIRECT FIELD COSTS MAT'L. $'s		FERMCO FIELD SUPPORT COSTS LABOR $'s		FERMCO FIELD SUPPORT COSTS S/C $'s		FERMCO FIELD SUPPORT COSTS MAT'L. $'s	
	BASE EST:	$8,089,500	BASE EST:	$3,743,700	BASE EST:	$11,301,500	BASE EST:	$0	BASE EST:	$0	BASE EST:	$0
COST DRIVER %	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH
LABOR EFFICIENCY	-5%	30%										
MATERIAL PRICING			-5%	30%	-5%	10%						
CLASS OF CONTAMINATION												
NEW TECHNOLOGY												
NEW LAWS/REG'S												
QUANTITY VARIATION												
PROJECT DEFINITION	-5%	20%	-5%	20%	-5%	20%						
(OTHER)												
TOTAL %	-10%	50%	-10%	50%	-10%	30%	0%	0%	0%	0%	0%	0%
TOTAL $	$7,280,550	$12,134,250	$3,369,330	$5,615,550	$10,171,350	$14,691,950	$0	$0	$0	$0	$0	$0

RISK PROFILE & CORRELATION FOR	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP
EACH COST ELEMENT	U		U		U		U		U		U	

186

000390

REQUESTOR: GREG JONES
CLIENT: U.S. DEPARTMENT OF ENERGY
PROJECT: SITEWIDE ON-SITE DISPOSAL FACILITY - BUDGET
LOCATION: FERNALD, OHIO
WBS # : 1.1.1.1.2.3.7

COST IMPACT MATRIX

EST. NO: C2950204
DATE: 03/09/95
BY: KEN KEPLER
TASK # : 2CC1

	ENGINEERING COSTS TOTAL $'s		SALES TAX SUBCONTRACT MATERIAL $'s		SALES TAX FERMCO MATERIAL $'s							
	BASE EST:	$0	BASE EST:	$1,149,600	BASE EST:	$0	BASE EST:		BASE EST:		BASE EST:	
COST DRIVER %	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH
LABOR EFFICIENCY												
MATERIAL PRICING			-1%	1%								
CLASS OF CONTAMINATION												
NEW TECHNOLOGY												
NEW LAWS/REG'S												
QUANTITY VARIATION			-5%	20%								
PROJECT DEFINITION												
(OTHER)												
TOTAL %	0%	0%	-6%	21%	0%	0%	0%	0%	0%	0%	0%	0%
TOTAL $	$0	$0	$1,080,624	$1,391,016	$0	$0	$0	$0	$0	$0	$0	$0

RISK PROFILE & CORRELATION FOR EACH COST ELEMENT	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP	RISK PROFILE	CORRELATION GROUP
	U		U		U		U		U		U	

000391

F:\LOTUS31\SW\BUDCELL\RISK.WK3

APPENDIX F

APPENDIX F

IMPACTED MATERIAL VOLUMES AND SCHEDULE FOR OSDF DISPOSAL

FERMCO
Restoration Management Corporation
Construction - Control Team

FERNALD
Environmental Management Project

Item No.	ARS No.	OU No.	Activity Description		FY- 2001				FY- 2002				FY- 2003				FY- 2004				FY- 2005				FY- 2006				FY- 2007			
					QTR 1	QTR 2	QTR 3	QTR 4	QTR 1	QTR 2	QTR 3	QTR 4	QTR 1	QTR 2	QTR 3	QTR 4	QTR 1	QTR 2	QTR 3	QTR 4	QTR 1	QTR 2	QTR 3	QTR 4	QTR 1	QTR 2	QTR 3	QTR 4	QTR 1	QTR 2	QTR 3	QTR 4
					O-N-D	J-F-M	A-M-J	J-A-S	O-N-D	J-F-M	A-M-J	J-A-S	O-N-D	J-F-M	A-M-J	J-A-S	O-N-D	J-F-M	A-M-J	J-A-S	O-N-D	J-F-M	A-M-J	J-A-S	O-N-D	J-F-M	A-M-J	J-A-S	O-N-D	J-F-M	A-M-J	J-A-S
1		1	OU # 1 - AREA 6	SOI	4.2	2.1	6.3	6.3	4.2	1.9	6.3	6.4	4.2	2.1	6.3	6.4	4.1	2.3	6.3	6.4	4.1											
2		1	OU # 1 - AREA UNDER PITS	RUB																												
3			OU # 1																													
4		2	OU # 2 - AREA 5	SOI																												
5		2		RUB																												
6			OU # 2																													
7		3	OU # 3 ABOVE GROUND	SOI																												
8		3		RUB	4.1	6.1	4.1	3.1	3.1	3.1	4.1	4.1	4.1	4.1	1.1	1.0	1.0	1.0	1.0	1.0	1.0											
9		3	OU # 3 AREA 3	SOI																												
10		3		RUB																												
11		3	OU # 3 AREA 4	SOI							178.2	197.2	130.2	63.2	141.2																	
12		3		RUB							17.4	24.4	21.6																			
13		3	OU # 3 AREA 5	SOI														53.0	145.0	142.0												
14		3		RUB													18.2	23.4	7.7													
15			OU # 3																													
16		4	OU # 4 BLDG RUBBLE	RUB																												
17		4	OU # 4 AREA 7	SOI							25.00	83.00	32.00																			
18			OU # 4																													
19		5	OU # 5 AREA 1	RUB																												
20		5		SOI																												
21			OU # 5																													
22			SUMMARY																													
23			ALL SOILS	SOI	4.2	2.1	6.3	6.3	4.2	1.9	209.6	286.7	166.6	68.3	147.6	6.4	4.1	55.3	151.3	148.4	4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24			ALL RUBBLE	RUB	4.1	6.1	4.1	3.1	3.1	3.1	21.6	28.6	26.7	4.1	1.1	1.0	17.2	24.4	8.7	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25																																
27																																
28			GRAND TOTAL CUMULATIVE		1,218.0	1,226.2	1,236.6	1,246.0	1,253.3	1,256.4	1,460.6	1,604.7	1,996.9	2,064.2	2,214.0	2,222.3	2,243.7	2,325.4	2,485.4	2,632.8	2,634.0	2,634.0	2,634.0	2,634.0	2,634.0	2,634.0	2,634.0	2,634.0	2,634.0	2,634.0	2,634.0	2,634.0
29																																
30																																

FERMCO
Restoration Management Corporation
Costreaches - Control Team

$ 276 MILLION CASE
Revision "1"

Item No.	ABS No.	OU No.	Activity Description		Remarks	Total Quantity	Quantity Check
1		1	OU # 1 - AREA 6	SOI		131,000	131.00
2		1	OU # 1 - AREA UNDER PITS	RUB			
3			OU # 1				
4		2	OU # 2 - AREA 5	SOI		317,500	317.50
5		2		RUB			
6			OU # 2				
7		3	OU # 3 ABOVE GROUND	SOI			
8		3		RUB		124,000	124.00
9		3	OU # 3 AREA 3	SOI		580,534	580.53
10		3		RUB		39,825	39.83
11		3	OU # 3 AREA 4	SOI		710,169	710.17
12		3		RUB		63,513	63.51
13		3	OU # 3 AREA 5	SOI		340,048	340.05
14		3		RUB		47,277	47.28
15			OU # 3				
16		4	OU # 4 BLDG RUBBLE	RUB			
17		4	OU # 4 AREA 7	SOI		140,000	140.00
18			OU # 4				
19		5	OU # 5 AREA 1	RUB			
20		5		SOI		161,000	161.00
21			OU # 5				
22			SUMMARY				
23			ALL SOILS	SOI		2,380,251	2,380.25
24			ALL RUBBLE	RUB		274,615	274.62
25							
27							
28			GRAND TOTAL CUMULATIVE				
29							
30							
					TOTALS:		
					TOTAL - By Quarter:		
					TOTAL - By Fiscal Year:		

Item No.	FY-1996 QTR 1 O-S-D	FY-1996 QTR 2 J-F-M	FY-1996 QTR 3 A-M-J	FY-1996 QTR 4 J-A-S	FY-1997 QTR 1 O-S-D	FY-1997 QTR 2 J-F-M	FY-1997 QTR 3 A-M-J	FY-1997 QTR 4 J-A-S	FY-1998 QTR 1 O-S-D	FY-1998 QTR 2 J-F-M	FY-1998 QTR 3 A-M-J	FY-1998 QTR 4 J-A-S
1											6.3	6.4
2												
3								58.6	58.6	31.0	69.6	58.6
4												
5												
6												
7	3.1	4.1	4.1	4.1	5.1	4.1	4.1	4.1	4.1	4.1	4.1	3.1
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19							120.00	41.00				
20												
21												
22	0.0	0.0	0.0	0.0	0.0	0.0	120.0	99.6	54.6	31.0	98.6	98.2
23	3.1	4.1	4.1	4.1	5.1	4.1	4.1	4.1	4.1	4.1	4.1	3.1
24												
25												
27	2.1	7.2	11.3	16.4	20.6	24.6	148.7	352.4	316.1	346.2	448.2	516.5
28												
29												
30												
TOTALS:												
TOTAL - By Quarter:												
TOTAL - By Fiscal Year:												

Item No.	FY-1999 QTR 1 O-S-D	FY-1999 QTR 2 J-F-M	FY-1999 QTR 3 A-M-J	FY-1999 QTR 4 J-A-S	FY-2000 QTR 1 O-S-D	FY-2000 QTR 2 J-F-M	FY-2000 QTR 3 A-M-J	FY-2000 QTR 4 J-A-S	FY-2001 QTR 1 O-S-D	FY-2001 QTR 2 J-F-M	FY-2001 QTR 3 A-M-J	FY-2001 QTR 4 J-A-S
1	4.1	2.2	6.3	6.4	4.1	2.3	6.3	6.3	4.2	2.1	6.3	6.3
2												
3	21.0											
4												
5												
6												
7	4.1	4.1	3.1	4.1	4.1	4.1	4.1	4.1	4.1	6.1	4.1	3.1
8			180.1	190.1	122.1	68.1						
9	1.9	12.6	12.8	12.6								
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												
21												
22	28.1	2.2	186.4	196.8	128.3	70.4	6.3	6.3	4.2	2.1	6.3	6.3
23	6.0	16.7	15.8	16.7	4.1	4.1	4.1	4.1	4.1	6.1	4.1	3.1
24												
25												
27	549.6	566.4	715.7	963.8	1,114.3	1,184.6	1,190.3	1,208.7	1,218.0	1,224.3	1,230.6	1,246.0
28												
29												
30												
TOTALS:												
TOTAL - By Quarter:												
TOTAL - By Fiscal Year:												

PRELIMINARY DESIGN
CALCULATION PACKAGE
ON-SITE DISPOSAL FACILITY

REVISION B
VOLUME 1 OF 3
DECEMBER 1995

United States Department of Energy
Fernald Environmental Management Project
Fernald, Ohio

prepared by

GEOSYNTEC CONSULTANTS
1100 Lake Hearn Drive, NE, Suite 200
Atlanta, Georgia 30342

under

Fernald Environmental Restoration Management Corporation
Subcontract 95PS005028

186 NO. 29

PRELIMINARY DESIGN CALCULATION PACKAGE ON-SITE DISPOSAL FACILITY

Volume I

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December 1995
Revision B

United States Department of Energy

Fernald Environmental Management Project
Fernald, Ohio

Prepared by

GeoSyntec Consultants
1100 Lake Hearn Drive, NE, Suite 200
Atlanta, Georgia 30342

Under

Fernald Environmental Restoration Management Corporation
Subcontract 95PS005028

000396

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SUMMARY OF SEQUENCE OF CALCULATION-PACKAGE REVIEWS AND APPROVALS

In accordance with GeoSyntec Engineering Procedure (EP) No. EP-305, the required sequencing of reviews and approvals of calculations for the FEMP OSDF design packages are as follows:

1. A written summary of specific calculation procedures is prepared by the Cognizant Engineer who also initials and dates each page.

2. The appropriate team leader reviews and approves the procedure summary and initials and dates each page of the procedures summary. Note that in some circumstances the project manager may serve as a team leader.

3. The Cognizant Engineer prepares written documentation of the collection and verification of calculation data in accordance with GeoSyntec EP-302 for inclusion in the calculations package, and initials and dates each page of the documentation.

4. The appropriate team leader reviews and approves the documentation of calculation data and initials and dates each page of the documentation.

5. The Cognizant Engineer prepares the calculations/analyses, including any computer input and output listings used, on sequentially numbered calculation sheets, and signs and dates each calculation sheet. (Numbered appendices require no initials or dates.)

6. The Cognizant Engineer prepares a title page (i.e., the Computation Cover Sheet) and signs and dates it on the appropriately designated lines.

7. The Checker reviews procedures, data verification, and calculations and initials and dates each page.

8. The Cognizant Engineer reconciles with the Checker any deficiencies or errors identified by the Checker. The Checker then signs and dates the title page on the appropriately designated lines.

9. The Cognizant Engineer performs an independent "backcheck" of the calculations and signs and dates the title sheet on the appropriately designated lines.

10. The Project Design Professional (PDP), who in many instances may be the same individual as the Cognizant Engineer, performs the required review and approval and signs and dates the title page on the appropriately designated lines.

11. The appropriate team leader performs the required review and approval and signs and dates the title page on the appropriately designated lines.

SECTION 1

1. DESIGN PARAMETER SUMMARY

COMPUTATION COVER SHEET

SUBJECT OF CALCULATION: DESIGN PARAMETER SUMMARY

Computations By: (Cognizant Engineer)
Signature: Mark Gleason by GES — Date: 18 Dec 95
Printed Name and Title: Mark Gleason, Asst. Project Engineer

Assumptions and Procedures Checked by: (Checker)
Signature: Daniel G. Pass — Date: 18 DEC 95
Printed Name and Title: DANIEL G. PASS, STAFF ENGINEER

Computations Checked by:
Signature: NO COMPUTATIONS IN THIS PACKAGE — Date:
Printed Name and Title:

Computations Backchecked by: (Cognizant Engineer)
Signature: NO COMPUTATIONS IN THIS PACKAGE — Date:
Printed Name and Title:

Approved by: (PDP)
Signature: Gary R. Schmertmann — Date: 18 Dec 95
Printed Name and Title: Gary R. Schmertmann, Senior ~~Staff~~ Project Engineer

Approved by: (DTL and TETL)
Signature: [illegible] — Date: 18 Dec 95
Printed Name and Title: Kenneth W. Cargill, Associate

Record of Revision (Number and initial all revisions)

Rev. No.	Reason	Date	By	Checked	Approval
~~A~~	~~30% submittal~~				
B	EPA Submittal - Preliminary Design	18 Dec 95	[illegible]		

DESIGN PARAMETER SUMMARY

INTRODUCTION AND SCOPE

The purpose of this design parameter summary is to provide information regarding the values of the parameters used in the design calculations for the On-Site Disposal Facility (OSDF). The summary addresses parameters that are used within two or more individual design calculation packages. Parameters that are used within only one individual design calculation package are addressed in the Data Verification section of that individual package.

For this summary, a number of general design parameter categories have been established. Each individual design parameter has been associated with one of the general categories. For example, an individual design parameter such as the thickness of the primary geomembrane in the liner system is associated with the general design parameter category of geosynthetics.

A general guide to the use of design parameters in the calculations is provided in the attached Table 1. This table is a matrix which lists the general parameter categories from top to bottom on the left edge and the individual sections of the design calculation package from left to right on the top edge. The checked boxes in the matrix indicate which calculation packages use parameters from any of the general parameter categories. For example, inspection of Table 1 indicates that parameters relating to site hydrogeology are used in the following four calculation packages: (i) Foundation Settlement; (ii) Foundation Stability; (iii) Perimeter Access Corridor; and (iv) Hydrostatic Forces.

The remainder of this summary provides information regarding the values of the parameters used in the design calculations. As discussed above, only parameters that are used within two or more individual design calculation packages are addressed. This summary is organized with each section addressing one of the general design parameter categories. The order of presentation is that used in Table 1.

GENERAL DESIGN PARAMETER CATEGORIES

OSDF Geometry

This section addresses design parameters relating to the geometry of the OSDF. Data such as dimensions, areas, and slopes are obtained from the Design Drawings. The source drawing titles are listed below:

- Site Plan;
- Subgrade Grading Plan;
- Leachate Collection System Grading Plan;
- Final Cover System Grading Plan;
- North - South Section Plan;
- East - West Section Plan(s);
- Liner and Cover System Details I;
- Liner and Cover System Details II;
- Borrow Area Development Plan; and
- Borrow Area Restoration Plan.

In addition, information needed for the "Earthwork Required Volumes" calculation and the "OSDF Required Volume" calculation was obtained from the following drawing provided by Fermco: "Alternatives 3A and 3D, On-Property, Undeveloped Park @ 1.E-6 + ALARA base + level 1 + level 2".

Based on these drawings, the following key design data were obtained.

- For general landfill design, the OSDF will have 8 cells (with a 9th cell for contingency). The area for each cell will be approximately 6.7 acres. The cell dimensions will be approximately 400 ft by 725 ft. The cells will be separated from the adjacent cell by intercell berms that are a maximum of 7 ft in height.

- The subgrade and leachate collection layer along the base of the OSDF will have a slope of 2.24 percent, resulting from design grades of 1 percent in the E-W direction (i.e., parallel to the leachate collection pipes) and 2 percent in the N-S direction (i.e., perpendicular to the leachate collection pipes). The maximum drainage length in the leachate collection layer will be 224 ft. The slope on the liner system perimeter sideslopes will be 25 percent, corresponding to 4H:1V design grades.

- The final cover system slopes of the OSDF vary on the East - West Sections from 20H:1V, to 10H:1V, to 6H:1V. The maximum final slope is 6H:1V. Details of the configuration of the final slopes is given in the Design Drawings. Interim OSDF slopes may be as steep as 3H:1V during construction and material placement.

Topography

This section addresses existing site topography. As indicated in Table 1, topography is primarily related to stormwater management calculations for the OSDF and the Borrow Area. The topography is also related to the Hydrostatic Forces calculation. All topographic data that is related to the calculations indicated on Table 1 was obtained from the following plans included in the Design Drawings: "Site Plan" and "Borrow Area Development Plan". Specific point elevations and slopes needed in the calculation packages are obtained from this plan.

Climate

Climate-related data such as temperature, evapotranspiration, and precipitation are addressed in this section. Climate data that are directly related to evaporative zone depth, average wind speed, and soil temperature are specific data that do not appear in multiple calculations, and therefore, are not discussed in this section.

Climate data for average monthly precipitation, solar radiation, and temperature are obtained from the "Hydrologic Evaluation of Landfill Performance (HELP) Model, Version 3" USEPA Office of Research and Development, Washington, D.C., Report No. EPA/600/R-94/168b, Sep 1994. The reference city (source for data input into model) for the temperature and solar radiation data is Cincinnati, Ohio. The reference city for the precipitation data is Covington, Kentucky. Covington, KY was used for the precipitation data because synthetic rainfall data is not available in the HELP Model for Cincinnati, Ohio.

Precipitation data are shared by many calculations. The data and sources used for the calculations are presented below:

- rainfall distribution is Type II for Ohio (USDA-SCS "Urban Hydrology for Small Watersheds", Technical Release 55 (TR-55), June 1986);

- rainfall for the following 2-year, 25-year, and 2000-year, 24-hour storm events is 2.55 in, 4.7 in, 13.0 in, respectively (Parsons, "2000 year Flood and Probable Maximum Flood, Sitewide Floodplain Determination", Revision A, August 1995); and

- average rainfall energy is 175 (Ohio SCS guidelines for "Water Management and Sediment Control for Urbanizing Areas", 1987).

The 25-year 24-hour storm event is used to calculate runoff and size the sedimentation basin for the OSDF construction and borrow area erosion and sediment control calculations. The 2000-year 24-hour storm event is used to calculate the runoff from the closed OSDF, size the perimeter drainage swale and calculate erosion on the final cover. The 2-year 24-hour storm event is used to size components of the leachate transmission system.

Hydrogeology

Data for hydrogeology at the OSDF is presented for the perched ground-water table and the static ground-water table.

- Data for the perched ground-water table is obtained from Figure 2-20 of Parsons "Pre-Design Investigation and Site Selection Report for the On-Site Disposal Facility", Volume 1 of 3, July 1995. Specific point elevations needed in the calculation packages are obtained from this source.

- Data regarding ground-water within the Great Miami Aquifer soils indicates that the elevation of the static ground-water table below the OSDF is variable, ranging from 70 to 90 feet below the ground surface (Parsons, Remedial Investigation Report for Operable Unit 2, 21 January 1995). For the foundation settlement and foundation stability calculations it is conservative to use a groundwater elevation corresponding to the upper elevation of the range. Therefore, for these calculations the location of the static ground-water table was assumed to be 70 ft below ground surface.

Vegetation

Design parameters in the vegetation category include ground cover descriptions for existing, construction and long-term conditions. Ground cover descriptions are used in the following types of calculations: (i) stormwater management; (ii) erosion control; (iii) leachate generation rate; and (iv) construction water demand. Ground cover descriptions are determined

for the OSDF area, the East Field OSDF borrow area and nearby drainage areas of the OSDF and the East field areas.

Data used to describe existing vegetative conditions was obtained from aerial photographs and from the report "Operable Unit 5 Remedial investigation" (March 1995). The existing vegetative cover at the OSDF and East Field borrow area is a grassland of good condition.

Parameters used for descriptions of expected vegetative cover for construction and long-term conditions were estimated considering anticipated construction activity and the design period. Vegetative cover is expected to vary from none for newly-graded areas as a result of construction activity to grassland for long-term (i.e., restored) conditions.

Geosynthetics

The geosynthetic materials that are considered in the design calculations are those shown in the Design Drawings. These materials are as follows:

- Primary and secondary geomembrane liner - textured 80 mil High Density Polyethylene (HDPE);
- Geomembrane cap - textured 60 mil HDPE;
- Primary Geosynthetic Clay Liner (GCL) - sodium montmorillonite clay core with textured 40 mil HDPE geomembrane backing;
- Secondary GCL - internally reinforced sodium montmorillonite core with geotextile backing (both sides);
- GCL Cap - reinforced or unreinforced GCL conforming to the specifications stated above (except 30 mil instead of 40 mil HDPE for geomembrane backing);
- Geotextile filter and geotextile cushion - polyester or polypropylene needle-punched nonwoven geotextile; and
- Geocomposite drainage layer - polyethylene geonet core with polypropylene or polyester needle-punched nonwoven geotextile bonded to each side.

Shear Strength

Interface shear strengths between these geosynthetics and the adjacent materials and the internal shear strength of the GCLs are used in several calculation packages. Although shear strength tests have not yet been performed, estimates of the shear strengths for the geosynthetics

and the interfaces in the liner and cover system are required. The shear strengths are estimated based on the following sources:

- geosynthetics manufacturer's literature;
- unpublished results from GeoSyntec Consultants;
- Martin, J.P., Koerner, R.M., and Whitty, J.E., "Experimental Friction Evaluation of Slippage Between Geomembranes, Geotextiles, and Soils", *Proceedings, International Conference on Geotextiles*, IFAI, Denver, 1984, pp. 191-196;
- Koerner, R.M., Martin, J.P., and Koerner, G.R., "Shear Strength Parameters Between Geomembranes and Cohesive Soils", *Geotextiles and Geomembranes*, Vol. 4, No. 1, 1986, pp. 21-30; and
- Williams, N.D., and Houlihan, M.F., "Evaluation of Interface Friction Properties Between Geosynthetics and Soils", *Proceedings, Geosynthetic '87*, New Orleans, LA, 1987, pp. 616-627.

Interface Shear Strength

- Geotextile/granular soil interface. The granular soils (i.e., vegetative layer, drainage layer, LCS and LDS layers, etc.) are assumed to have an internal friction angle of 30 degrees and a cohesion of zero (discussion in cover and liner system sections). Based on the sources listed above, it is reasonable to assume that the interface strength is 70 to 80 percent of the soil strength. Therefore, the geotextile/granular soil interfaces are assumed to have an internal friction angle of 22 to 25 degrees and an adhesion of zero.

- Geotextile/textured HDPE geomembrane interface. Based on the sources listed above, it is reasonable to assume that this interface has an internal friction angle of 25 degrees and an adhesion of zero.

- Compacted clay/textured HDPE geomembrane interface. The shear strength of the compacted clay used in the cover and liner system is assumed to be represented by a friction angle of 25 degrees and an cohesion of zero (discussion in cover and liner system sections). Based on the sources listed above, it is reasonable to assume that the interface strength is 80 percent of the soil strength. Therefore, it is assumed that the interface has an internal friction angle of 20 degrees and an adhesion of zero.

GCL Internal Shear Strength

The shear strength of the GCL is a function of GCL type (i.e., reinforced or unreinforced), normal stress acting on the GCL, hydration conditions, and the duration of loading. The assumed shear strengths discussed below are based on the information sources listed above.

For short-term conditions:

- The unreinforced GCL is protected on either side by a geomembrane and is assumed to remain dry. The peak shear strength of the clay component is assumed to be represented by an internal friction angle of 25 degrees and a cohesion of zero. The interface shear strength of the GCL and the HDPE geomembrane is assumed to be 80 percent of the peak strength, or an internal friction angle of 20 degrees and an adhesion of zero.

- The reinforced GCL is assumed to be hydrated. The peak internal shear strength is assumed to be represented by an internal friction angle of 30 degrees and a cohesion of zero.

For long-term conditions:

- The reinforced GCL and the unreinforced GCL are assumed to have the same shear strength due to long-term reduction in the effect of the reinforcing elements. The unreinforced GCL is assumed to be hydrated. The shear strength is assumed to be a function of the normal stress as follows:

Normal Stress	Angle of Internal Friction for Peak Shear Strength (cohesion taken as zero)
850 psf	15 degrees
1900 psf	12 degrees
5600 psf	9 degrees
7500 psf	8 degrees

Installation and Performance of Geomembrane

The following assumptions are made regarding installation and performance of the geomembrane for the leachate generation rate and leachate transmission system calculations.

- saturated hydraulic conductivity of the geomembrane, 2xE-13 cm/s;
- pinhole density, zero;
- placement quality, good;
- installation defect density for cover system geomembrane for leachate generation calculations, 1 sq cm per acre; and
- installation defect density for liner system geomembrane for leachate transmission calculations, zero defects.

It is noted that the use of the two different defect density values provides a characterization which is conservative for each calculation.

HDPE Pipe

Design parameters for HDPE pipe are used in the leachate collection system calculations, the leakage detection system calculations, and in the leachate transmission system calculations. The pipes for the leachate collection and leakage detection system are SDR 11 pipes with a 6 in. nominal diameter. The pipe for the leachate transmission system is a dual-containment SDR 11 pipe with an outer pipe nominal diameter of 12 in. and an inner pipe nominal diameter of 6 in. The following additional design parameters are used:

- hydraulic gradient (slope) - varies - 1 percent for leachate collection and detection system pipes, 0.5 percent minimum for the leachate transmission system pipes. Values based on OSDF geometry given in the Design Drawings.

- concentrated construction loads (wheel loads) - 20,000 lbs. Values represents assumed wheel load for a 35-ton capacity dump truck.

- impact factor for dynamic loads, 1.5, and minimum pipe effective length , 3 ft. Values based on ASCE publication "Design and Construction of Sanitary and Storm Sewers", Manual and Report on Engineering Practice No. 37, reprinted 1979.

- modulus of soil reaction - 4.32 x 10^5 psf. Value based on GeoSyntec project experience.

In addition, the following data obtained from pipe manufacturer's literature is used for the pipe design calculations:

- modulus of elasticity - 2.7 x 10^6 psf;
- compressive yield strength - 2.16 x 10^5 psf;
- allowable ring deflection - 7 percent; and
- manning's roughness coefficient - 0.013.

Cover System

This section addresses design parameters for the OSDF final cover system. The parameters are related to the geometry and cross section of the cover system and the properties of the individual material components of system. Based on the Design Drawings, the cover system consists of the following components from bottom to top:

- 2-ft thick compacted clay cap;
- geosynthetic clay liner;
- 60-mil textured HDPE geomembrane;
- geotextile cushion;
- 1-ft thick cover drainage layer;
- geotextile filter;
- 3-ft thick biointrusion barrier layer;
- 0.5-ft thick granular filter layer;
- 1.75-ft thick vegetative soil layer; and
- 0.5-ft thick topsoil layer.

Parameters related to the geosynthetic components of the cover system are discussed in the geosynthetics section of this document.

Geometry

The total thickness of the soil components of the cover system is 8.75 ft (approximately 9 ft) with the geosynthetic components adding negligible additional thickness. The total thickness of the soil components of the cover system that overlie the geomembrane is 6.75 ft

(approximately 7-ft) with the geosynthetic components adding negligible additional thickness. It is noted that cover system slopes are discussed in the OSDF Geometry section of this summary.

Total Unit Weight

The total unit weight of each of the soil components of the cover system, with the exception of the compacted clay component, is assumed to be 125 pcf. This value is based on typical values used in geotechnical practice for the moist unit weight of primarily granular soils. For the "Erosion of the OSDF Final Cover" calculation a smaller value of 100 pcf is used for the unit weight of the topsoil component of the final cover. This value is appropriate because it is conservative in the context of the calculation (i.e., the smaller the unit weight, the fewer number of years calculated for full topsoil erosion).

The total unit weight of the compacted clay component is assumed to be 130 pcf. This value is based on tests performed on remolded samples of the on-site brown till material which is proposed for use as the compacted clay component of the cover system (and liner system). The test data is presented in the Parson's report entitled "Disposal Facility Pre-Design Geotechnical Investigation and Report", Operable Unit 2, Revision 0, July, 1995. For the "Construction Water Demand Estimation" calculation a smaller value of 125 pcf is used. Although inconsistent with the value used for other calculations, this value is acceptable because its use results in a negligible (i.e., less than 1 percent) underprediction of water demand.

It is noted that for the "Hydrostatic Forces" forces calculation a value of 126.1 pcf is used for the average total unit weight of the final cover system. This value is appropriate because it represents a weighted average of the unit weights of the compacted clay component and the other soil components.

Shear Strength

The shear strength of the soil components of the cover system, with the exception of the compacted clay component, is assumed to be represented by an internal friction angle of 30 degrees and a cohesion of zero. This value is based on typical values used in geotechnical practice for the near-lower-bound shear strength of primarily granular soils.

The long-term (drained) shear strength of the compacted clay component is assumed to be represented by an internal friction angle of 25 degrees and a cohesion of zero. This value is

based on tests performed on remolded samples of the on-site brown till material which is proposed for use as the compacted clay component of the cover system (and liner system). The test data is presented in the Parson's report entitled "Disposal Facility Pre-Design Geotechnical Investigation and Report", Operable Unit 2, Revision 0, July, 1995.

Other Parameters

The porosity of the compacted clay is assumed to be 0.398 for the "Leachate Generation Rate" calculation and 0.464 for the "Erosion of OSDF Final Cover" calculation. These values were obtained from guidelines in the HELP program documentation - "Hydrologic Evaluation of Landfill Performance (HELP) Model, Version 3" USEPA Office of Research and Development, Washington, D.C., Report No. EPA/600/R-94/168b, Sep 1994. Although the values differ slightly, they are appropriate because the use of a slightly higher value is conservative for erosion calculation (i.e., the higher the porosity, the smaller the allowable tractive force).

A 1-ft thick contouring layer, underlying the compacted clay, is considered to be part of the final cover system in some calculations. Where considered, the properties of this layer are assumed to be similar to the compacted clay.

Impacted Material

The impacted material to be placed in the OSDF consists of a combination of on-site contaminated soil, fly ash, demolition debris from the existing buildings, municipal solid waste, and lime sludge. It is anticipated that approximately 80 percent of the impacted materials will be soil (see "OSDF Required Volume" calculation). The majority of this soil will be excavated from the brown till. Therefore, the properties of the impacted material are assumed to be similar to recompacted brown till.

It is assumed that the impacted material will be compacted at its optimum water content to 85 to 90 percent relative compaction (with respect to Standard Proctor compaction). Based on data obtained from tests performed on recompacted brown till the following assumptions regarding the impacted material's properties are made (Parsons, "Disposal Facility Pre-Design Geotechnical Investigation and Report", Operable Unit 2, Revision 0, July, 1995.):

- total unit weight of 125 pcf;
- short-term shear strength represented by an internal friction angle of 25 degrees and a cohesion of 200 psf; and
- long-term shear strength represented by an internal friction angle of 25 degrees and a cohesion of zero.

For the "Hydrostatic Forces" calculation a total unit weight of 80 pcf was assumed. This assumed lower value, which is based on the total unit weight of an impacted material that consists primarily of fly ash, is conservative for the calculation (i.e., the lower the unit weight the greater the potential for liner uplift).

The total thickness of the impacted material varies across the OSDF. Based on the Design Drawings the maximum impacted material thickness is estimated to be 50 ft. For the "Hydrostatic Forces" and "Leachate Generation Rates" calculations, smaller thicknesses of impacted material are used in some cases. These smaller values are appropriate for the "Hydrostatic Forces" calculation because they represent actual design thicknesses at spot locations where uplift calculations are performed. These smaller values are appropriate for the "Leachate Generation Rates" calculation because they represent impacted material thicknesses prior to final cover construction.

It is noted that settlement, water balance, and compaction properties for the impacted material are described in the Data Verification sections of the calculations where they are used (i.e., "Impacted Material Settlement", Leachate Generation Rates", and "OSDF Required Volume" calculations, respectively).

Liner System

This section addresses design parameters for the OSDF liner system. The parameters are related to the geometry and cross section of the liner system and the properties of the individual material components of system. Based on the Design Drawings, the liner system consists of the following components from bottom to top:

- 3-ft thick compacted clay liner;
- secondary geosynthetic clay liner;
- secondary 80-mil textured HDPE geomembrane;
- geotextile cushion;
- 1-ft thick leachate detection layer;

- primary geosynthetic clay liner;
- primary 80-mil textured HDPE geomembrane;
- geotextile cushion;
- 1-ft thick leachate collection layer;
- geotextile filter; and
- 1-ft thick protective soil layer.

Parameters related to the geosynthetic components of the liner system are discussed in the geosynthetics section of this document.

Geometry

The total thickness of the soil components of the liner system is 6 ft. with the geosynthetic components adding negligible additional thickness. It is noted that liner system base and side slopes are discussed in the OSDF Geometry section of this summary.

Total Unit Weight

The total unit weight of each soil component of the liner system, with the exception of the compacted clay component, is assumed to be 125 pcf. This value is based on typical values used in geotechnical practice for the moist unit weight of primarily granular soils.

The total unit weight of the compacted clay component is assumed to be 130 pcf. This value is based on tests performed on remolded samples of the on-site brown till material which is proposed for use as the compacted clay component of the liner system (and liner system). The test data is presented in the Parson's report entitled "Disposal Facility Pre-Design Geotechnical Investigation and Report", Operable Unit 2, Revision 0, July, 1995.

Shear Strength

The shear strength of the soil components of the liner system, with the exception of the compacted clay component, is assumed to be represented by an internal friction angle of 30 degrees and a cohesion of zero. This value is based on typical values used in geotechnical practice for the near-lower-bound shear strength of primarily granular soils.

The long-term (drained) shear strength of the compacted clay component is assumed to be represented by an internal friction angle of 25 degrees and a cohesion of zero. The short-term

(undrained) shear strength of the compacted clay component is assumed to be represented by an internal friction angle of zero degrees and a cohesion of 1200 psf. These values are based on tests performed on remolded samples of the on-site brown till material which is proposed for use as the compacted clay component of the liner system. The compacted clay for the liner system is assumed to be placed at 95 to 98 percent relative compaction (with respect to Standard Proctor compaction). The test data is presented in the Parson's report entitled "Disposal Facility Pre-Design Geotechnical Investigation and Report", Operable Unit 2, Revision 0, July, 1995.

Other Parameters

For the leachate generation and leachate collection and detection calculations, the saturated hydraulic conductivity of the granular materials in the leachate collection and detection system is taken as of 0.1 cm/s. This value is equal to the minimum hydraulic conductivity permitted in the project material specifications.

Values of void ratio for the compacted clay component of the liner system will be discussed in the future versions of this summary document.

Subsurface Soils

This section addresses design parameters for the subsurface soils at the OSDF. Subsurface soils are the in-situ soils and consist of the brown till, the gray till, and the Great Miami Aquifer (GMA) granular soils. Parameters that are used in two or more calculations include thickness, total unit weight, undrained shear strength, and drained shear strength. Parameters that are specific to individual calculations such as consolidation parameters, elastic settlement parameters, and dynamic parameters are presented in the Data Verification section of the calculations in which the parameters appear.

Material parameters discussed below are based on data presented in two Parson's reports: "Disposal Facility Predesign Geotechnical Investigation, Soil Investigation Data Report", July 1995, Revision 1, and "Disposal Facility Pre-Design Geotechnical Investigation and Report, Operable Unit 2", Revision A, July, 1995. The thicknesses of the soil layers are based on existing site conditions and planned excavations shown on the Design Drawings.

For the brown till soils, the cited sources indicate that the layer thickness ranges from 5 to 15 ft. For stability analyses (static and seismic) the brown till is a weak layer and is therefore assumed to have the maximum expected thickness, 15 ft. For settlement analyses, calculations

are performed for 5 and 10 ft thicknesses to obtain a range of calculated settlement values. Based on the cited sources, the total unit weight of the brown till is assumed to be 135 pcf. The shear strength of the brown till is assumed to be represented by an internal friction angle of zero degrees and a cohesion of 1200 psf for short-term (undrained) conditions and by an internal friction angle of 25 degrees and a cohesion of zero for long-term (drained) conditions.

For the gray till soils, the cited sources indicate that the material thickness ranges from a minimum of 15 ft to a maximum of 45 ft across the OSDF site. The total unit weight of the gray till is assumed to be 145 pcf. The shear strength of the gray till is assumed to be represented by an internal friction angle of zero degrees and a cohesion of 1900 psf for short-term (undrained) conditions and by an internal friction angle of 30 degrees and a cohesion of zero for long-term (drained) conditions.

For the GMA granular soils, the aquifer thickness is assumed to range between 172 and 210 ft in thickness. The 210 ft GMA soils thickness is associated with use of the 5 ft thick brown till and 15 ft thick gray till layers. The total unit weight of the GMA soils is assumed to be 135 pcf and the shear strength is assumed to be represented by an internal friction angle of 35 degrees and a cohesion of zero.

Bedrock

Design parameters relating to the bedrock at the OSDF site are addressed in this section. The parameters assumed for bedrock are used in the foundation settlement, foundation stability, and seismic calculations. Only the seismic-related parameters are addressed herein because they are the only parameters used in two or more calculations. Based on data presented by Parsons in a report entitled "Remedial Investigation Report for Operable Unit 5, Draft Final, March 1995", the bedrock is assumed to be approximately 230 ft below the OSDF. The dynamic properties of the bedrock that are used in the seismic calculations are the following: (i) the peak bedrock acceleration from the design seismic event is 0.16 g; (ii) the maximum moment magnitude of the design seismic event is 6.1; (iii) the artificial accelerogram used to simulate the design seismic event is B2-SYN; and (iv) a value of 5 percent viscous damping is used.

Leachate Generation

The "Leachate Generation Rate" calculation is used to verify the adequacy of the leachate collection, detection, and transmission system designs. One of the results of the calculation is

the predicted maximum leachate generation rate for the initial stages of cell operation, 1771 gpad. This predicted rate is used as a design parameter in several other individual calculations.

Hydrology

Design parameters considered in the hydrology parameter category include information regarding runoff curve number and Manning's roughness coefficient for the OSDF and the borrow area during various stages of site activity. Assumed parameters are needed for existing conditions, construction conditions, and final conditions for both the OSDF and the OSDF borrow area.

Parameters relating to existing, construction, and final surface conditions are needed for each calculation. The associated runoff curve number and Manning's roughness coefficient are directly related to the type of surface condition or hydraulic structure. These parameters are used in the calculations for stormwater runoff and erosion control. Values for these parameters are obtained from the following sources:

- Chow, Ven Te, "Open-Channel Hydraulics", 1959;
- USDA-SCS, "Urban Hydrology for Small Watersheds", 1986;
- American Iron and Steel Institute, "Handbook of Drainage & Highway Construction Products", 1983; and
- USDA-SCS, "Engineering Manual for Conservation Practice", Nov 1986.

Erosion and Sediment Control

This section addresses design parameters used in two or more calculations for erosion and sediment (E&S) control. Based on state and federal regulations, the required sediment storage volume for use in the calculations is 1800 cubic feet per disturbed acre. This value is used for the "OSDF E&S Basin Sizing" and the "Impacted Runoff Catch Basin Sizing" calculation. For the "Borrow Area E&S Basin Sizing" calculation a value of 5450 cubic feet per disturbed acre is used. The appropriateness of these two differing values of required storage volume will be discussed in the future versions of this summary document.

The calculations involving erosion of the OSDF final cover and the OSDF perimeter drainage swale both use a value of 5 tons of soil per acre as the maximum allowable annual soil loss.

Structural Fill

There are no design parameters related to structural fill material that are used in two or more calculations. Therefore, further discussion is not provided herein.

Drainage Structures

This category includes design parameters for the OSDF and the Borrow Area stormwater and basin sizing calculations. The parameters discussed in this section are directly related to the geometry of drainage structures in these areas and are obtained from the Design Drawings.

The drainage swales to be constructed for this project have the following cross sections; (i) for the OSDF, the permanent perimeter drainage swale is parabolic; (ii) for the Borrow Area, the permanent drainage swale is trapezoidal; and (iii) for construction conditions, the drainage swales are generally triangular.

The culverts in the Borrow Area are reinforced concrete pipe. The culverts in the OSDF area are HDPE.

Construction Equipment

With the exception of wheel loads used in HDPE pipe stability calculations, there are no design parameters related to construction equipment that are used in two or more calculations. As these wheel loads are addressed in the HDPE pipe category in this document, no further discussion of construction equipment parameters is provided herein.

MHG 18 Dec 95
by GRS

CHECKED: DGP 18 DEC. 95
GRS 18 DEC 95

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Table 1 : Design Parameter Usage Matrix

Category / Report Section	Calculation Title	Construction Equipment	Drainage Structures	Structural Fill	E & S Control	Hydrology	Leachate Generation	Bedrock	GMA soils	Gray Till	Brown Till	Subsurface Soils	Compacted Clay	LDS Drainage	LCS Drainage	Protective Soil	Liner System	Impacted Material	Contouring Layer	Compacted Clay	Cover Drainage	Biointrusion Barrier	Granular Filter	Vegetative Soil	Topsoil	Cover System	HDPE pipe	Geosynthetics	Vegetation	Hydrogeology	Climate	Topography, existing	OSDF Geometry
2.1	Foundation Settlement							×	×	×	×	×	×				×													×			×
2.2	Impacted Materials Settlement																	×								×							×
3.1	Foundation Stability							×	×	×	×	×	×	×	×	×	×	×								×				×			×
3.2	Short-term Liner System Stability on Side Slopes												×	×	×	×	×											×			×		×
3.3	Interim/Final Waste Slope Stability												×	×	×	×	×	×		×						×		×					×
3.4	Cover System Stability																		×	×	×	×	×	×	×	×		×					×
3.5	Perimeter Access Corridor			×				×	×	×	×	×																		×			×
3.6	Borrow Area Cut Slope Stability																																
4.1	Seismic Hazard Assessment							×																									
4.2	Seismic Site Response Analysis							×	×	×	×	×	×				×	×								×							×
4.3	Seismic Performance Evaluation								×	×	×	×	×				×	×								×		×					×
5.1	Hydrostatic Forces												×	×	×		×	×								×				×		×	
6.1	Leachate Generation Rates					×							×	×	×	×	×	×	×	×	×	×	×	×	×	×		×	×		×		×
7.1	Leachate Collection System						×								×	×	×										×						×
7.2	LCS Clogging Potential																																
8.1	Leachate Detection System						×							×			×										×						×
9.1	Leachate Transmission System						×					×			×		×										×	×			×		×
10.1	Liner System and Final Cover System Materials Evaluation	×												×	×		×				×					×		×					×
10.2	Liner System Frost Protection												×	×	×	×	×														×		
11.1	Final Cover System						×													×	×	×	×	×	×	×		×			×		×
12.1	OSDF Perimeter Swale Sizing		×		×	×																							×		×	×	×
12.2	OSDF Perimeter Berm Flood Protection				×	×																							×		×	×	×
12.3	Borrow Area Stormwater Management		×			×																							×		×	×	
13.1	OSDF E&S Basin Sizing		×		×	×																							×		×	×	×
13.2	Borrow Area E&S Basin Sizing				×	×																							×		×	×	
13.3	Impacted Runoff Catch Basin Sizing		×		×	×																							×		×	×	
13.4	Revegetation Design																																
13.5	Erosion of OSDF Final Cover				×	×																		×	×	×			×		×		×
13.6	Erosion Resistance: OSDF Perimeter Drainage Swale				×	×																		×	×	×			×		×		×
14.1	Decontamination Water Demand Estimation	×																															
14.2	Construction Water Demand Estimation			×									×				×			×						×			×				×
15.1	OSDF Required Volume																	×															
15.2	OSDF Capacity Verification												×	×	×	×	×			×	×	×	×	×	×	×							×
15.3	Earthwork Required Volumes			×							×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×							×
15.4	Borrow Area Capacity Verification										×	×																					
16.1	Unpaved Access Roads																																
16.2	Paved Access Roads																																
16.3	Staging Area Pavement																																
16.4	Equipment Decon Area Pavement																																
17.1	Power																																
17.2	Potable Water																																
17.3	Wastewater																																

Note: Shaded columns not included in the preliminary design

F95301 2/18/95

FER SDF GE3900

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SECTION 2

2. SETTLEMENT

2.1 Foundation Settlement
2.2 Impacted Materials Settlement

2.1 Foundation Settlement

COMPUTATION COVER SHEET

SUBJECT OF CALCULATION: FOUNDATION SETTLEMENT

Computations By: (Cognizant Engineer)
Signature: Mark H. Gleason — Date: 5 OCT 95
Printed Name and Title: MARK H. GLEASON, ASSISTANT PROJECT ENGINEER

Assumptions and Procedures Checked by: (Checker)
Signature: Thomas B. Maier — Date: 5 OCT 95
Printed Name and Title: Thomas B. Maier, Asst. Project Engineer

Computations Checked by:
Signature: Thomas B. Maier — Date: 5 OCT 95
Printed Name and Title: Thomas B. Maier, Asst. Proj. Engineer

Computations Backchecked by: (Cognizant Engineer)
Signature: Mark H. Gleason — Date: 5 OCT 95
Printed Name and Title: MARK H. GLEASON, ASSISTANT PROJECT ENGINEER

Approved by: (PDP)
Signature: Mark H. Gleason — Date: 5 OCT 95
Printed Name and Title: MARK H. GLEASON, ASSISTANT PROJECT ENGINEER

Approved by: (DTL and TETL)
Signature: Rudolph Bonaparte — Date: 6 Oct 95
Printed Name and Title: Rudolph Bonaparte, Principal

Record of Revision (Number and initial all revisions)

NO.	REASON	DATE	BY	CHECKED	APPROVAL
B	Preliminary Design EPA Submittal	14 Dec 95	KL		

Signature: _____
Number: _____
Registration Stamp (if applicable)

Written by: M. Gleason Date: 95 / 12 / 14 Reviewed by: TM Date: 95 / 12 / 14

Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 9.9

14 Dec 95

FOUNDATION SETTLEMENT

EXECUTIVE SUMMARY

Purpose

The purpose of this calculation package is to calculate settlements of the foundation soils due to surcharge applied by the On-Site Disposal Facility (OSDF). The calculations are performed to evaluate total and differential settlements of the foundation soils, tensile strains and grade change in the liner system, and time rate of primary settlement of the cohesive foundation soils.

Procedure

The settlements are calculated using established geotechnical equations and procedures for elastic and consolidation settlement. The settlements are calculated for points within the OSDF at the center, crest, sump and toe of the facility. Based on the total calculated settlements, differential settlements, tensile strain, and minimum final grade are calculated.

Results

Based on the calculations, the following results are obtained.

- Maximum Calculated Settlement: 2.83 ft (Case 2 Point A)
- Maximum calculated tensile strain due to differential settlement

  $\epsilon_{max} = 0.01\%$ Satisfies limits of maximum allowable tensile strain for HDPE geomembranes as stated in Berg and Bonaparte (1992) (Reference 12).

- Maximum calculated grade change due to differential settlement

  Max change = 0.64% Post-settlement grade of leachate collection pipes will maintain positive flow toward the sump. No grade reversal is calculated.

- Calculated time rate of primary settlement

  - 90% consolidation; minimum: 6.1 yrs. maximum: 39 yrs.
  - 95% consolidation; minimum: 8.4 yrs. maximum: 54 yrs.

Written by: M. GLEASON Date: 95/10/5 (YY MM DD) Reviewed by: JM Date: 95/10/5 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

RB 95/10/6

FOUNDATION SETTLEMENT CALCULATION PACKAGE

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Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

RB 95/10/6

FOUNDATION SETTLEMENT

SUMMARY OF CALCULATIONS

POINT LOCATIONS: CENTER, CREST, SUMP, AND TOE OF OSDF

MAXIMUM CALCULATED SETTLEMENT 2.83 ft (CASE 2 POINT A)

MAXIMUM CALCULATED TENSILE STRAIN DUE TO DIFFERENTIAL SETTLEMENT

$\varepsilon_{max} = 0.01\%$ WHICH SATISFIES LIMITS OF MAXIMUM ALLOWABLE TENSILE STRAIN FOR HDPE GEOMEMBRANES AS STATED IN BERG AND BONAPARTE (1992) REF 12

MAXIMUM CALCULATED GRADE CHANGE DUE TO DIFFERENTIAL SETTLEMENT

MAX CHANGE = 0.64%. POST SETTLEMENT GRADE OF LEACHATE COLLECTION PIPES WILL MAINTAIN POSITIVE FLOW TOWARD THE SUMP. NO GRADE REVERSAL IS CALCULATED

CALCULATED TIME RATE OF PRIMARY SETTLEMENT

90% CONSOLIDATION MINIMUM 6.1 yrs MAXIMUM 39 yrs

95% CONSOLIDATION MINIMUM 8.4 yrs MAXIMUM 54 yrs

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RB 95/9/15

FOUNDATION SETTLEMENT - CALCULATION PACKAGE

PURPOSE: The purpose of this document is to provide the engineering calculations for foundation settlement of the OSDF. The calculations provide an estimate of settlement of the surface of the liner system due to consolidation and elastic settlement of the underlying soil materials.

Included in the analysis is the elastic, primary consolidation, and secondary consolidation of the cohesive soils underlying the OSDF as well as the elastic settlement of the granular cohesionless soils underlying the OSDF. Also included in this calculation package is an analysis of the time rate of primary consolidation for the cohesive soils.

Based on the calculated settlements an analysis will be made of the maximum change in liner system grade, the maximum differential settlement, and the maximum tensile strain expected in the liner system due to differential settlement.

PROCEDURE: The calculation procedure for foundation settlement is described in detail in the Design Criteria Package and is summarized here. The engineering properties of the underlying soil materials used in the analysis are provided on the attached sheets and have been included in the Data Verification Package.

Calculate the elastic and consolidation settlement of the foundation soils due to the load imposed by the OSDF. Use widely known equations from elastic theory and consolidation Theory.

Settlement is dependent upon

- subsurface stratigraphy;
- subsurface material properties;
- load imposed by the landfill materials;
- Geometry of the landfill; and
- location of the settlement point for calculation.

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Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.9

Foundation Settlement RB 95/9/15

ANALYSIS

A GIVEN THE LANDFILL GEOMETRY SHOWN IN FIGURE 1, CALCULATE THE TOTAL SETTLEMENT OF THE GEOMEMBRANE COMPONENTS OF THE LINER SYSTEM DUE TO CONSOLIDATION AND COMPRESSION OF THE UNDERLYING SOILS

B CALCULATE SETTLEMENTS AT POINTS A, B, C, and D INDICATED ON FIG 1.

C ESTIMATE THE UNIT WEIGHT OF LANDFILL WASTE AND THE CORRESPONDING SURCHARGE TO THE SUBSURFACE SOILS APPLIED BY THE LANDFILL

D ESTIMATE VARIATION IN THE INFLUENCE OF THE LANDFILL SURCHARGE ON THE SOILS BENEATH THE POINTS A, B, & C (FIG 1) WITH INCREASED DEPTH (i.e. $\Delta\sigma_v$ variable with location and depth)

E USING THE MATERIAL PROPERTIES DESCRIBED LATER IN THIS PACKAGE (IN DATA VERIFICATION SECTION) AND THE METHODS DESCRIBED BELOW, AND IN THE DESIGN CRITERIA PACKAGE, CALCULATE THE TOTAL SETTLEMENT AT POINTS A, B, and C.

E 1. SETTLEMENT OF COHESIVE SOILS

TOTAL SETTLEMENT $S_t = S_i + S_p + S_s$

where S_i = elastic settlement (immediate)
S_c = primary consolidation settlement (time & surcharge dependent)
S_s = secondary compression settlement (time dependent)

a. Elastic Settlement, S_i (or Δh_i for each layer)

$$\Delta h_i = (\Delta\sigma_v / M)\, H_o$$

where $\Delta\sigma_v$ = additional vertical stress due to OSDF surcharge
M = Constrained Modulus
H_o = Initial layer thickness

CONSTRAINED MODULUS, M

$$M = \frac{E_{ut}(1-\nu)}{(1+\nu)(1-2\nu)}$$

where E_{ut} = Undrained Tangent Modulus
ν = Poissons Ratio

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Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.9

RB 95/9/15

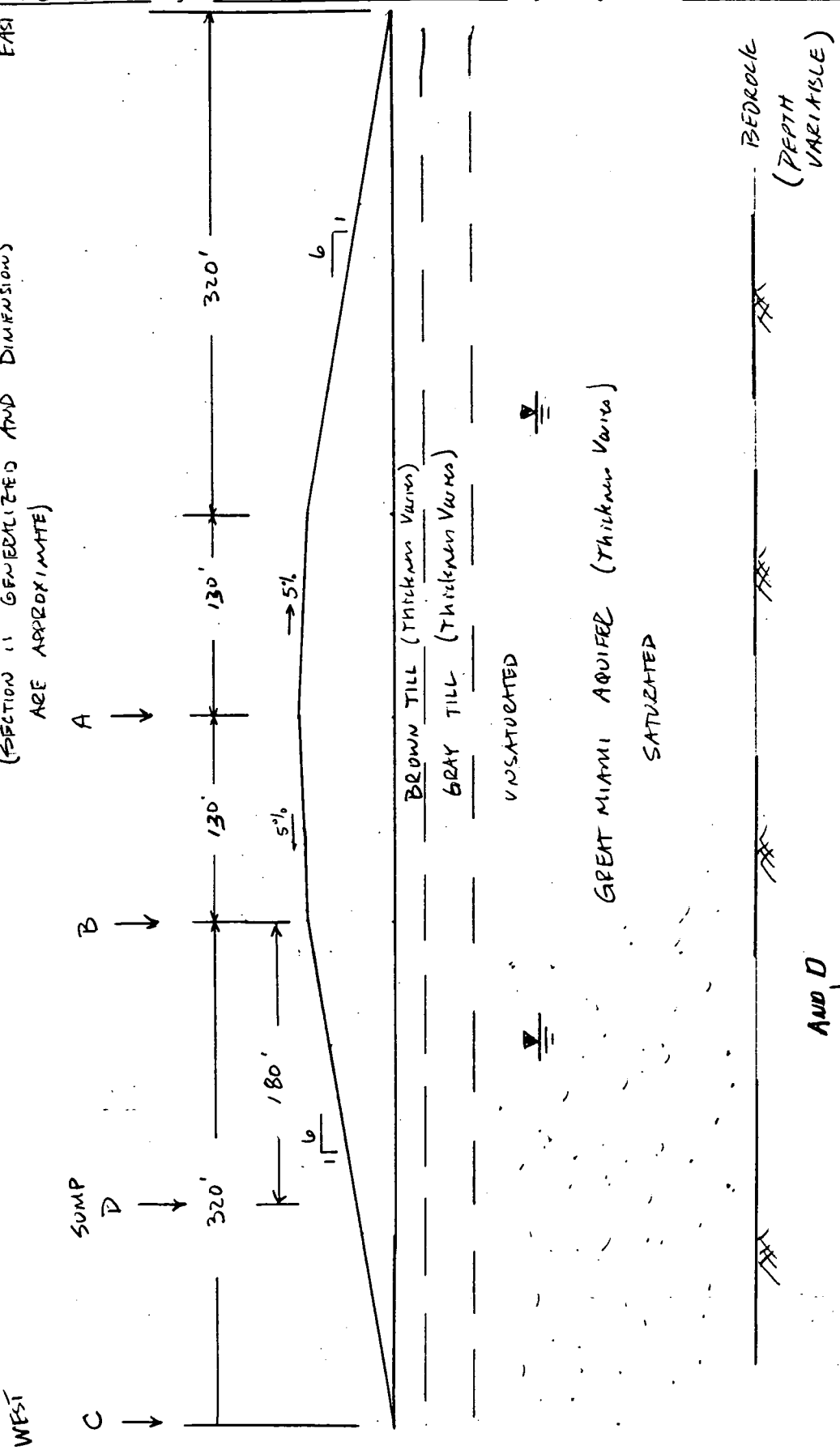

FIGURE 1. CROSS SECTION THROUGH IDEALIZED OSDF SECTION IN WEST TO EAST DIRECTION (SECTION IS GENERALIZED AND DIMENSIONS ARE APPROXIMATE)

POINTS A, B, & C AND D INDICATE LOCATIONS FOR SETTLEMENT ANALYSES & LOCATIONS TO CALCULATE INFLUENCE VALUE OF LANDFILL LOADING WITH DEPTH

Written by: M. BLEAKON Date: 95/9/13 (YY MM DD) Reviewed by: JM Date: 95/10/5 (YY MM DD)

Client: FEZMCO Project: OSDF Project/Proposal No.: 6E 3900 Task No.: 09.9

FOUNDATION SETTLEMENT 95/9/15

E. 1.a. SETTLEMENT OF COHESIVE SOILS, Elastic Settlement

UNDRAINED TANGENT MODULUS, Eut (from Ref. 3)

$$E_{ut} = K p_a (\sigma_c / p_a)^n [1 - R_f (\sigma_1 - \sigma_3)/(2 s_u)]^2$$

where p_a = atmospheric pressure (2117 psf)
K, n, R_f = modulus parameters
$\sigma_c = \sigma_3$ = minor principal stress (total stress)
σ_1 = major principal stress (total stress)
s_u = undrained shear strength

b. PRIMARY CONSOLIDATION SETTLEMENT, S_p (or Δh_p for each layer)

$$\Delta h_p = C_r \frac{H_o}{1+e_o} \log \frac{\bar{\sigma}_p}{\bar{\sigma}_{vo}} + C_c \frac{H_o}{1+e_o} \log \frac{\bar{\sigma}_{vo} + \Delta\bar{\sigma}_v}{\bar{\sigma}_p}$$

where C_c = coefficient of compression
C_r = coefficient of recompression
e_o = initial layer void ratio
$\bar{\sigma}_{vo}$ = initial vertical effective stress
$\Delta\bar{\sigma}_v$ = additional vertical effective stress
$\bar{\sigma}_p$ = past maximum pressure due to overconsolidation or desiccation
H_o = Initial layer thickness

c. SECONDARY COMPRESSION SETTLEMENT, S_s (or Δh_s for each layer)

$$\Delta h_s = C_\alpha \frac{H_o}{1+e_p} (\log t_2/t_1)$$

where C_α = Secondary Compression index
H_o = Initial layer thickness
e_p = void ratio at the start of secondary compression time
$\log t_2/t_1$ = the time ratio t_2/t_1 where t_1 is the time from loading to the end of primary consolidation (i.e., 90% of primary) and t_2 is a future time of interest (i.e. 200 years or 1000 years).
Assume t_1 = 10 years t_2 = 1000 years

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FOUNDATION SETTLEMENT

RB 95/9/15

E. 2. SETTLEMENT OF COHESIONLESS SOILS (GRANULAR NON-PLASTIC SOILS)

GRANULAR SETTLEMENT IS ELASTIC & IMMEDIATE.

$$\Delta h_s = (\Delta\bar{\sigma}_v / M)\, H_o$$

where Δh_s = elastic settlement of sand layer
$\Delta\bar{\sigma}_v$ = additional vertical effective stress
M = Constrained Modulus
H_o = initial layer thickness

$$M = \frac{E_t(1-\nu)}{(1+\nu)(1-2\nu)}$$

where E_t = Elastic Tangent Modulus
ν = Poisson's Ratio

$$E_t = K p_a (\bar{\sigma}_3 / p_a)^n \left[1 - R_f (1-\sin\bar{\phi})(\bar{\sigma}_1 - \bar{\sigma}_3)/(2\bar{\sigma}_3 \sin\bar{\phi})\right]^2$$

where p_a = atmospheric pressure
$\bar{\sigma}_1$ = major principal effective stress
$\bar{\sigma}_3$ = minor principal effective stress
$\bar{\phi}$ = effective stress angle of internal friction
K, n, R_f = hyperbolic model parameters

3. TOTAL SETTLEMENT = COHESIVE SOIL SETTLEMENT + COHESIONLESS SOIL SETTLEMENT

4. CALCULATE TOTAL SETTLEMENT AT EACH POINT FOR TWO CASES.
(see data verification for parameter back-up)

CASE	BROWN TILL THICKNESS (ft)	GRAY TILL Thickness (ft)	GREAT MIAMI[1] AQUIFER THICKNESS (ft) (Approximate)	GROUND WATER[2] DEPTH (ft)
1	5	15	210	70
2	10	45	175	70

1) Depth to bedrock beneath site is a maximum of 230 ft - worst case.
2) Elevation of ground water beneath site is relatively constant: 70 ft. Depth represents the shallowest depth of groundwater and will result in a more conservative estimate of total settlement.
3) 3-foot thick clay liner is not included in this table.

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Client: FERMCO Project: OSDF Project/Proposal No.: GF 3900 Task No.: 09.9

FOUNDATION SETTLEMENT

RB 95/9/15

F. USING THE TOTAL SETTLEMENT CALCULATED AT EACH POINT (FOR EACH CASE) CALCULATE DIFFERENTIAL SETTLEMENT BETWEEN POINTS, GRADE CHANGE BETWEEN POINTS, AND TENSILE STRAIN (IF ANY) IN THE GEOMEMBRANE.

a. Differential Settlement, Δ_s

$$\Delta_s = \Delta h_B - \Delta h_A$$

where Δh_B = total settlement at Point B
Δh_A = " " " Point A

b. GRADE CHANGE

Grade change % $= (\Delta_s / L)\,100$

where L = horizontal distance between points of concern

c. Tensile Strain, ε

$$\varepsilon = 8/3 \left(\frac{\Delta_s}{L}\right)^2 (100) \qquad \text{(Giroud, 1977).}$$

where Δ_s, L, as described above.

G. FINALLY, FOR THE COHESIVE SOILS, CALCULATE THE TIME FOR PRIMARY CONSOLIDATION OF THE COHESIVE SOILS (ie. TIME RATE OF SETTLEMENT). GRANULAR SOIL SETTLEMENTS ARE IMMEDIATE

$$t = \frac{T\,H_{dr}^2}{C_v}$$

where t = time for % settlement of concern
T = time factor - variable depending on % of total consolidation. T = 0.848 for 90% consolidation which is generally considered the end of primary settlement.
H_{dr} = the length of the longest drainage path for water to escape the cohesive layer
C_v = coefficient of consolidation (property of the clay)

t varies with cohesive soil thickness. Calculate t for several cohesive soil thicknesses.

GEOSYNTEC CONSULTANTS

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FOUNDATION SETTLEMENT DATA VERIFICATION PACKAGE RB 95/9/15

SUMMARY OF MATERIAL PROPERTIES
FOR CONSOLIDATION AND ELASTIC SETTLEMENT OF COHESIVE SOILS

Property	MATERIAL: Recompacted Clay	Brown Till	Gray Till
Unit Weight, γ_T pcf	130	135	145
% SATURATION, S	90	95	100
INITIAL VOID RATIO, e_o	0.43	0.29	0.38 (AVERAGE) of 5 ✓
Compression Index, C_c	0.13	0.075	0.074 (AVG) of 5 ✓
Recompression Index, C_r	0.035	0.015	0.014 (AVG) of 5 ✓
Secondary Compression, $C_{\alpha\epsilon}$	0.0015	0.0015	0.0013
Coefficient of Consolidation, C_v in^2/min	0.055 in^2/min	0.06 in^2/min	0.035 in^2/min (Avg) of 5 ✓
Over Consolidation Ratio, OCR	σ_p = 1000 psf	1.7	1
Void Ratio at End of Primary (σ_p) (assume 75% e_o), e_p	0.32	0.22	0.29
Elastic Parameter, k	150	175	175
Elastic Parameter, n	1	1	1
Elastic Parameter, R_f	0.9	0.9	0.9
Poisson's Ratio, ν	0.475	0.475	0.49
Undrained Shear Strength, Su, psf	1200	1200	1900
	✓		✓

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FOUNDATION SETTLEMENT

MATERIAL PROPERTIES

RECOMPACTED CLAY (LINER SYSTEM)

FROM PREDESIGN Investigation Report Appendix 6
CONSOLIDATION TEST DATA ON REMOULDED SAMPLES

BORING 11476 3.5'-7.5' Brown Till (Remolded)

γ_T = 130 pcf % S = 81 e_0 = 0.43

G_s = 2.64

C_c = 0.14 C_r = 0.03 Assume σ_p = 1000 psf - compaction

Use $\sqrt{t}$ fitting method to estimate C_v (Semi log method gives similar results).

load	C_v
1600 psf	5.7 $\times 10^{-3}$ cm²/s
3200 psf	8.5 $\times 10^{-3}$ cm²/s
6400 psf	5 $\times 10^{-3}$ cm²/s
12800 psf	4.4 $\times 10^{-3}$ cm²/s

Average 5.9 $\times 10^{-3}$ cm²/s ✓
= 0.055 in²/min ✓

Estimate C_{α} from Kulhawy & Mayne 1990

$C_{\alpha e} \approx 0.0001\, w_n$ for NC Clays w_n = 15.7 (post consolidation)

$C_{\alpha e} \approx$ 0.0016

BORING 11479 7.5-10.5' BROWN TILL (Remolded)

γ_T = 134.2 pcf % S = 76% G_s = 2.74

e_0 = 0.4233

C_c = 0.12 C_r = 0.04 Assume σ_p = 1000 psf

$C_{\alpha e}$ from Kulhawy & Mayne (1990)

$C_{\alpha e} \approx 0.0001\, w_n$ w_n = 12.8%

$C_{\alpha e}$ = 0.0013

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Foundation Settlement
BORING 11479 cont.

RB 95/9/15

ESTIMATE Cv use √t method (Semi log method gives similar results).

	load (psf)	Cv
Average ~ 6×10^{-3} cm²/s ✓	3200	5.5×10^{-3} cm²/s
~ 0.056 in²/min ✓	6400	6×10^{-3} cm²/s
	12800	7.2×10^{-3} cm²/s
loads will not be this high on liner →	25600	1.9×10^{-3} cm²/s

BORING 11481 13.5' - 18.5' - Gray Till

- Material is not applicable to these analyses (recompacted material will be brown till)
- Also, depth of sample is beyond the limit of excavation expected for the OSDF.

Summary of Recompacted Brown Till for Boring 11476 & 11479

PARAMETERS FOR USE IN CONSOLIDATION SETTLEMENT ANALYSIS

- γ_T = 130 pcf
- e_0 = 0.43
- C_c ≈ 0.13 (avg)
- C_r = 0.035 (avg) N/A if OCR = 1.0 σ_p = 1000 psf assumed
- $C_{\alpha\epsilon}$ = 0.0015 (avg)
- C_v = 5.9×10^{-3} cm²/s (0.055 in²/min)
- S = 90

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Foundation Settlement

MATERIAL PROPERTIES

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CONSOLIDATION SETTLEMENT OF BROWN TILL FROM Parsons 1995 Predesign Report

BORING 11472 9.5 - 11.5 ft ONLY BORING IN OSDF AREA WITH BROWN TILL CONSOLIDATION TEST.

γ_T = 145 pcf (for this sample) Saturation ~ 100% (for this sample)

G_s = 2.69 e_o = 0.284

C_c = 0.061 C_r = 0.01 OCR = 1.7 Confirmed w/ Parsons Table 4-4

Calculate Cv use $\sqrt{t}$ method from test data

LOAD (psf)	Cv cm²/s
1600	3.6×10^{-3}
3200	7.6×10^{-3}
6400	9.7×10^{-3}
12800	1.1×10^{-2}

Average 8.0×10^{-3} cm²/s = 0.074 in²/min

Average Cv from PARSONS TABLE 4-4 Cv = 0.10 in²/min use

Estimate C_α from Kulhawy and Mayne (1990) p. 6-16

$C_{\alpha\epsilon} \approx 0.0001\, W_n$ for NC clays (Brown till is OC)

W_n for test sample = 10.8 %
W_n for Brown till ≈ 15% (average)

$C_{\alpha\epsilon}$ = 0.0001 (15) = 0.0015

This value is slightly greater than the range of values of $C_{\alpha\epsilon}$ for OC clays stated in Kulhawy & Mayne 1990

i.e., $0.0005 < C_{\alpha\epsilon} < 0.001$

∴ use of $C_{\alpha\epsilon}$ = 0.0015 is considered conservative for the brown till.

FROM TABLE 4-3 of Parsons
Average unit weight of Clay γ_T ≈ 135 pcf

Average degree of Saturation ≈ 95%

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Foundation Settlement
MATERIAL PROPERTIES

RB 95/9/15

CONSOLIDATION SETTLEMENT OF BROWN TILL FROM PARSONS (Ref 10)

BORING G2-127 7.5 - 9.5' deep

γ_T = 140pcf S = 96% OCR = 2.3

C_c = 0.070 C_r = 0.019 e_0 = 0.39

Average C_v = 0.035 in²/min (TABLE G-3)

BORING G2-133 7.5 - 9.5'

γ_T = 145pcf S = 100 OCR = 1.7

C_c = 0.057 C_r = 0.014 e_0 = 0.36

Average C_v = 0.06 in²/min

Assume Conservative Values for analysis

γ_T = 135pcf S = 95% OCR = 1.7

e_0 = 0.29 C_c = 0.075

C_r = 0.015 C_α = 0.0015

Average C_v = 0.06 in²/min

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Foundation Settlement RB 95/9/15

MATERIAL PROPERTIES

CONSOLIDATION SETTLEMENT OF GRAY TILL

Based on consolidation tests performed by Parsons (or Pre-Design Geotechnical Investigation July 1995

5 consolidation tests run on gray till

BORING 11469 15.5' - 18.0' Gray Till CL

$\gamma_T = 141.7$ pcf $S = 100\%$ $G_s = 2.73$

$e_o = 0.373$

$C_c = 0.072$ $C_r = 0.02$ OCR = 1.4

Estimate Cv using $\sqrt{t}$ method:

load psf	Cv (cm²/s)
1600	3.9×10^{-3}
3200	3.5×10^{-3}
6400	3.2×10^{-3}
12800	2.5×10^{-3}

Average Cv = 3.3×10^{-3} cm²/s ✓
= 0.031 in²/min ✓

Average Cv from Parsons (1995) Table 4-4 = 0.023 in²/min

Estimate C_α from Kulhawy & Mayne (1990)

$C_{\alpha\epsilon} = 0.0001\, w_n$ $w_n = 14.1\%$

$C_{\alpha\epsilon} = .0001(14.1) = 0.0014$ (for this sample)

BORING 11471 17 - 19.5' Gray Till CL

$\gamma_T = 149.4$ pcf $S = 100\%$ $G_s = 2.77$ $e_o = 0.277$

$C_c = 0.051$ $C_r = 0.01$ OCR = 1

Data is in agreement with Parsons 1995 data (table 4-4)

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Foundation Settlement

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CONSOLIDATION SETTLEMENT OF TILL CONT.

BORING 11471 cont.

Cr data

LOAD psf	Cr cm²/s
1600	2×10^{-3}
3200	4.6×10^{-3}
6400	2.4×10^{-3}
12800	4.8×10^{-3}

Average = 3.5×10^{-3} cm²/s ✓

= 0.032 in²/min ✓

Estimate $C_{\alpha\epsilon}$

$C_{\alpha\epsilon} = 0.0001 (w_n)$ (K+M 1990) $w_n = 10.3\%$

$C_{\alpha\epsilon} = 0.0001 (10.3) = 0.0013$ (for this sample)

BORING 11474 14 - 16.5' Gray Till CL

$\gamma_T = 142.9$ $S = 96\%$ $G_s = 2.75$

$e_0 = 0.3475$ $w_c = 12.2\%$

$C_c = 0.068$ $C_r = 0.013$ OCR = 1.2 - 1.3

Data is in general agreement with Parsons (1995).

Cr data

Load psf	Cr cm²/s
1600	2.8×10^{-3}
3200	2.4×10^{-3}
6400	2.2×10^{-3}
12800	3.6×10^{-3}

Average ≈ 2.8×10^{-3} cm²/s ✓

= 0.026 in²/min ✓

Estimate $C_{\alpha\epsilon} = 0.0001 w_n$ $w_n = 12.2\%$

$C_{\alpha\epsilon} = 0.0012$ (for this sample)

BORING 11476 9.5' - 12.0' Gray Till CL-ML

$\gamma_T = 140.5$ $S = 95\%$ $G_s = 2.77$

$e_0 = 0.40$ $w_c = 13.8\%$

$C_c = 0.064$ $C_r = 0.01$ OCR = 1

Data is in General agreement with Parsons 1995 data table 4-4

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Foundation Settlement RB 95/9/15

CONSOLIDATION SETTLEMENT OF GRAY TILL CONT.

BORING 11476 cont

Cv

LOAD (psf)	Cv cm²/s
1600	3.7×10^{-3}
3200	5.9×10^{-3}
6400	8.2×10^{-3}
12800	7.9×10^{-3}

Average 6.4×10^{-3} cm²/s ✓

0.060 in²/min ✓

Estimate $C_{\alpha E} = 0.0001\, W_n$
$= 0.0001\,(13.8) = 0.0014$ (for this sample)

BORING 11477 14.0-16.5' Gray Till CL

$\gamma_T = 134$ pcf $S = 99\%$ $G_s = 2.72$

$e_0 = 0.486$ $W_c = 17.7\%$

$C_c = 0.114$ $C_r = 0.016$ OCR = 1

Data is in agreement with Parsons (1995) report table 4.4

Cv data

LOAD psf	Cr cm²/s
1600	2.6×10^{-3}
3200	3.2×10^{-3}
6400	2.2×10^{-3}
12800	2.0×10^{-3}

Average = 2.5×10^{-3} cm²/s ✓
= 0.023 in²/min ✓

Estimate $C_{\alpha E} = 0.0001\,(17.7) = 0.0018$ (for this sample)

AVERAGE UNIT WEIGHT OF GRAY TILL

FROM PARSONS, 1995 TABLE 4-3 $\gamma_{average} \approx 145$ pcf

AVERAGE WATER CONTENT OF GRAY TILL

FROM PARSONS 1995 TABLE 4-3 $W_{c\,avg} \approx 13\%$

ESTIMATE $C_{\alpha E} = 0.0001\,(13) = 0.0013$

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Foundation Settlement RB 95/9/15

ELASTIC SETTLEMENT PARAMETERS FOR COHESIVE SOILS

EQUATION

$$E_{ut} = k\, p_a \left(\sigma_c / p_a\right)^n \left[1 - R_f (\sigma_1 - \sigma_3)/(2\, s_u)\right]^2$$

E_{ut} = undrained tangent modulus
p_a = atmospheric pressure
k, n, R_f = modulus parameters
$\sigma_c = \sigma_3$ = minor principal stress (total)
σ_1 = major principal stress (total)
s_u = undrained shear strength

$$M = \frac{E_{ut}(1-\nu)}{(1+\nu)(1-2\nu)}$$

M = Confined Modulus
ν = Poisson's Ratio

FOR RECOMPACTED CLAY (LINER MATERIAL)

Material is expected to be Brown Till excavated from on-site sources

From Kulhawy & Mayne (1990) for CL material

k = 100 to 200 $n = 1$ $R_f = 0.9$
use $k = 150$

s_u - no test data on remoulded undrained shear strength.
use Unconfined compression tests on Brown Till

Boring	Depth (ft)	s_u (psf)
11472	3.5-6.0	4400
11473	6.5-8.5	4058
11480	0.5-3.0	2127
11481	6.5-9.0	4458

> Average = 3800 psf

Use reduced strength for clay liner. Use SAME strength as used (conservatively) for Brown Till (s_u = 1200 psf)
∴ Assume s_u = 1000 psf

Assume $\sigma_1 = \sigma_1$ $\sigma_3 = 0.8\,\sigma_1$

Poissons Ratio ν for partially saturated clay S = 80%

Assume ν = 0.475 for partially saturated clay.

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Foundation Settlement RB 95/9/15

Elastic Settlement Parameters for Cohesive Soils cont.

FOR BROWN TILL

K = 100 - 200 n = 1 Rf = 0.9 (Kulhawy & Mayne [1990])
use K = 175 for stiff till material
Su = Average of 3800 psf (Parsons, Pre Design Geotechnical Report [1995])
For analysis use Su = 1200 psf (conservative).
Assume $\sigma_1 = \sigma_v$ $\sigma_3 = 0.8\,\sigma_1$

Poissons Ratio - Brown Till is partially saturated S = 95%
Assume $\nu = 0.475$ for elastic settlement

FOR GRAY TILL

K = 100 - 200 (use 175 for stiff) n = 1 Rf = 0.9 (Kulhawy & Mayne [1990])

Su from Unconfined Compression Tests (Parsons [1995])

Boring	Depth (ft)	Su (psf)
11468	15 - 17.5	2738
11469	15.5 - 18	2650
11471	17.0 - 19.5	3733
11473	15.5 - 18	2975
11474	14 - 16.5	3647
11475	15.5 - 18	4848
11476	9.5 - 12	2635
11479	18.5 - 21	1974

AVERAGE = 3063 psf
use Su = 1900 psf as used in Foundation Stability Calculations

Assume $\sigma_1 = \sigma_v$ $\sigma_3 = 0.8\,\sigma_1$

Gray Till is Saturated (S = 100%)

By Definition Poissons Ratio $\nu = 0.5$

For Analysis assume $\nu = 0.49$

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RB 95/9/15

Foundation Settlement DATA VERIFICATION PACKAGE

ELASTIC SETTLEMENT PROPERTIES OF COHESIONLESS SOILS

As indicated in the Design Criteria Package and in the Calculation package, the following equations will be used to calculate elastic settlement of the cohesionless soils of the GMA soils (Great Miami Aquifer). These equations are listed below with the parameters required for the calculation.

Elastic Tangent Modulus (from Duncan and Chang (1970)) (Ref 3)

$$E_t = kP_a \left(\bar{\sigma}_3/p_a\right)^n \left[1 - R_f\left(1-\sin\bar{\phi}\right)\left(\bar{\sigma}_1 - \bar{\sigma}_3\right)/2\sin\bar{\phi}\,\bar{\sigma}_3\right]^2$$

where
E_t = Elastic Tangent Modulus
P_a = atmospheric pressure
$\bar{\sigma}_1, \bar{\sigma}_3$ = major and minor effective principal stresses
$\bar{\phi}$ = effective angle of internal friction
k, n, R_f = hyperbolic model parameters

Constrained Modulus (M) from Elastic Theory

$$M = \frac{E(1-\nu)}{(1+\nu)(1-2\nu)}$$

where $E = E_t$ from above
ν = Possions Ratio

PARAMETERS REQUIRED FOR MATERIAL PROPERTIES

- Relationship between $\bar{\sigma}_1$ and $\bar{\sigma}_3$;
- $\bar{\phi}$;
- $k, n, \& R_f$; and
- ν

ESTIMATE MATERIAL PROPERTIES & RELATIONSHIPS based on information obtained from soil boring logs at the site and published correlations.

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Client: FERMCO Project: OSDF Project/Proposal No.: 6F 3900 Task No.: 09.9

Foundation Settlement - Data Verification RB 95/9/15

Cohesionless Soils (cont.)

Description of GMA (Great Miami Aquifer) Soils Based on Site Borings (DOE, 1995 Ref 4)

- medium dense to very dense in consistency based on SPT (Standard Penetration Test) N-values ranging from 12 to greater than 50. Average range of SPT-N values is in "dense consistency" with 30 to 50 blows per foot.
- Soils generally consist of a well graded sand and gravel with trace to little silt or clay. Soils are non-plastic
- Soils are unsaturated to saturated depending on depth (i.e. GMA contains the natural groundwater table).

DESIGN ASSUMPTIONS

- UNIT WEIGHT γ_T = 135 pcf Bouyant unit weight = γ_s = 72.6 pcf
- Shear Strength: Based on correlation between SPT N value and friction angle, $\bar{\phi}$, assume $\bar{\phi}$ = 35°.
  - From Peck, Hanson, Thornburn (1974) high end of medium sand, low end of dense sand.

Elevation of Groundwater

Based on data provided by Parsons (1995) in the Remedial Investigation for OU2 dated 21 January, 1995, the elevation of the groundwater table beneath the OSDF is approximately elevation 523 ft above Mean Sea Level (MSL).

The elevation of the ground surface in the OSDF area varies from approximately el. 615 ft MSL to el 590 ft MSL, corresponding to a depth of groundwater beneath the OSDF of 92 to 67 ft.

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Client: FEZMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.9

Foundation Settlement - Data Verification RB 95/9/15

Cohesionless Soils cont

Material Properties of GMA soils

As indicated on previous pages the following properties are assumed

$\gamma_T = 135$ pcf $\bar{\phi} = 35°$

Relationship between $\bar{\sigma}_1$ and $\bar{\sigma}_3$

Assume $\bar{\sigma}_3 = K_0 \bar{\sigma}_1$ $K_0 = 1 - \sin\bar{\phi}$ (JAKY, 1944) Ref 6

$\therefore \bar{\sigma}_3 = 0.426\bar{\sigma}_1$

Elastic Parameters k, n, & Rf

Estimate $k \doteq 300 + 900\,\phi_{rel}$ (Ref 2 page 5-15)

$\phi_{rel} = (\bar{\phi}_{tc} - 25°)/(45° - 25°)$ (Ref 2 page 5-3)

$\phi_{rel} = (35-25)/20 = 0.5$ $k = 300 + 900(0.5) = 750$

TABLE 5-6 of Ref 2 has k range from 300 to 1200 for SW and SP soils. For dense GMA soil assume $k = \underline{900}$

From Table 5-6 of Ref 2 for SW soil:

$n = 0.5$ $R_f = 0.7$

ESTIMATE Poissons Ratio; ν From Ref 2 page 5-4 Table 5-1

For dense Sand $\nu = 0.3 - 0.4$

Assume $\nu = 0.3$

SUMMARY FOR GMA soils

$\gamma_T = 135$ pcf	$k = 900$
$\bar{\phi} = 35°$	$n = 0.5$
	$R_f = 0.7$
$\bar{\sigma}_3 = 0.426\bar{\sigma}_1$	$\nu = 0.3$

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Foundation Settlement - Data Verification RB 95/9/15

BEDROCK

Bedrock beneath the OSDF consists of a shale and fossiliferous limestone with essentially horizontal bedding planes. (Ref 4).

The topographic surface of the bedrock beneath the OSDF ranges from approximately elevation 400 ft MSL to 370 ft MSL (Ref 4 Figure 3-15).

The Maximum depth to bedrock beneath the ground surface is approximately 230 ft.

The bedrock has experienced past glacial activity and is assumed to be incompressible.

CLAY INTERBED IN GMA soils

Subsurface data indicates the presence of a thin clay interbed in the GMA soils. The maximum thickness of this interbed beneath the OSDF is approximately 2 ft at a depth of approximately 150 ft below ground surface (Ref 4, Fig 3-19, 3-20).

The interbed is located only partially beneath the OSDF. Because of limited information, the depth of the interbed, and the thickness of the interbed, the clay interbed will not be factored into the settlement analysis.

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FOUNDATION SETTLEMENT RB 95/9/15

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Client: Fernco Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

RB 95/9/15

Foundation Settlement

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12) BERG, R.R. and Bonaparte, R., "Long Term Allowable Tensile Stresses for Polyethylene Geomembranes," Geotextiles and Geomembranes, Vol. 12, No. 4, 1992 pp 287 - 306.

Written by: M. GLEASON Date: 95/9/16 (YY MM DD) Reviewed by: JM Date: 95/10/5 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.9

FOUNDATION SETTLEMENT - CALCULATION OF TOTAL SETTLEMENT

PROFILE BENEATH OSDF WITH DEPTH / LAYER THICKNESS

CASE 1

LAYER #		MIDPOINT	LAYER THICKNESS	DEPTH
				0
1	LINER	1.5'	3'	3
2	Br. Till	5.5'	5'	8
3	GRAY TILL	12	7.5'	(15.5)
4		19	7.5'	23
5		29	12'	35'
6	GMA unsaturated	42.5'	15'	50'
7		60'	20'	70'
8		80'	20'	90'
9		100	20'	110
10	GMA SATURATED	120'	20'	130
11		140'	20'	150
12		160	20'	170
13		185	30'	200
14		215	30'	230

CASE 1 ↓

BEDROCK (INCOMPRESSIBLE)

CASE 2

LAYER #		MIDPOINT	LAYER THICKNESS	DEPTH
1	LINER	1.5	3'	3'
2	Br. Till	5.5	5'	13'
3		10.5	5'	18'
4		15.5	5'	28'
5		23	10'	38'
6	Gray Till	33	10'	48
7		43	10'	58'
8		53	10'	70'
9	GMA unsat	64	12'	90'
10		80	20'	110'
11		100	20'	130'
12	GMA SATURATED	120'	20'	150'
13		140'	20'	170'
14		160'	20'	200'
15		185'	30'	230'
16		215'	30'	

Written by: M. GLEASON Date: 95/9/16 (YY MM DD) Reviewed by: JM Date: 95/10/5 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

FOUNDATION SETTLEMENT – CALCULATION OF TOTAL SETTLEMENT

CALCULATE INFLUENCE VALUES (vertical stress increase)

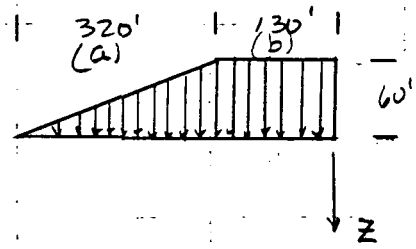
AT THE FOLLOWING DEPTHS: (for midpoint depths shown on the previous page)

1.5'	23'	60'	160'
5.5'	29'	64'	185'
10.5'	33'	80'	215'
13'	42.5'	100'	
15.5'	43'	120'	
18'	53'	140'	

FOR POINTS A, B, & C

POINT A

- CALCULATE INFLUENCE VALUES UNDERNEATH CENTER OF OSDF
- MODEL OSDF AS EMBANKMENT
- USE METHOD PRESENTED IN HOLTZ AND KOVACS (1981) AND US NAVY (1971) after Osterberg (1957) FOR INFLUENCE VALUES FOR VERTICAL STRESS UNDER A VERY LONG EMBANKMENT
- USE THE FOLLOWING DIMENSIONS (From Fig 1 page 3)



ASSUME EMBANKMENT IS UNIFORMLY LOADED

a = 320'
b = 130'

USE ATTACHED CHART solve for a/z & b/z
Double Influence value for mirror half of embankment

Depth	a/z	b/z	I	2I	DEPTH	a/z	b/z	I	2I
1.5	213	87	0.5	1.0	53	6.0	2.5	0.5	1.0
5.5	58	24	0.5	1.0	60	5.3	2.2	0.495	0.99
10.5	30	12.4	0.5	1.0	64	5.0	2.0	0.495	0.99
13	25	10	0.5	1.0	80	4.0	1.6	0.49	0.98
15.5	21	8.4	0.5	1.0	100	3.2	1.3	0.485	0.97
18	18	7.2	0.5	1.0	120	2.7	1.1	0.48	0.96
23	14	5.7	0.5	1.0	140	2.3	0.93	0.47	0.94
29	11	4.5	0.5	1.0	160	2.0	0.81	0.46	0.92
33	9.7	3.9	0.5	1.0	185	1.7	0.7	0.45	0.90
42.5	7.5	3.0	0.5	1.0	215	1.5	0.6	0.435	0.87
43	7.5	3.0	0.5	1.0					

Written by: M. GLEASON Date: 95/9/17 (YY MM DD) Reviewed by: JM Date: 95/10/5 (YY MM DD)

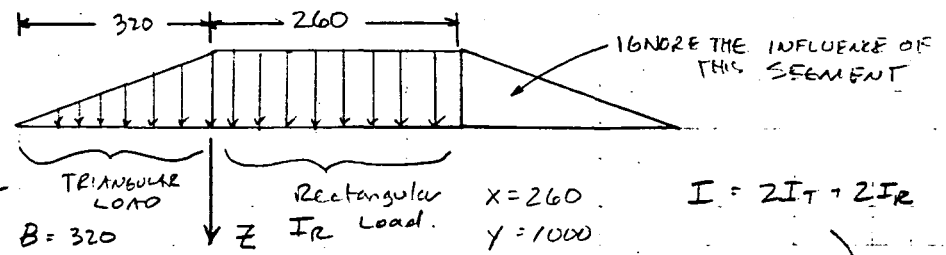
Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

FOUNDATION SETTLEMENT - TOTAL SETTLEMENT

CALCULATE INFLUENCE VALUES (vertical stress increase)

FOR POINT B

- Calculate influence values beneath crest of OSDF
- Model OSDF as uniformly loaded rectangular area and triangular load - sum the values for each analysis use the method presented in Holtz & Kovacs 1981 after U.S. Navy (1971).
- Use the following dimensions.



	TRIANGULAR LOAD				RECTANGULAR LOAD				TOTAL
DEPTH	$m = L/z$	$n = B/z$	I_T	$2I_T$	$m = X/z$	$n = Y/z$	I_R	$2I_R$	I
1.5	666	213	0.25	0.5	173	666	0.25	0.50	1.0
5.5	181	58	0.25	0.5	47	181			1.0
10.5	95	30	0.25	0.5	25	95			1.0
13	77	25	0.25	0.5	20	77			1.0
15.5	65	21	0.25	0.5	17	65			1.0
18	56	18	0.245	0.49	14	56			0.99
23	43	14	0.24	0.48	11.3	43			0.98
29	34	11	0.235	0.47	9	34			0.97
33	30	9.7	0.23	0.46	7.9	30			0.96
42.5/43	23	7.4	0.225	0.45	6.0	23			0.95
53	19	6	0.22	0.44	4.9	19	0.25	0.5	0.94
60	17	5.3	0.22	0.44	4.3	17	0.25	0.5	0.94
64	16	5	0.218	0.436	4.1	16	0.25	0.5	0.93
80	12.5	4	0.217	0.434	3.3	12.5	0.247	0.494	0.93
100	10	3.2	0.202	0.404	2.6	10	0.245	0.49	0.90
120	8.3	2.7	0.195	0.39	2.16	8.3	0.24	0.48	0.87
140	7.1	2.3	0.185	0.37	1.9	7.1	0.238	0.476	0.85
160	6.3	2	0.177	0.354	1.6	6.3	0.232	0.464	0.82
185	5.4	1.7	0.165	0.33	1.4	5.4	0.227	0.454	0.784
215	4.7	1.5	0.156	0.312	1.2	4.7	0.218	0.436	0.75

Written by: M. GLEASON Date: 95/9/17 Reviewed by: JM Date: 95/10/5

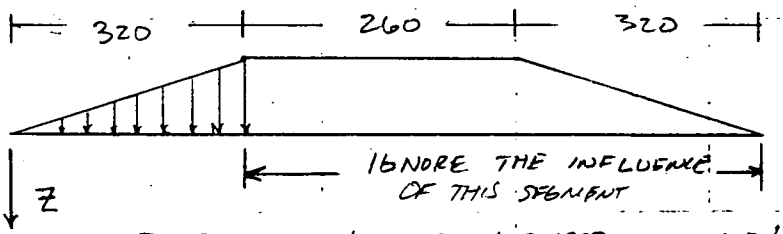
Client: EFRMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

FOUNDATION SETTLEMENT - TOTAL SETTLEMENT

CALCULATE INFLUENCE VALUES (vertical stress increase)

FOR POINT C

- Calculate Influence values with depth at toe of OSDF. Values will be used in settlement analysis. Values found will underestimate settlement at the sump location therefore will be a conservative estimate of grade change and tensile strain when compared to settlements at Points A & B.
- Use the method presented in Holtz & Kovacs 1981 after US Navy (1971) to calculate the vertical stress increase at the toe of a uniformly loaded triangular area.
- Use the following Dimensions



B = 320 ASSUME L = 1000 m = L/z n = B/z

Depth	m = L/z	n = B/z	I	2I
1.5	666	213	0.005	0.01
5.5	181	58	0.006	0.012
10.5	95	30	0.007	0.014
13	77	25	0.008	0.016
15.5	65	21	0.009	0.018
18	56	18	0.01	0.02
23	43	14	0.012	0.024
29	34	11	0.014	0.028
33	30	9.7	0.015	0.03
43	23	7.4	0.02	0.04
53	19	6	0.025	0.05
60	17	5.3	0.028	0.056
64	16	5	0.03	0.06
80	12.5	4	0.04	0.08
100	10	3.2	0.045	0.09
120	8.3	2.7	0.052	0.104
140	7.1	2.3	0.059	0.118
160	6.3	2	0.062	0.124
185	5.4	1.7	0.067	0.134
215	4.7	1.5	0.071	0.142

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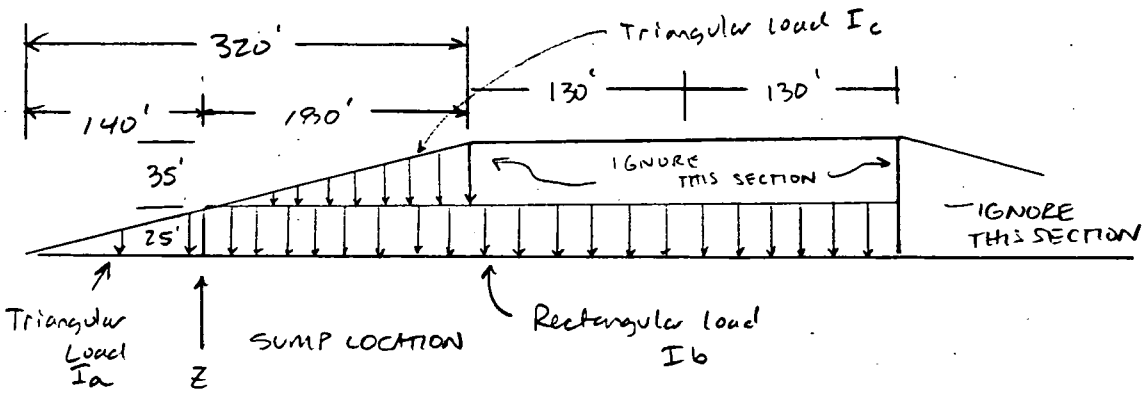
Client: Fernco Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement

Calculate Influence Values

POINT D

- Calculate Influence Values with depth at location of sump
- Use method presented in Holtz and Kovacs 1981 after US Navy, 1971
- Use the following dimensions



I_a = triangular load. (HEEL LOAD)

Maximum stress increase = 25' × 125 pcf = 3125 psf

L = 1000 B = 140

I_b = Rectangular Load

Maximum stress increase = 25' × 125 pcf = 3125 psf

X = 440 (i.e. 130 × 2 + 180) y = 1000

I_c = Triangular Load (TOE LOAD)

Maximum stress (correction) = 35' × 125 pcf = 4375 psf

B = 180 ft y = 1000

Add 25 ft for depth correction

$$\Delta\sigma_{v_D} = 2I_a(3125\,psf) + 2I_b(3125\,psf) + 2I_c(4375\,psf)$$

FOUNDATION SETTLEMENT

INFLUENCE VALUES AND INCREASE IN VERTICAL STRESS FOR POINT D (SUMP)

same values for each case

	Triangular Load (heel)				Rectangular x = 440'			Triangular Load (toe) B = 180'					
Depth	m = L/z	n = B/z	I_a	$2I_a$	n = x/z	I_b	$2I_b$	Depth	m = L/z	n = B/z	I_c	$2I_c$	$\Delta\sigma_v$ psf
1.5	666	93	0.25	0.5	293	.25	.5	26.5	38	6.8	.025	.05	3340
5.5	181	25	0.25	0.5	80			30.5	33	5.9	.028	.056	3370
10.5	95	13.3	0.25	.5	42			35.5	28	5.1	.03	.06	3390
13	77	10.8	0.24	.48	34			38	26	4.7	.032	.064	3340
15.5	65	9.0	0.23	.46	28			40.5	25	4.4	.035	.07	3310
18	56	7.8	0.225	.45	24			43	23	4.2	.038	.076	3300
23	43	6.1	0.222	.44	19			48	21	3.8	.041	.082	3290
29	34	4.8	0.215	.43	15			54	18	3.3	.043	.086	3280
33	30	4.2	0.21	.42	13			58	17	3.1	.047	.094	3290
43	23	3.3	0.205	.41	10			68	15	2.6	.054	.108	3270
53	19	2.6	0.19	.38	8.3			78	13	2.3	.058	.116	3260
60	17	2.3	0.185	.37	7.3			85	12	2.1	.061	.122	3250
64	16	2.2	0.18	.36	6.9			89	11	2.0	.063	.126	3240
80	12.5	1.8	0.17	.34	5.5	.25	.5	105	9.5	1.7	.068	.136	3220
100	10	1.4	0.15	.30	4.4	.249	.498	125	8	1.4	.072	.144	3130
120	8.3	1.15	0.135	.27	3.7	.248	.496	145	6.9	1.2	.076	.152	3070
140	7.1	1.0	0.125	.25	3.1	.245	.49	165	6	1.1	.078	.156	3020
160	6.3	0.9	0.115	.23	2.75	.245	.488	185	5.4	.97	.078	.156	2960
185	5.4	0.75	0.10	.20	2.4	.242	.485	210	4.8	.86	.074	.148	2830
215	4.7	0.65	0.09	.18	2.0	.24	.48	240	4.2	.75	.07	.14	2740

$$\Delta\sigma_v = 2I_a(3125) + 2I_b(3125) + 2I_c(4375)$$
$$= (2I_a + 2I_b)3125 + 2I_c(4375)$$

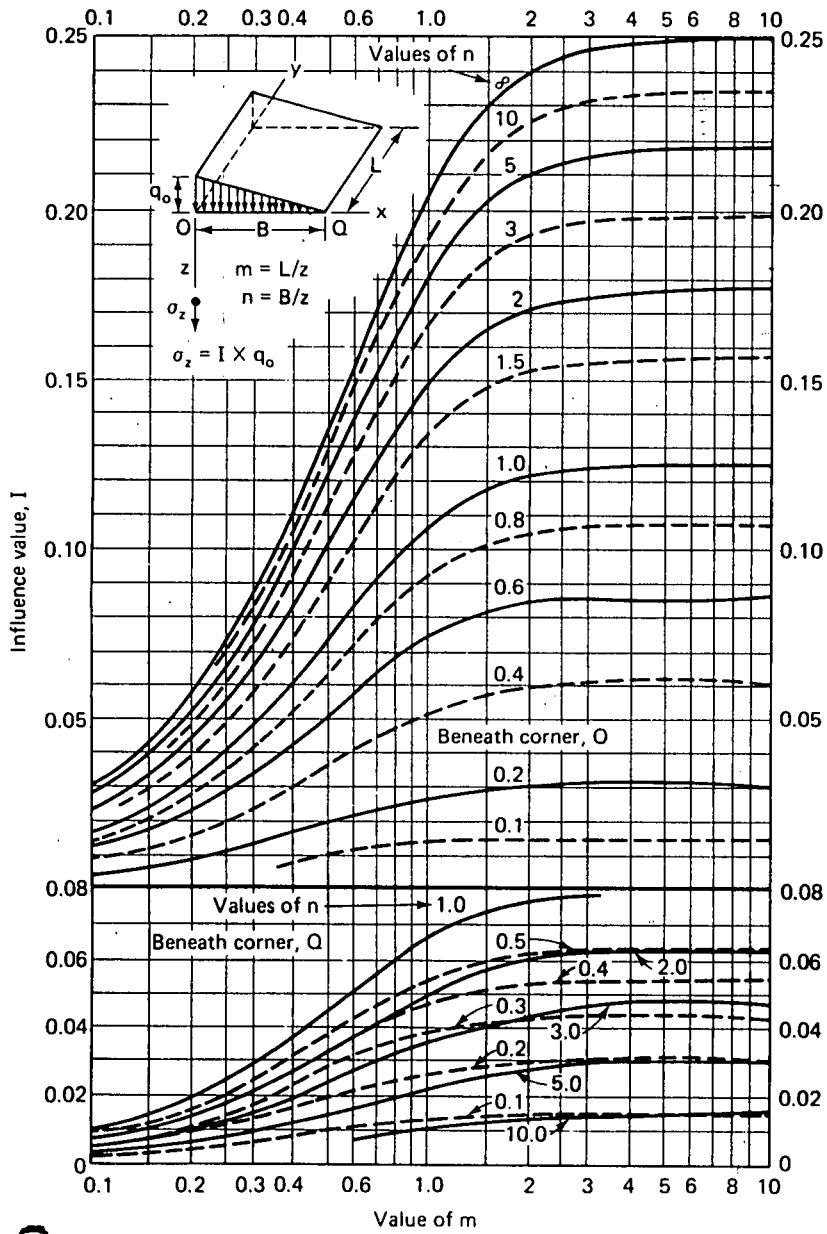


Fig. 8.24 Influence values for vertical stress under the corners of a triangular load of limited length (after U.S. Navy, 1971).

EXAMPLE 8.21

Given:

A highway embankment, as shown in Fig. Ex. 8.21. Assume the average density of the material in the embankment is 2.0 Mg/m^3.

Required:

Compute the vertical stress under the centerline at depths of 3 and 6 m.

Solution:

First, calculate the applied surface stress q_o and the dimensions of the embankment in terms of a and b.

$$q_o = \rho g h = 2.0\ \text{Mg/m}^3 \times 9.81\ \text{m/s}^2 \times 3\ \text{m} = 59\ \text{kPa}$$

From Fig. 8.23, and Fig. Ex. 8.21,

$$b = 5\ \text{m}$$
$$a = 2 \times 3\ \text{m} = 6\ \text{m}$$

Next, calculate the vertical stress for $z = 3$ m.

$$a/z = 6/3 = 2$$
$$b/z = 5/3 = 1.67$$

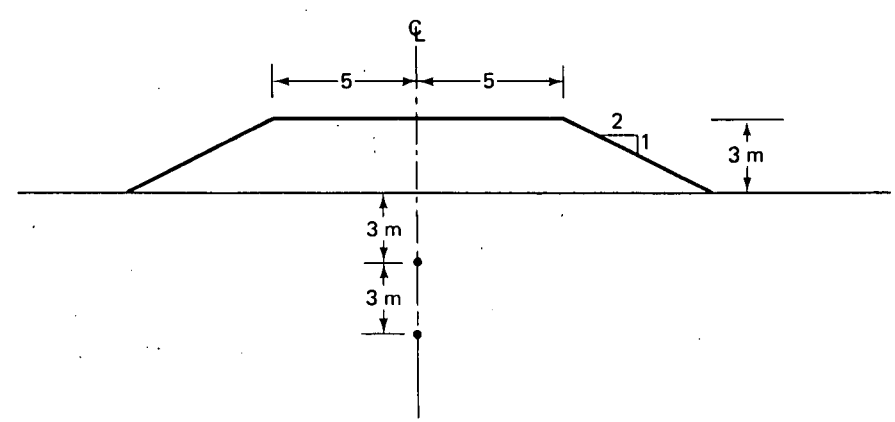


Fig. Ex. 8.21

vertical stress is

$$\sigma_z = \frac{2P}{\pi}\frac{z^3}{x^4} \tag{8-26}$$

where P = line load, and
$x = (z^2 + r^2)^{1/2}$ (see Fig. 8.20a).
Equations for the horizontal and shear stress are also available.

The next logical step is to integrate a line load over a finite area. Newmark (1935) performed the integration of Eq. 8.26 and derived the following equation for the vertical stress under the corner of a *uniformly loaded rectangular area*:

$$\sigma_z = q_o \frac{1}{4\pi}\left[\frac{2mn(m^2+n^2+1)^{1/2}}{m^2+n^2+1+m^2n^2} \times \frac{(m^2+n^2+2)}{(m^2+n^2+1)} + \arctan\frac{2mn(m^2+n^2+1)^{1/2}}{m^2+n^2+1-m^2n^2}\right] \tag{8-27}$$

where q_o = surface or contact stress,
$m = x/z$, (8-28)
$n = y/z$, and (8-29)
x, y = length and width of the uniformly loaded area, respectively.
The parameters m and n are interchangeable. Fortunately Eq. 8-27 may be rewritten as

$$\sigma_z = q_o I \tag{8-30}$$

where I = an influence value which depends on m and n.

Values of I for various values of m and n are shown in Fig. 8.21.

EXAMPLE 8.18

Given:

The 3 × 4 m rectangular footing of Example 8.17 is loaded uniformly by 117 kPa.

Required:

a. Find the vertical stress under the corner of the footing at a depth of 2 m.

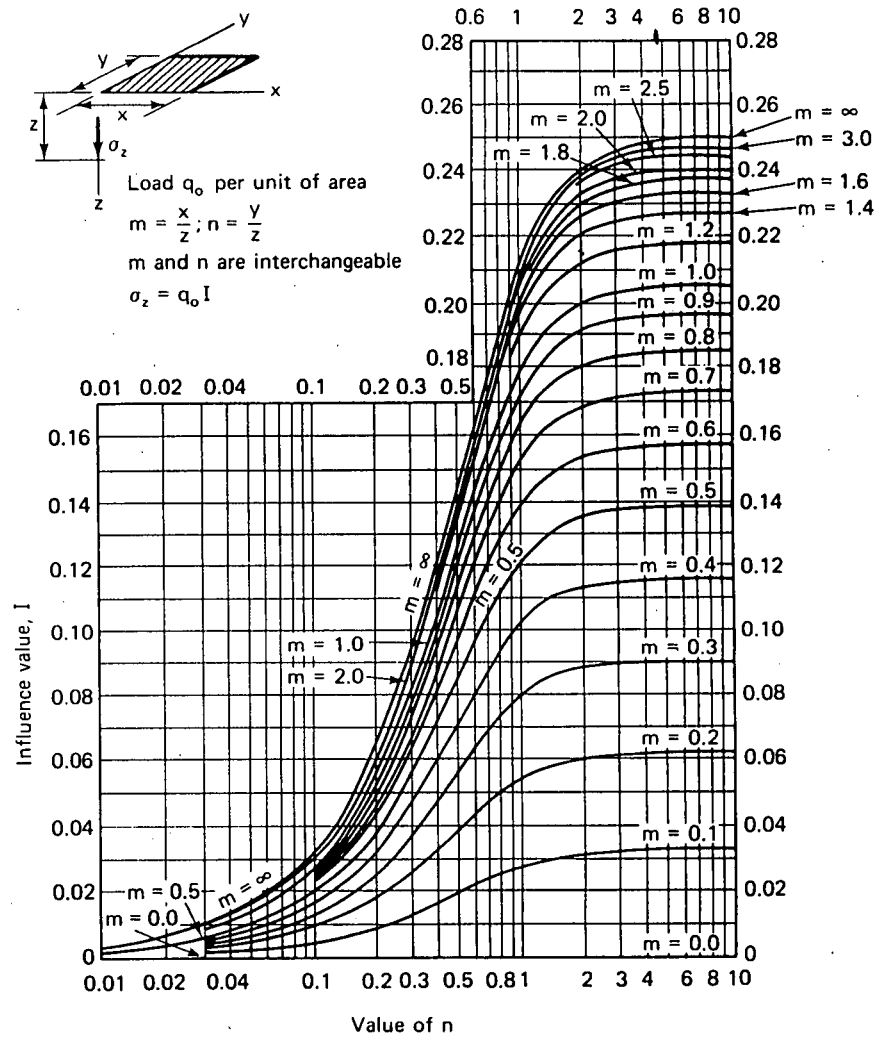


Fig. 8.21 Influence value for vertical stress under corner of a uniformly loaded rectangular area (after U.S. Navy, 1971).

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186 31/05

Required:

a. Compute the stress under the center of the tank at a depth of 2 m below the tank.
b. Compute the stress under the edge of the tank, also a depth of 2 m.

Solution:

a. Refer to Fig. 8.22.

$$z = 2 \text{ m}$$
$$r = 3.91/2 = 1.95 \text{ m}$$
$$x = 0; \text{ then}$$
$$z/r = 2/1.95 = 1.02$$
$$x/r = 0/1.95 = 0.$$

Find $I = 0.63$. Using Eq. 8-30 we obtain,

$$\sigma_z = q_o I = 117 \times 0.63 = 74 \text{ kPa}$$

(This compares exactly with $\sigma_z = 74$ kPa at the center for a 3×4 m rectangular area in Example 8.18. In both cases, the area is 12 m^2.)

b. Again, refer to Fig. 8.22. For the edge of the circular loaded area:

$$z = 2 \text{ m}$$
$$r = 1.95 \text{ m}$$
$$x = r = 1.95 \text{ m}$$
$$z/r = 2/1.95 = 1.02$$
$$x/r = 1.0$$

Find $I = 0.33$; then using Eq. 8-30,

$$\sigma_z = q_o I = 117 \times 0.33 = 39 \text{ kPa}$$

This compares with $\sigma_z = 26$ kPa at a corner for a 3×4 m uniformly loaded rectangular area. In both cases, the area of the loaded area is the same.)

Another useful integration of the Boussinesq equations is the trapezoidal loading shown in Fig. 8.23, which models the loading caused by a *long embankment*. Influence values are in terms of the dimensions a and b, as shown in the figure. If the embankment is not infinitely long, then use Fig. 8.24 together with Fig. 8.21 to represent different load configurations.

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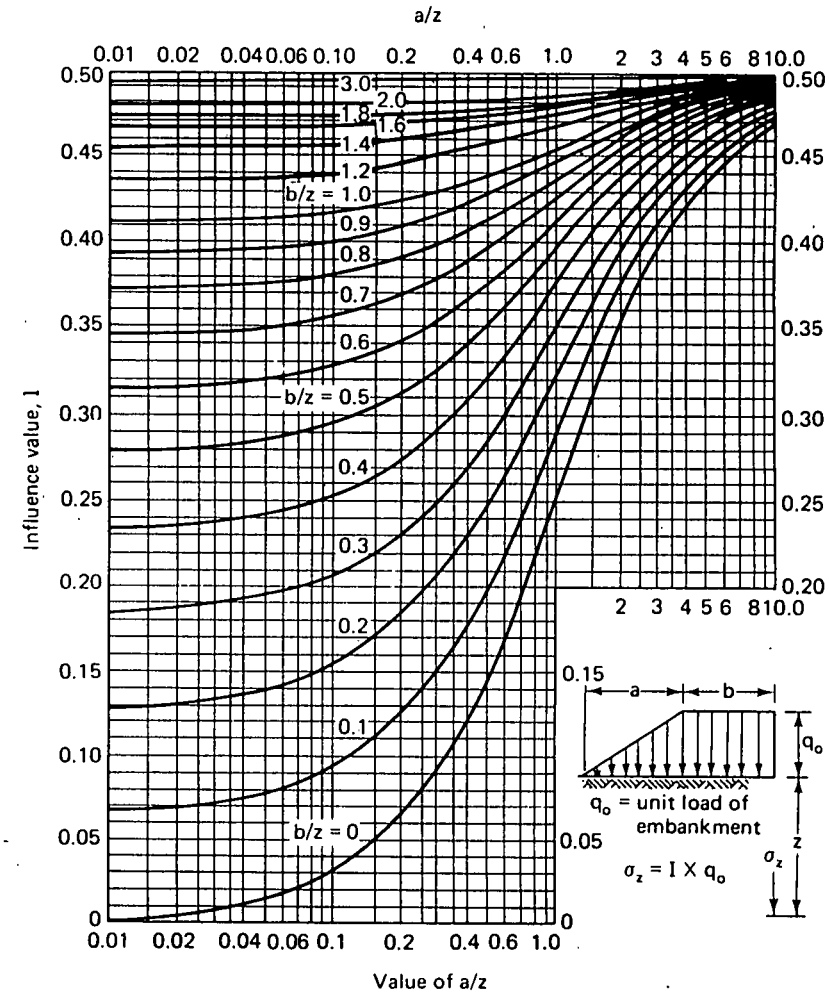

Fig. 8.23 Influence values for vertical stress under a very long embankment; length = ∞ (from U.S. Navy, 1971, after Osterberg, 1957).

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Written by: M. GLEASON Date: 95/9/17 Reviewed by: JM Date: 95/10/5

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

FOUNDATION SETTLEMENT - CALCULATION OF TOTAL SETTLEMENT

OVERBURDEN FROM OSDF

- ASSUME UNIFORM UNIT WEIGHT $\gamma = 125$ pcf FOR WASTE AND GRANULAR COMPONENTS OF COVER AND LINER
- CALCULATE SETTLEMENT OF LINER FOR FINAL WASTE CONFIGURATION WITH COVER SYSTEM IN PLACE
- Maximum height of OSDF above Liner = 60 ft
- MAXIMUM Overburden Pressure

$$\sigma_{n\,max} = 60\text{ft} \times 125\text{ pcf} = 7500\text{ psf}$$

- ASSUME LOAD IS PLACED AT ONE TIME
  CALCULATE TOTAL SETTLEMENT FOR THIS CONDITION

CASE 1

CLAY LINER	3 ft	thick
BROWN TILL	5 ft	thick
GRAY TILL	15 ft	thick
GMA SOILS	210 ft	thick
WATER TABLE	AT	70 FT DEPTH

POINT A:

Layer 1 3ft compacted clay Liner SEE DATA VERIFICATION

$e_p = 0.32$

$\gamma = 130$ pcf	$C_{\alpha\varepsilon} = 0.0015$	$R_f = 0.9$
$e_0 = 0.43$	$\sigma_p = 1000$ psf	$\nu = 0.40$ .45
$C_c = 0.13$	$k = 150$	$S_u = 1200$ psf
$C_r = 0.035$	$n = 1$	mid point @ 1.5 ft
		$\sigma_1 = 195$ psf

Vertical stress increase = 7500 psf ($I = 1.0$ for this layer)

Assume $\sigma_3 = 0.8\sigma_1$ for elastic settlement analysis (for undrained loading)

This is a simplification, however the elastic settlement of the cohesive soils is expected to be a minor component of the total settlement

$\therefore \sigma_3 = 150$ psf

Written by: M. Gleason Date: 95/9/27 (YY MM DD) Reviewed by: JM Date: 95/10/5 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: 6E 3960 Task No.: 9.9

Foundation Settlement - Total Settlement

CASE 1 POINT A

Layer 1

$$E_{ut} = K_{pa}(\sigma_3/p_a)^n\left[1 - R_f(\sigma_1-\sigma_3)/(2\,s_u)\right]^2$$

$$E_{ut} = 150(2117)(150/2117)^1\left[1 - 0.9(195-150)/2(1200)\right]^2$$

$$E_{ut} = 21700 \text{ psf}$$

$$M = \frac{E_{ut}(1-\nu)}{(1+\nu)(1-2\nu)} = \frac{21700(1-0.475)}{1.475(0.05)} = 154{,}000$$

$$\Delta h_{i1} = (7500/154{,}000 \text{ psf})(3\text{ft}) = 0.146\text{ ft} \checkmark$$

$$\Delta h_{p1} = 0.035\frac{3}{1+0.43}\log\frac{1000}{195} + 0.13\frac{3}{1+0.43}\log\frac{195+7500}{1000}$$

$$\Delta h_{p1} = 0.052 + 0.242 = 0.294\text{ ft} \checkmark$$

$$\Delta h_{s1} = 0.0015\frac{3}{1+0.32}\log\frac{1000}{10} = 0.007\text{ ft} \checkmark$$

LAYER 1 $0.146\text{ft} + 0.294\text{ft} + 0.007\text{ft} = 0.447\text{ ft} \checkmark$

LAYER 2

5ft Brown Till

$\gamma = 135$ $e_0 = 0.29$ $e_p = 0.22$ $R_f = 0.9$

$C_c = 0.075$ $C_r = 0.015$ $k = 175$ $\nu = 0.475$

$C_{\alpha\epsilon} = 0.0015$ $OCR = 1.7$ $n = 1$ $s_u = 1200$

Influence Value = 1.0 $\Delta\sigma_v = 7500$ psf

Layer midpoint @ 5.5 ft $\sigma_0 = 3\times130 + 2.5(135) = 730$ psf

$\sigma_3 = 580$ psf

$$E_{ut} = 175(2117)(580/2117)^1\left[1 - 0.9(730-580)/2(1200)\right]^2$$

$$E_{ut} = 90{,}400 \text{ psf}$$

$$M = \frac{90{,}400(1-0.475)}{(1.475(0.05)} = 643{,}500$$

$$\Delta h_{i2} = (7500/643500)\,5\text{ft} = 0.058\text{ ft} \checkmark$$

Written by: M. GLEASON Date: 95/9/17 Reviewed by: JM Date: 95/10/5

Client: FERMCO Project: OSDF Project/Proposal No.: 65 3900 Task No.: 9.9

Foundation Settlement -

CASE 1 POINT A
Layer 2 (cont.)

OCR = 1.7 σ_p = 1200

$$\Delta h_{p2} = 0.015 \frac{5}{1+0.29} \log 1.7 + 0.075 \frac{5}{1+0.29} \log \frac{730+7500}{1200}$$

$$\Delta h_{p2} = 0.013 + 0.243 \text{ ft} = 0.256 \text{ ft} \checkmark$$

$$\Delta h_{s2} = 0.0015 \frac{5}{1+0.22} \log 1000/10 = 0.012 \text{ ft} \checkmark$$

LAYER 2 $\Delta h = (0.058 + 0.256 + 0.012)$ ft $= 0.326$ ft ✓

LAYER 3 7.5' thick gray till

$\gamma = 145$ pcf
$e_0 = 0.38$
$C_c = 0.074$
C_r = N/A OCR = 1

$C_{\alpha\epsilon} = 0.0013$
$C_p = 0.29$
$k = 175$
$n = 1$

$R_f = 0.9$
$\nu = 0.49$
$S_u = 7900$

Influence Value $I = 1.0$ $\Delta\sigma_v = 7500$ psf

$\sigma_1 = 3(130) + 5(135) + 3.75(145) = 1600$ psf $\sigma_3 = 1300$ psf

$$E_{ut} = 175(\cancel{2117})\left(\frac{1300}{\cancel{2117}}\right)^1 \left[1 - 0.9(1600-1300)/2(1900)\right]^2$$

$$E_{ut} = 196{,}000 \qquad M = \frac{196{,}000(1-0.49)}{(1+0.49)(0.02)} = 3.35\times10^6$$

$$\Delta h_{i3} = \left(7500/3.35\times10^6\right) 7.5' = 0.017 \text{ ft} \checkmark$$

$$\Delta h_{p3} = 0.074 \frac{7.5}{1+0.38} \log\left(\frac{1600+3500}{1600}\right) = 0.304 \text{ ft} \checkmark$$

$$\Delta h_{s3} = 0.0013 \frac{7.5}{1+0.29} \log 1000/10 = 0.015 \text{ ft} \checkmark$$

LAYER 3 $\Delta h_T = 0.017$ ft $+ 0.304$ ft $+ 0.015$ ft $= 0.336$ ft ✓

Written by: M. Gilbertson Date: 95/9/17 (YY MM DD) Reviewed by: TM Date: 95/10/5 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement

CASE 1 POINT A

Layer 4 7.5' Gray Till. Parameters as in Layer 3 depth = 19 ft

$I = 1.0$ $\Delta\sigma_v = 7500$ psf $\sigma_0 = 390 + 675 + 11.25(145) = 2700$ psf

$\sigma_3 = 2150$ psf

$E_{ut} = 175 \cdot 2117 \left(2150/2117\right)^1 \left[1 - 0.9(2700-2150)/(2(1900))\right]^2 = 284{,}600$ psf

$M = 284600$ psf $(17.1) = 4.9 \times 10^6$ psf

$\Delta h_{i\,4} = \left(7500/4.9\times10^6\right) 7.5$ ft $= 0.012$ ft

$\Delta h_{p\,4} = 0.074 \dfrac{7.5}{1+0.38} \log\left(\dfrac{2700+7500}{2700}\right) = 0.232$ ft ✓

$\Delta h_{s\,4} = 0.0013 \dfrac{7.5}{1+0.29} \log 1000/10 = 0.015$ ft ✓

Layer 4 $\Delta h_T = (0.012 + 0.232 + 0.015)$ ft $= 0.259$ ft ✓

Layer 5 12' unsaturated GMA soils

$\gamma_T = 135$ $\phi = 35$ $k = 900$ $n = 0.5$ $R_f = 0.7$ $\nu = 0.3$

$\sigma_1 = 3(130) + 5(135) + 15(145) + 6(135) = 4050$ psf

$\sigma_3 = \sigma_1(1 - \sin\phi) = 1730$ psf $1 - \sin\phi = 0.426$

$E_t = k p_a (\sigma_3/p_a)^n \left[1 - R_f(1-\sin\phi)(\sigma_1 - \sigma_3)/2\sin\phi\,\sigma_3\right]^2$

$E_t = 900(2117)\left(1730/2117\right)^{0.5}\left[1 - 0.7(0.426)(4050-1730)/2(.574)1730\right]^2$

$E_t = 7.3\times10^5$ psf

$M = \dfrac{7.3\times10^5(1-0.3)}{(1+0.3)(1-2(0.3))} = 9.85\times10^5$ psf

$\Delta h_5 = \left(7500/9.85\times10^5\right) 12$ ft $= 0.092$ ft ✓

Written by: M. GLEASON Date: 95/9/17 (YY MM DD) Reviewed by: JM Date: 95/10/5 (YY MM DD)

Client: FERMCO Project: DSDF Project/Proposal No.: 6E 3900 Task No.: 9.9

Foundation Settlement

CASE 1 POINT A

Layer 6 - Same parameters as layer 5 15' unsaturated EMA

$I_f = 1.0$ $\Delta\sigma_v = 7500$ psf $\sigma_1 = 4050\text{psf} + 135(6+7.5) = 5870$ psf
$\sigma_3 = 2500$ psf

$$E_t = 900(2117)\left(2500/2117\right)^{1/2}\left[1 - 0.7(0.426)(5870-2500)/2(.574)2500\right]^2$$

$E_t = 8.7 \times 10^5$ psf $M = 8.7 \times 10^5 (1.35) = 1.2 \times 10^6$ psf

$\Delta h_6 = \left(7500/1.2 \times 10^6\right) 15' = 0.096$ ft ✓

Layer 7 20' unsaturated EMA Depth = 60 ft

$I_f = 0.99$ $\Delta\sigma_v = 7425$ psf $\sigma_1 = 5870 + 17.5(135) = 8200$ psf
$\sigma_3 = 3500$ psf

$$E_t = 900(2117)\left(3500/2117\right)^{1/2}\left[1 - .7(.426)(8200-3500)/2(.574)3500\right]^2$$

$E_t = 1.0 \times 10^6$ $M = 1.0 \times 10^6 \times 1.35 = 1.4 \times 10^6$ psf

$\Delta h_7 = \left(7425/1.4 \times 10^6\right) 20' = 0.106$ ft ✓

Layer 8 20' Saturated EMA. Depth to midpoint = 80'
EWT @ 70 ft

$I_f = 0.98$ $\Delta\sigma_v = 7350$ psf

$\sigma_0 = 8200$ psf $+ 10(135) + 10(72.6) = 10280$ psf $\sigma_3 = 4380$

$$E_t = 900(2117)\left(4380/2117\right)^{1/2}(1-0.35)^2 = 1.1 \times 10^6 \text{ psf}$$

$M = 1.1 \times 10^6 \times 1.35 = 1.5 \times 10^6$ psf

$\Delta h_8 = \left(7350/1.5 \times 10^6\right) 20\text{ft} = 0.095$ ft ✓

Written by: M. GLEASON Date: 95/9/17 (YY MM DD) Reviewed by: JM Date: 95/10/5 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement

CASE 1 Point A

Layer 9 20' GMA - saturated Depth to Mid point = 100'

$I_f = 0.97$ $\Delta\sigma_v = 7275$ psf

$\sigma_\phi = 3(130) + 5(135) + 15(145) + 47(135) + 30(72.6) = 11760$ psf

$\sigma_3 = 5000$ psf

$E_t = 900(2117)\left(5000/2117\right)^{1/2}[1-0.35]^2 = 1.24 \times 10^6$ psf

$M = 1.24 \times 10^6 \times 1.35 = 1.67 \times 10^6$ psf

$\Delta h_9 = \left(7275/1.67\times10^6\right) 20\text{ft} = 0.087\text{ ft}$ ✓

Layer 10 20' GMA Saturated Depth to mid point = 120'

$I_f = 0.96$ $\Delta\sigma_v = 7200$ psf

$\sigma_1 = 11760 + 20(72.6) = 13200$ psf $\sigma_3 = 5600$

$E_t = 900(2117)\left(5600/2117\right)^{1/2}[1-0.35]^2 = 1.31 \times 10^6$ psf

$M = 1.35 E_t = 1.76 \times 10^6$ psf

$\Delta h_{10} = \left(7200/1.76\times10^6 \text{ psf}\right) 20\text{ ft} = 0.082\text{ ft}$ ✓

Layer 11 20' GMA Depth to midpoint = 140'

$I_f = 0.94$ $\Delta\sigma_v = 7050$ psf

$\sigma_1 = 13200 + 20(72.6) = 14650$ psf $\sigma_3 = 6240$ psf

$E_t = 900(2117)\left(6240/2117\right)^{1/2}[1-0.35]^2 = 1.38 \times 10^6$ psf

$M = 1.35 E_t = 1.86 \times 10^6$ psf

$\Delta h_{11} = \left(7050/1.86\times10^6\right) 20\text{ ft} = 0.076\text{ ft}$ ✓

Written by: M. GLEASON Date: 95/9/17 (YY MM DD) Reviewed by: JM Date: 95/10/5 (YY MM DD)

Client: FERMILAB Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement

CASE 1 Point A

Layer 12 20' GMA Mid depth 160 ft

$I_f = 0.92$ $\Delta\sigma_v = 6900$ psf

$\sigma_1 = 14650 + 20(72.6) = 16100$ psf $\sigma_3 = 6860$ psf

$E_t = 900(2117)\left(6860/2117\right)^{1/2}[1-0.35]^2 = 1.44\times10^6$ psf

$M = 1.35E_t = 1.9\times10^6$ psf

$\Delta h_{12} = (6900/1.9\times10^6 \text{ psf})\,20\text{ ft} = 0.073$ ft ✓

Layer 13 30' GMA Mid depth = 185 ft

$I_f = 0.9$ $\Delta\sigma_v = 6750$ psf

$\sigma_1 = 390 + 675 + 2175 + 6345 + 115(72.6) = 17900$ psf $\sigma_3 = 7640$ psf

$E_t = 900(2117)\left(7640/2117\right)^{1/2}[1-0.35]^2 = 1.52\times10^6$ psf

$M = 1.35E_t = 2.06\times10^6$ psf

$\Delta h_{13} = (6750/2.06\times10^6)\,30\text{ ft} = 0.098$ ft ✓

Layer 14 30' GMA Mid Depth = 215 ft

$I_f = 0.87$ $\Delta\sigma_v = 6525$

$\sigma_1 = 17900 + 30(72.6) = 20100$ psf $\sigma_3 = 8550$ psf

$E_t = 900(2117)\left(8550/2117\right)^{1/2}(.65)^2 = 1.62\times10^6$ psf

$M = 1.35E_t = 2.2\times10^6$ psf

$\Delta h_{13} = (6525/2.2\times10^6 \text{ psf})\,30\text{ ft} = 0.090$ ft ✓

Written by: M. GLEASON Date: 95/9/17 (YY MM DD) Reviewed by: JM Date: 95/10/5 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement

CASE 1 POINT A

TOTAL SETTLEMENT	LAYER	SETTLEMENT (ft)
	1	.447
	2	.326
	3	.336
	4	.259
	5	.091
	6	.096
	7	.106
	8	.095
	9	.087
	10	.082
	11	.076
	12	.073
	13	.098
	14	.090
	TOTAL	2.26 ft ✓

CASE 1 POINT B

BECAUSE INFLUENCE VALUES ARE IDENTICAL FOR LAYERS 1, 2, and 3, the settlements will be the same also.

Layer 1 $\Delta h_T = 0.447$ ✓
Layer 2 $\Delta h_T = 0.326$ ✓
Layer 3 $\Delta h_T = 0.336$ ✓

Layer 4 7.5' Gray Till parameters obtained from Point A calculation
$I_f = 0.99$ $\Delta\sigma_r = 7425$ psf $\sigma_1 = 2700$

Elastic Settlement Parameters: E_t and M remain constant regardless of $\Delta\sigma_v$ $E_t = 284,600$ $M = 4.9 \times 10^6$ psf

$$\Delta h_{i4} = (7425/4.9\times10^6)\ 7.5\text{ ft} = 0.011\text{ ft}$$ ✓

$$\Delta h_{p4} = 0.074 \frac{7.5}{1+0.38} \log\left(\frac{2700+7425}{2700}\right) = 0.231\text{ ft}$$ ✓

Δh_{s4} is not influenced by $\Delta\sigma_r$ ∴ is equal to Δh_{s4} for Point A (0.015 ft) ✓

Layer 4 $\Delta h_T = 0.011 + 0.231 + 0.015 = 0.257$ ft ✓

Written by: M. GLEASON Date: 95/9/17 (YY MM DD) Reviewed by: JM Date: 95/10/5 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation settlement

CASE 1 POINT B

Layer 5 — 12' unsaturated GMA — mid depth 29' — values as in Point A layer 5
Et and M are identical to values calculated for Point A layer 5

$E_t = 7.3 \times 10^5$ psf $M = 9.85 \times 10^5$ psf $I_f = 0.97$ $\Delta\sigma_v = 7275$ psf

$\Delta h_5 = (7275/9.85 \times 10^5)\, 12\text{ft} = 0.089$ ft ✓

Layer 6 — 15' unsaturated GMA — mid depth = 42.5 ft.
values for parameters, properties as in Point A layer 6

$I_f = 0.95$ $\Delta\sigma_v = 7125$ $M = 1.2 \times 10^6$ psf

$\Delta h_6 = (7125/1.2 \times 10^6)\, 15' = 0.089$ ft ✓

Layer 7 — 20' unsaturated GMA — mid depth = 60 ft
values from Point A layer 6

$I_f = 0.94$ $\Delta\sigma_v = 7050$ psf $M = 1.4 \times 10^6$ psf

$\Delta h_7 = (7050/1.4 \times 10^6)\, 20\text{ft} = 0.101$ ft ✓

Layer 8 — 20' saturated GMA — mid depth = 80'

$I_f = 0.93$ $\Delta\sigma_v = 6975$ psf $M = 1.5 \times 10^6$

$\Delta h_8 = (6975/1.5 \times 10^6)\, 20\text{ft} = 0.093$ ft ✓

Layer 9 — 20' sat. GMA — mid depth = 100'

$I_f = 0.90$ $\Delta\sigma_v = 6750$ psf $M = 1.67 \times 10^6$ psf

$\Delta h_9 = (6750/1.67 \times 10^6)\, 20\text{ft} = 0.081$ ft ✓

Written by: M. Gilleesen Date: 95/9/17 (YY MM DD) Reviewed by: TM Date: 95/10/5 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement

CASE 1 POINT B cont.

Layer 10 20' GMA (sat) Mid Depth @ 120'

$I_f = 0.87$ $\Delta\sigma_v = 6525$ psf $M = 1.76 \times 10^6$ psf

$\Delta h_{10} = (6525 / 1.76 \times 10^6) \times 20ft = 0.074$ ft ✓

Layer 11 20' GMA (sat) Mid depth @ 140'

$I_f = 0.85$ $\Delta\sigma_v = 6375$ psf $M = 1.86 \times 10^6$ psf

$\Delta h_{11} = (6375 / 1.86 \times 10^6)\ 20' = 0.069$ ft ✓

Layer 12 20' GMA (sat.) Mid depth @ 160'

$I_f = 0.82$ $\Delta\sigma_v = 6150$ psf $M = 1.9 \times 10^6$ psf

$\Delta h_{12} = (6150 / 1.9 \times 10^6 \text{ psf})\ 20' = 0.065$ ft ✓

Layer 13 30' GMA (Saturated) Mid depth = 185 ft

$I_f = 0.784$ $\Delta\sigma_v = 5880$ psf $M = 2.06 \times 10^6$ psf

$\Delta h_{13} = (5880 / 2.06 \times 10^6 \text{ psf})\ 30ft = 0.086$ ft ✓

Layer 14 30' GMA (Sat) Mid depth = 215 ft

$I_f = 0.75$ $\Delta\sigma_v = 5625$ psf $M = 2.2 \times 10^6$ psf

$\Delta h_{14} = (5625 / 2.2 \times 10^6)\ 30ft = 0.077$ ft ✓

Written by: M. GLEASON Date: 95/9/17 (YY MM DD) Reviewed by: DM Date: 95/10/5 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement

CASE 1 POINT B

TOTAL SETTLEMENT	LAYER	SETTLEMENT (FT)
	1	.447
	2	.326
	3	.336
	4	.257
	5	.089
	6	.089
	7	.101
	8	.093
	9	.081
	10	.074
	11	.069
	12	.065
	13	.086
	14	.077
	TOTAL	2.19 ✓

CASE 1 POINT C

LAYER 1 Recompacted Clay 3 ft Mid depth = 1.5 ft
Use Parameters from Point A Layer 1
$I_f = 0.01$ $\Delta\sigma_v = 75$ psf $M = 153{,}700$

$\Delta h_{i_1} = (75/154{,}000)\,3 = 0.001$ ft ✓

$\Delta h_{p_1} = 0.035 \frac{3}{1+0.43} \log \frac{75+195}{195} = 0.01$ ft ✓

$\Delta h_{s_1} = 0.007$ ft from previous analysis (not dependent on $\Delta\sigma_v$) ✓

LAYER 1 $\Delta h_T = 0.018$ ft ✓

LAYER 2 5' Brown Till Mid depth @ 5.5'
$I_f = 0.012$ $\Delta\sigma_v = 90$ psf $M = 6.4\times10^5$ psf $\sigma_v = 730$

$\Delta h_{i_2} = (90/6.4\times10^5)\,5' = 0.001$ ft ✓

$\Delta h_{p_2} = 0.015 \frac{5}{1+0.29} \log \frac{730+90}{730} = 0.000$ ft ✓

$\Delta h_{s_2} = 0.012$ ft ✓

Layer 2 $\Delta h_T = 0.013$ ft ✓

Written by: M. ELERSON Date: 95/9/17 Reviewed by: TM Date: 95/10/5
YY MM DD YY MM DD

Client: FERMCO Project: OSDF Project/Proposal No.: 6E 3900 Task No.: 9.9

Foundation Settlement

CASE 1 POINT C

Layer 3 7.5' Gray Till Midelpth = 12' I_f = 0.016 $\Delta\sigma_v$ = 120 psf
$M = 3.35 \times 10^6$ psf σ_o = 1600 psf

$\Delta h_{i3} = (120/3.35 \times 10^6)\, 7.5' = 0.000$ ft ✓

$\Delta h_{p3} = 0.074 \frac{7.5}{1+0.38} \log \frac{1600+120}{1600} = 0.013$ ft ✓

Δh_{s3} = 0.015 ft (from Point A analysis) ✓

Layer 3 Δh_T = 0.028 ft ✓

Layer 4 7.5' Gray Till Midelpth = 19' I_f = 0.02 $\Delta\sigma_v$ = 150 psf
$M = 4.9 \times 10^6$ σ_o = 2700 psf

$\Delta h_{i4} = (150/4.9 \times 10^6)\, 7.5 = 0.000$ ft ✓

$\Delta h_{p4} = 0.074 \frac{7.5}{1.38} \log \frac{2700+150}{2700} = 0.009$ ft ✓

Δh_{s4} = 0.015 ft (from Point A Analysis) ✓

Layer 4 Δh_T = 0.024 ft ✓

Layer 5 12' Unsaturated GMA Midelpth = 29' I_f = 0.028 $\Delta\sigma_v$ = 210 psf
Values from Analysis for Point A

$M = 9.85 \times 10^5$ psf

$\Delta h_5 = (210/9.85 \times 10^5)\, 12' = 0.003$ ft ✓

Layer 6 15' GMA Midelpth = 42.5'

I_f = 0.04 $\Delta\sigma_v$ = 300 psf $M = 1.2 \times 10^6$ psf

$\Delta h_6 = (300/1.2 \times 10^6)\, 15' = 0.004$ ft ✓

Written by: M. GLEASON Date: 95/9/17 Reviewed by: TM Date: 95/10/5
YY MM DD YY MM DD

Client: FERMCO Project: DSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement
CASE 1 Point C

Layer 7 20' GMA Middepth = 60'

$I_f = 0.056$ $\Delta\sigma_v = 420$ psf $M = 1.4 \times 10^6$ psf

$\Delta h_7 = (420/1.4 \times 10^6)\, 20' = 0.006$ ft ✓

Layer 8 20' saturated GMA Middepth = 80'

$I_f = 0.08$ $\Delta\sigma_v = 600$ psf $M = 1.5 \times 10^6$ psf

$\Delta h_8 = (600/1.5 \times 10^6)\, 20' = 0.008$ ft ✓

Layer 9 20' sat. GMA Middepth = 100'

$I_f = 0.09$ $\Delta\sigma_v = 675$ $M = 1.67 \times 10^6$ psf

$\Delta h_9 = (675/1.67 \times 10^6)\, 20' = 0.008$ ft ✓

Layer 10 20' Sat GMA Middepth 120'

$I_f = 0.104$ $\Delta\sigma_v = 780$ $M = 1.76 \times 10^6$

$\Delta h_{10} = (780/1.76 \times 10^6)\, 20' = 0.009$ ft ✓

Layer 11 20' Sat GMA Middepth 140'

$I_f = 0.118$ $\Delta\sigma_v = 885$ $M = 1.86 \times 10^6$

$\Delta h_{11} = (885/1.86 \times 10^6)\, 20' = 0.010$ ft ✓

Layer 12 20' Sat GMA Middepth 160'

$I_f = 0.124$ $\Delta\sigma_v = 930$ psf $M = 1.9 \times 10^6$

$\Delta h_{12} = (930/1.9 \times 10^6)\, 20' = 0.010$ ft ✓

GEOSYNTEC CONSULTANTS

Written by: M. GILEASON Date: 95/9/17 (YY MM DD) Reviewed by: TM Date: 95/10/5 (YY MM DD)

Client: FERMILAB Project: GSDE Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement
CASE 1 Point C

Layer 13 30' GMA Middepth = 185

$I_f = 0.134$ $\Delta\sigma_v = 1005$ $M = 2.06 \times 10^6$ psf

$\Delta h_{13} = (1005 / 2.06 \times 10^6)\ 30' = 0.015$ ft ✓

Layer 14 30' GMA Middepth 215'

$I_f = 0.142$ $\Delta\sigma_v = 1065$ $M = 2.12 \times 10^6$

$\Delta h_{14} = (1065 / 2.12 \times 10^6)\ 30' = 0.015$ ft ✓

CASE 1
POINT C TOTAL SETTLEMENT

LAYER	SETTLEMENT (ft)
1	.018
2	.013
3	.028
4	.024
5	.003
6	.004
7	.006
8	.008
9	.008
10	.009
11	.010
12	.010
13	.015
14	.015

TOTAL = 0.17 ft ✓

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Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement Calculation

CASE 1 POINT D - SEE INFLUENCE VALUE PAGES FOR CALCULATION OF $\Delta\sigma_v$

Layer 1 3' Clay Liner Mid pt = 1.5' $\sigma_o = 195$ $\Delta\sigma_v = 3340$ psf

From Point A $M = 153{,}800$

$\Delta h_{i_1} = (3340/154000)\,3' = 0.065$ ft ✓

$\Delta h_{p1} = 0.035 \frac{3}{1+.43} \log \frac{1000}{195} + 0.13 \frac{3}{1+.43} \log \frac{195+3340}{1000} = 0.202'$ ✓

$\Delta h_{s_1} = 0.0015 \frac{3}{1+.32} \log 1000/10 = 0.007$ ft ✓

$\Delta h_{T_1} = 0.274$ ft ✓

Layer 2 5 ft Brown Till Midpt @ 5.5' $\sigma_o = 730$ psf

From Pt A $M = 643{,}500$ $\Delta\sigma_v = 3370$ psf

$\Delta h_{i_2} = (3370/643{,}500)\,5' = 0.026$ ft ✓ $\sigma_p = 1200$

$\Delta h_{p2} = 0.015 \frac{5}{1+0.29} \log \overset{=OCR}{1.7} + 0.075 \frac{5}{1+.29} \log \frac{730+3370}{1200} = 0.169$ ft ✓

$\Delta h_{s_2} = 0.0015 \frac{5}{1.22} \log 1000/10 = 0.012$ ft ✓

$\Delta h_{T_2} = 0.207$ ft ✓

Layer 3 7.5 ft Gray Till Midpt @ 13' $\sigma_o = 1600$ $\Delta\sigma_v = 3340$ psf

$M = 3.35 \times 10^6$ $\Delta h_{i_3} = (3340/3.35\times10^6)\,7.5' = 0.007$ ft ✓

$\Delta h_{p3} = 0.074 \frac{7.5}{1+.38} \log \left(\frac{1600+3340}{1600}\right) = 0.197$ ft ✓

$\Delta h_{s_3} = 0.0013 \frac{7.5}{1+.29} \log 1000/10 = 0.015$ ✓

$\Delta h_{T_3} = 0.219$ ft ✓

Written by: M. GLEASON Date: 95/9/21 (YY/MM/DD) Reviewed by: JM Date: 95/10/5 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement

CASE 1 POINT D - sump

Layer 4 7.5' Gray Till Mid pt @ 18' $\sigma_o = 2700$ psf $\Delta\sigma_v = 3300$

$M = 4.9 \times 10^6$ psf $\Delta h_i = (3300/4.9 \times 10^6)\,7.5' = 0.005$ ft ✓

$\Delta h_p = 0.074 \frac{7.5}{1+.38} \log\left(\frac{3300+2700}{2700}\right) = 0.139$ ft ✓

$\Delta h_s = 0.015$ ft ✓

Layer 4 $\Delta h_T = 0.159$ ft ✓

Layer 5 12' unsaturated GMA Mid pt @ 29 ft $\Delta\sigma_v = 3280$ psf

$M = 9.85 \times 10^5$ psf $\Delta h_5 = (3280/9.85 \times 10^5)\,12' = 0.040$ ft ✓

Layer 6 15' unsaturated GMA Mid pt @ 42.5' $\Delta\sigma_v = 3270$ psf

$M = 1.2 \times 10^6$ psf $\Delta h_6 = (3270/1.2 \times 10^6)\,15' = 0.041$ ft ✓

Layer 7 20' Unsaturated GMA Mid pt @ 60' $\Delta\sigma_v = 3250$ psf

$M = 1.4 \times 10^6$ psf $\Delta h_7 = (3250/1.4 \times 10^6)\,20' = 0.046$ ft ✓

Layer 8 20' Saturated GMA Mid pt @ 80' $\Delta\sigma_v = 3220$ psf

$M = 1.5 \times 10^6$ psf $\Delta h_8 = (3220/1.5 \times 10^6)\,20' = 0.043$ ft ✓

Layer 9 20' Saturated GMA Mid pt @ 100' $\Delta\sigma_v = 3130$ psf

$M = 1.67 \times 10^6$ $\Delta h_9 = (3130/1.67 \times 10^6)\,20' = 0.037$ ft ✓

Layer 10 20' Sat. GMA Mid pt @ 120' $\Delta\sigma_v = 3070$ psf

$M = 1.76 \times 10^6$ $\Delta h_{10} = (3070/1.76 \times 10^6)\,20' = 0.035$ ft ✓

Written by: M. GLEASON Date: 95/9/21 (YY MM DD) Reviewed by: JM Date: 95/10/5 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement

CASE 1 POINT D

Layer 11 20' GMA Midpt @ 140 ft $\Delta\sigma_v$ = 3020 psf

$M = 1.86\times10^6$ psf $\Delta h_{11} = (3020/1.86\times10^6)20' = 0.032$ ft ✓

Layer 12 20' GMA Midpt @ 160 ft $\Delta\sigma_v$ = 2960 psf

$M = 1.9\times10^6$ psf $\Delta h_{12} = (2960/1.9\times10^6)20' = 0.031$ ft ✓

Layer 13 30' GMA Midpt @ 185 ft $\Delta\sigma_v$ = 2830 psf

$M = 2.06\times10^6$ psf $\Delta h_{13} = (2830/2.06\times10^6)30' = 0.041$ ft ✓

Layer 14 30' GMA Midpt @ 215 ft $\Delta\sigma_v$ = 2740 psf

$M = 2.2\times10^6$ psf $\Delta h_{14} = (2740/2.2\times10^6)\times30' = 0.037$ ft ✓

CASE 1 POINT D TOTAL SETTLEMENT

LAYER	SETTLEMENT
1	.274
2	.207
3	.219
4	.159
5	.040
6	.041
7	.046
8	.043
9	.037
10	.035
11	.032
12	.031
13	.041
14	.037
TOTAL	1.24 ✓

Written by: M. GLEASON Date: 95/9/17 (YY MM DD) Reviewed by: JM Date: 95/10/5 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement

CASE 2

Clay Liner 3 ft
Brown Till 10 ft
Gray Till 45 ft
GMX Soils 175 ft
Water Table at 70 ft Depth

Point A

Layer 1 and Layer 2 have the same values as for CASE 1

Layer 1 $\Delta h_T = 0.447$ ft ✓
Layer 2 $\Delta h_T = 0.326$ ft ✓

Layer 3 5' Thick Brown Till $\Delta\sigma_v = 7500$ psf
Middepth @ 10.5 ft $\sigma_0 = 3(130) + 7.5(135) = 1400$ psf
Material Properties as Case 1 $\sigma_3 = 1100$ psf

$$E_{ut} = 175(2117)\left(1100/2117\right)^1\left[1 - 0.9(1400-1100)/2(1200)\right]^2$$

$$E_{ut} = 1.5\times10^5 \text{ psf} \qquad M = \frac{E_{ut}(1-0.475)}{(1+0.475)(1-0.95)} = 1.07\times10^6 \text{ psf}$$

$$\Delta h_{i_3} = (7500/1.07\times10^6)\,5' = 0.035 \text{ ft} ✓ \qquad \sigma_p = 1.7\times\sigma_0 = 2380$$

$$\Delta h_{p_3} = \underbrace{0.015}_{.013}\frac{5}{1+0.29}\log 1.7 + \underbrace{0.075}_{.067}\frac{5}{1+0.29}\log\frac{1400+7500}{2380} = 0.180 \text{ ft} ✓$$

$$\Delta h_{s_3} = 0.0015\frac{5}{1+0.22}\log 1000/10 = 0.012 \text{ ft} ✓$$

Layer 3 $\Delta h_T = 0.227$ ft ✓

Layer 4 5' Gray Till $\Delta\sigma_v = 7500$ ($I_F = 1.0$) OCR = 1.0
Middepth = 15.5'
$\sigma_0 = 3(130) + 10(135) + 2.5(145) = 2100$ $\sigma_3 = 1700$

$$E_{ut} = 175(2117)\left(1700/2117\right)^1\left[1 - 0.9(2100-1700)/2(1900)\right]^2$$

$$E_{ut} = 2.4\times10^5 \text{ psf} \qquad M = \frac{E_{ut}(1+.49)}{1.49(0.02)} = 4.2\times10^6 \text{ psf}$$

$$\Delta h_{i_4} = (7500/4.2\times10^6)\,5' = 0.009 \text{ ft} ✓$$

$$\Delta h_{p_4} = 0.074\frac{5}{1+0.38}\log\frac{2100+7500}{2100} = 0.177 \text{ ft} ✓$$

$$\Delta h_{s_4} = 0.0013\frac{5}{1+0.29}\log 1000/10 = 0.010 \text{ ft} ✓$$

Layer 4 $\Delta h_T = 0.196$ ft ✓

Written by: M. GLEASON Date: 95/9/17 (YY MM DD) Reviewed by: JM Date: 95/10/5 (YY MM DD)

Client: FERMILCO Project: OSDF Project/Proposal No.: 6E 3900 Task No.: 9.9

Foundation Settlement

Point A

CASE 2 Layer 5 10' Gray Till $\Delta\sigma_v = 7500$ psf ($I_f = 1.0$) OCR = 1

Middepth = 23'

$\sigma_1 = 390 + 1350 + 10(145) = 3190$ psf $\sigma_3 = 2550$ psf

$E_{ut} = 175(2117)(2550/2117)^1[1 - .9(3190 - 2550)/2(1900)]^2$

$E_{ut} = 3.2\times10^5$ $M = E_{ut}(17.1) = 5.5\times10^6$

$\Delta h_{is} = (7500/5.5\times10^6)10' = 0.014$ ft ✓

$\Delta h_{ps} = 0.074 \frac{10'}{1+0.38} \log \frac{7500+3190}{3190} = 0.282$ ft ✓

$\Delta h_{ss} = 0.0013 \frac{10}{1+0.29} \log 1000/10 = 0.020$ ft ✓

Layer 5 $\Delta h_T = 0.316$ ft ✓

Layer 6 10' Gray Till Middepth @ 33' $I_f = 1.0$ $\Delta\sigma_v = 7500$ psf OCR = 1.0

$\sigma_1 = 390 + 1350 + 20(145) = 4640$ $\sigma_3 = 3700$

$E_{ut} = 175(2117)(3700/2117)^1[1 - 0.9(4640 - 3700)/2(1900)]^2$

$E_{ut} = 3.9\times10^5$ $M = E_{ut}(17.1) = 6.7\times10^6$ psf

$\Delta h_{i6} = (7500/6.7\times10^6)10' = 0.011$ ft ✓

$\Delta h_{p6} = 0.074 \frac{10'}{1+0.38} \log \frac{4640+7500}{4640} = 0.224$ ft ✓

$\Delta h_{s6} = 0.0013 \frac{10}{1+0.29} \log 1000/10 = 0.020$ ft ✓

Layer 6 $\Delta h_T = 0.255$ ft ✓

Layer 7 10' Gray Till Middepth @ 43' $I_f = 1.0$ $\Delta\sigma_v = 7500$ OCR = 1

$\sigma_1 = 390 + 1350 + 30(145) = 6090$ psf $\sigma_3 = 4870$

$E_{ut} = 175(2117)(4870/2117)^1[1 - 0.9(6090 - 4870)/2(1900)]^2$

$E_{ut} = 4.3\times10^5$ $M = E_{ut}\times17.1 = 7.4\times10^6$ psf

$\Delta h_{i7} = (7500/7.4\times10^6 \text{ psf})10' = 0.010$ ft ✓

$\Delta h_{p7} = 0.074 \frac{10}{1.38} \log \frac{6090+7500}{6090} = 0.187$ ✓ $\Delta h_{s7} = 0.02$ ft ✓

$\Delta h_T = 0.217$ ft ✓

Written by: M. Gleason Date: 95/9/17 (YY MM DD) Reviewed by: JM Date: 95/10/5 (YY MM DD)

Client: Fermco Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement
CASE 2 Point A
Layer 8 10' Gray Till Middepth @ 53' $I_f = 1.0$ $\Delta\sigma_v = 7500$ psf

$\sigma_1 = 390 + 1350 + 40(145) = 7540$ $\sigma_3 = 6030$

$E_{ut} = 175(2117)^{6030/2117}\left[1 - 0.9(7540 - 6030)/2(1900)\right]^2$

$E_{ut} = 4.4 \times 10^5$ psf $M = 7.4 \times 10^6$ psf

$\Delta h_{i8} = (7500/7.4\times10^6)\,10' = 0.010$ ft ✓

$\Delta h_{p8} = 0.074 \frac{10}{1+.38} \log\left(\frac{7540+7500}{7540}\right) = 0.161$ ft ✓

$\Delta h_{s8} = 0.0013 \frac{10}{1+.29} \log 1000/10 = 0.020$ ft ✓

$\Delta h_8 = 0.191$ ft ✓

Layer 9 12' GMA Soils Middepth = 64 ft $I_f = 0.99$ $\Delta\sigma_v = 7475$ psf

$\gamma = 135$ $\phi = 35$ $\sigma_3 = \sigma_1(1 - \sin\phi)$ $K = 750$ $R_f = 0.7$ $n = 1/2$

$\sigma_1 = 390 + 1350 + 45(145) + 6(135) = 9075$ psf $\sigma_3 = 3870$ psf

$E_t = 900(2117)\left(3870/2117\right)^{1/2}\left[1 - 0.7\overbrace{(1 - \sin 35)(9075 - 3870)/2\sin 35\,(3870)}^{0.65}\right]^2$

$E_t = 1.09 \times 10^6$ psf $M = \frac{1.09\times10^6(1-0.3)}{(1+0.3)(1-.6)} = E_t \times 1.35 = \cancel{1.25\times10^6\text{ psf}}$ 1.47×10^6 psf ✓

$\Delta h_9 = \left(7425/\cancel{1.25\times10^6}\ 1.47\times10^6\right) 12' = \cancel{0.071'}$ $0.061'$ ✓

LAYER 10 20' Saturated GMA Soils Mid depth = 80'

$I_f = 0.98$ $\Delta\sigma_v = 7350$

$\sigma_1 = 8265 + 12(135) + 10(72.6) = 10{,}600$ psf $\sigma_3 = 4520$ psf

$E_t = 900(2117)\left(4520/2117\right)^{1/2}[.65]^2 = 1.18\times10^6$ psf

$M = 1.35\,E_t = 1.6\times10^6$ psf

$\Delta h_{10} = (7350/1.6\times10^6)\,20' = 0.093$ ft. ✓

Written by: M. GLEASON Date: 95/9/17 (YY MM DD) Reviewed by: JM Date: 95/10/5 (YY MM DD)

Client: FERMILAB Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement
CASE 2 Point A

Layer 11 — 20' GMA Mid @ 100' $I_f = 0.97$ $\Delta\sigma_v = 7275$ psf

$\sigma_1 = \overbrace{390 + 1350 + 6525 + 12(135)}^{9885} + 30(72.6) = 12060$ $\sigma_3 = 5140$ psf

$E_t = 900(2117)\left(5140/2117\right)^{1/2}(.65)^2 = 1.26 \times 10^6$ $M = 1.35 E_t = 1.7 \times 10^6$ psf

$\Delta h_{11} = \left(7275/1.7 \times 10^6\right) 20\text{ft} = 0.086$ ft ✓

Layer 12 — 20' GMA Mid @ 120' $I_f = 0.96$ $\Delta\sigma_v = 7200$ psf

$\sigma_1 = 9885 + 50(72.6) = 13515$ psf $\sigma_3 = 5760$ psf

$E_t = 900 \cdot 2117\left(5760/2117\right)^{1/2}(.65)^2 = 1.3 \times 10^6$ psf $M = 1.7 \times 10^6$ psf

$\Delta h_{12} = \left(7200/1.7 \times 10^6\right) 20' = 0.085$ ft ✓

Layer 13 — 20' GMA Mid @ 140' $I_f = 0.94$ $\Delta\sigma_v = 7050$ psf

$\sigma_1 = 9885 + 70(72.6) = 14970$ psf $\sigma_3 = 6370$ psf

$E_t = 900 \cdot 2117\left(6370/2117\right)^{1/2}(.65)^2 = 1.4 \times 10^6$ psf $M = 1.9 \times 10^6$ psf

$\Delta h_{13} = \left(7050/1.9 \times 10^6\right) 20' = 0.075$ ft ✓

Layer 14 — 20' GMA Mid @ 160' $I_f = 0.92$ $\Delta\sigma_v = 6900$ psf

$\sigma_1 = 9885 + 90(72.6) = 16400$ psf $\sigma_3 = 7000$ psf

$E_t = 900 \cdot 2117\left(7000/2117\right)^{1/2}(.65)^2 = 1.46 \times 10^6$ psf $M = 1.98 \times 10^6$ psf

$\Delta h_{14} = \left(6900/1.98 \times 10^6\right) 20' = 0.070$ ft ✓

Layer 15 — 30' GMA Mid @ 185' $I_f = 0.9$ $\Delta\sigma_v = 6750$ psf

$\sigma_1 = 9885 + 115(72.6) = 18234$ $\sigma_3 = 7770$ psf

$E_t = 900 \cdot 2117\left(7770/2117\right)^{1/2}(.65)^2 = 1.54 \times 10^6$ psf $M = 2.07 \times 10^6$ psf

$\Delta h_{15} = \left(6750/2.07 \times 10^6\right) 30' = 0.098$ ft ✓

Written by: M. Gleason Date: 95/9/17 (YY/MM/DD) Reviewed by: JM Date: 95/10/5 (YY/MM/DD)

Client: Femco Project: OSDF Project/Proposal No.: 6E 3900 Task No.: 9.9

Foundation Settlement
CASE 2 POINT A

Layer 16 30' GMA Mid @ 215' $I_f = 0.87$ $\Delta\sigma_v = 6525$ psf

$\sigma_1 = 9885 + 145(72.6) = 20{,}400$ psf $\sigma_3 = 8700$ psf

$E_t = 900 \cdot 2117 \left(8700/2117\right)^{1/2} (.65)^2 = 1.63 \times 10^6$ $M = 2.2 \times 10^6$ psf

$\Delta h_{16} = \left(6525 / 2.2 \times 10^6\right) 30' = 0.089$ ft ✓

CASE 2 POINT A TOTAL SETTLEMENT

LAYER	SETTLEMENT
1	.447
2	.326
3	.227
4	.196
5	.316
6	.255
7	.217
8	.191
9	~~.071~~ .061 ✓
10	.093
11	.086
12	.085
13	.075
14	.070
15	.098
16	.089
TOTAL	~~2.84~~ 2.83 ✓

CASE 2 POINT B

Because Influence Values for Points 1, 2, 3, and 4 are the same as for Point A, total settlements will also be the same.

Layer 1 Δh_T = 0.447 ✓
Layer 2 Δh_T = 0.326 ✓
Layer 3 Δh_T = 0.227 ✓
Layer 4 Δh_T = 0.196 ✓

Written by: M. GLEASON Date: 95/9/17 (YY MM DD) Reviewed by: JM Date: 95/10/5 (YY MM DD)

Client: FERMILAB Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement
CASE 2 Point B

Layer 5 10' Gray Till Midpoint @ 23' $I_f = 0.98$ $\Delta\sigma_v = 7350$ psf

From Calculation for Point A Case 2 layer 5 : $M = 5.5 \times 10^6$ psf
$\sigma_1 = 3190$ psf

$\Delta h_{i5} = (7350/5.5 \times 10^6)10' = 0.013$ ft ✓

$\Delta h_{p5} = 0.074 \frac{10}{1+.38} \log \frac{7350+3190}{3190} = 0.278$ ft ✓

$\Delta h_s = 0.020$ ft From Point A layer 5 ✓

Layer 5 $\Delta h_T = 0.311$ ft ✓

Layer 6 10' Gray Till Midpt @ 33' $I_f = 0.96$ $\Delta\sigma_v = 7200$ psf

From Point A, #6 $M = 6.7 \times 10^6$ psf $\sigma_1 = 4640$ psf

$\Delta h_{i6} = (7200/6.7 \times 10^6)10' = 0.016$ ft ✓

$\Delta h_{p6} = .074 \frac{10}{1+.38} \log \frac{4640+7200}{4640} = 0.218$ ft ✓

$\Delta h_{s6} = 0.02$ ft ✓

Layer 6 $\Delta h_T = 0.249$ ft ✓

Layer 7 10' Gray Till Midpt @ 43' $I_f = 0.95$ $\sigma_v = 7125$ psf

$M = 7.4 \times 10^6$ psf $\sigma_1 = 6090$ psf

$\Delta h_{i6} = (7125/7.4 \times 10^6)10' = 0.010$ ft ✓

$\Delta h_{p6} = .074 \frac{10}{1+.38} \log \frac{6090+7125}{6090} = 0.180$ ft ✓

$\Delta h_{s7} = 0.02$ ft ✓

Layer 7 $\Delta h_T = 0.210$ ft ✓

Written by: M. GLEASON Date: 95/9/17 (YY MM DD) Reviewed by: JM Date: 95/10/5 (YY MM DD)

Client: FERMILO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement
CASE 2 Point B

Layer 8 10' Gray Till Middepth @ 53' $I_f = 0.94$ $\Delta\sigma_v = 7050$
$\sigma_1 = 7540$ ~~$\sigma_3 = 6030$~~ $M = 7.4 \times 10^6$

$\Delta h_i = (7050/7.4 \times 10^6)10' = 0.010$ ft ✓ 7540

$\Delta h_p = 0.074 \frac{10'}{1+.38} \log \frac{7050 + \cancel{6030}}{\cancel{6030}\ 7540} =$ ~~0.144 ft~~ 0.154 ft ✓

$\Delta h_s = 0.02$ ✓ $\Delta h_{T_8} =$ ~~0.174 ft~~ 0.184 ft ✓

Layer 9 12' GMA Soils Midpt @ 64'

$I_f = 0.93$ $\Delta\sigma_v = 6975$ $M =$ ~~1.25~~ 1.47 $\times 10^6$ psf ✓

$\Delta h_9 = (6975/$ ~~1.25~~ 1.47 $\times 10^6)12' =$ ~~0.067~~ 0.057 ft ✓

Layer 10 20' GMA Soils - Saturated Midpt @ 80'

$I_f = .93$ $\Delta\sigma_v = 6975$ $M = 1.6 \times 10^6$ psf

$\Delta h_{10} = (6975/1.6 \times 10^6)20' = 0.087$ ft ✓

Layer 11 20' GMA Midpt @ 100' $I_f = .90$ $\Delta\sigma_v = 6750$ psf

$M = 1.7 \times 10^6$ psf $\Delta h_{11} = (6750/1.7 \times 10^6)20' = 0.079$ ft ✓

Layer 12 20' GMA Midpt @ 120' $I_f = .87$ $\Delta\sigma_v = 6525$ psf

$M = 1.8 \times 10^6$ psf $\Delta h_{12} = (6525/1.7 \times 10^6)20' = 0.077$ ft ✓

Layer 13 20' GMA Midpt @ 140' $I_f = 0.85$ $\Delta\sigma_v = 6375$

$M = 1.9 \times 10^6$ psf $\Delta h_{13} = (6375/1.9 \times 10^6)20' = 0.067$ ft ✓

Layer 14 20' GMA Midpt @ 160' $I_f = 0.82$ $\Delta\sigma_v = 6150$ psf

$M = 1.98 \times 10^6$ psf $\Delta h_{14} = (6150/1.98 \times 10^6$ psf$)20' = 0.062$ ft ✓

Written by: M. Gleason Date: 95/9/17 (YY/MM/DD) Reviewed by: JM Date: 95/10/5 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement
CASE 2 POINT B

Layer 15 30' GMA Midpt @ 185' I_f = .784 $\Delta\sigma_v$ = 5880 psf

$M = 2.07 \times 10^6$ psf $\Delta h_{15} = (5880/2.07\times10^6)\,30' = 0.085$ ft ✓

Layer 16 30' GMA Midpt @ 215' I_f = 0.75 $\Delta\sigma_v$ = 5625 psf

$M = 2.2 \times 10^6$ psf $\Delta h_{16} = (5625/2.2\times10^6)\,30' = 0.077$ ft ✓

CASE 2 POINT B TOTAL SETTLEMENT

LAYER	SETTLEMENT
1	.447
2	.326
3	.227
4	.196
5	.311
6	.249
7	.210
8	~~.194~~ 0.184 ✓
9	~~.067~~ 0.057 ✓
10	.087
11	.079
12	.077
13	.067
14	.062
15	.085
16	.077
TOTAL	2.74 ft ✓ ✓

CASE 2 POINT C

FOR Layers 1 & 2 use Parameters & Settlements from CASE 1 Point C

LAYER 1 Δh_T = 0.018 ft ✓
LAYER 2 Δh_T = 0.013 ft ✓

Written by: M. GLEASON Date: 95/9/17 (YY MM DD) Reviewed by: JM Date: 95/10/5 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement
CASE 2 POINT C

Layer 3 — 5' Brown Till Midpt @ 10.5' $I_f = 0.014$ $\Delta\sigma_v = 105$ psf
From Point A, CASE 2
$M = 1.07 \times 10^6$ psf $\sigma_o = 1400$ psf OCR = 1.7
$\sigma_p = 2380$

$\Delta h_{i_3} = (105/1.07 \times 10^6) \cdot 5' = 0.000$ ft ✓

$\Delta h_{p_3} = 0.015 \frac{5}{1+0.29} \log \frac{1400+105}{1400} = 0.002$ ft ✓

$\Delta h_{s_3} = 0.012$ ft ✓

Layer 3 $\Delta h_T = 0.014$ ft ✓

Layer 4 — 5' Gray Till Midpt @ 15.5' $I_f = 0.018$ $\Delta\sigma_v = 135$ psf
From Point A CASE 2
$M = 4.2 \times 10^6$ $\sigma_o = 2100$

$\Delta h_{i_4} = (135/4.2 \times 10^6)\, 5' = 0.000$ ft ✓

$\Delta h_{p_4} = 0.074 \frac{5}{1+.38} \log \frac{2100+135}{2100} = 0.007$ ft ✓

$\Delta h_{s_4} = 0.0013 \frac{5}{1+0.29} \log 1000/10 = 0.010$ ft ✓

Layer 4 $\Delta h_T = 0.017$ ft ✓

Layer 5 — 10' Gray Till Midpt @ 23' $I_f = 0.024$ $\Delta\sigma_v = 180$ psf
From Point A CASE 2
$M = 5.5 \times 10^6$ psf $\sigma_o = 3180$ psf

$\Delta h_{i_5} = (180/5.5 \times 10^6)\, 10' = 0.000$ ft ✓

$\Delta h_{p_5} = 0.074 \frac{10}{1+0.38} \log \frac{180+3180}{3180} = 0.013$ ft ✓

$\Delta h_{s_5} = 0.0015 \frac{10}{1+0.29} \log 1000/10 = 0.020$ ft ✓

Layer 5 $\Delta h_T = 0.033$ ft ✓

Written by: M. GLEASON Date: 95 / 9 / 18 (YY MM DD) Reviewed by: JM Date: 95 / 10 / 5 (YY MM DD)

Client: FERMILAB Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement
CASE 2 POINT C

Layer 6 10' Gray Till Midpt @ 33' $I_f = 0.03$ $\Delta\sigma_v = 225$ psf

$M = 6.7 \times 10^6$ psf $\sigma_o = 4640$

$\Delta h_{i_6} = (225/6.7\times10^6)10' = 0.000$ ft ✓

$\Delta h_{p_6} = 0.074 \frac{10}{1+0.38} \log \frac{225+4640}{4640} = 0.011$ ft ✓

$\Delta h_{s_6} = 0.0013 \frac{10}{1+0.29} \log 1000/10 = 0.020$ ft ✓

Layer 6 $\Delta h_T = 0.031$ ft ✓

Layer 7 10' Gray Till Midpt @ 43' $I_f = 0.04$ $\Delta\sigma_v = 300$ psf

$M = 7.4 \times 10^6$ psf $\sigma_o = 6090$ psf

$\Delta h_{i_7} = (300/7.4\times10^6)10' = 0.000$ ft ✓

$\Delta h_{p_7} = 0.074 \frac{10}{1+0.38} \log \frac{6090+300}{6090} = 0.011$ ft ✓

$\Delta h_{s_7} = 0.020$ ft ✓

Layer 7 $\Delta h_T = 0.031$ ft ✓

Layer 8 10' Gray Till Midpt @ 53' $I_f = 0.05$ $\Delta\sigma_v = 375$ $M = 7.4\times10^6$ $\sigma_o = 7540$ psf

$\Delta h_{i_8} = (375/7.4\times10^6)10' = 0.001$ ft ✓ $\Delta h_p = 0.074 \frac{10}{1.38} \log \frac{7540+375}{7540} = 0.011$ ft ✓

$\Delta h_s = 0.020$ ft ✓ $\Delta h_{T_8} = 0.032$ ft ✓

Layer 9 12' GMA Soils Midpt @ 64' $I_f = 0.06$ $\Delta\sigma_v = 450$ psf

$M = \overset{1.47}{\cancel{1.25}} \times 10^6$ psf $\Delta h_9 = (450/\overset{1.47}{\cancel{1.25}}\times10^6)12' = 0.004$ ft ✓

Layer 10 20' GMA Soils Midpt @ 80' $I_f = 0.08$ $\Delta\sigma_v = 600$ psf

$M = 1.6 \times 10^6$ psf $\Delta h_{10} = (600/1.6\times10^6)20' = 0.008$ ft ✓

Written by: M. GLEASON Date: 95/9/18 (YY/MM/DD) Reviewed by: TM Date: 95/10/5 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: 6E 3900 Task No.: 9.9

Foundation Settlement
CASE 2 POINT C

Layer 11 20' GMA soils Midpt @ 100' $I_f = 0.09$ $\Delta\sigma_v = 675$

$M = 1.7 \times 10^6$ psf $\Delta h_{11} = (675/1.7 \times 10^6)\ 20' = 0.008$ ft ✓

Layer 12 20' GMA midpt @ 120' $I_f = 0.104$ $\Delta\sigma_v = 780$ psf

$M = 1.8 \times 10^6$ psf $\Delta h_{12} = (780/1.7 \times 10^6)\ 20' = 0.009$ ft ✓

Layer 13 20' GMA Midpt @ 140' $I_f = 0.118$ $\Delta\sigma_v = 885$ psf

$M = 1.9 \times 10^6$ psf $\Delta h_{13} = (885/1.9 \times 10^6)\ 20' = 0.009$ ft ✓

Layer 14 20' GMA Midpt @ 160' $I_f = 0.124$ $\Delta\sigma_v = 930$ psf

$M = 1.98 \times 10^6$ $\Delta h_{14} = (930/1.98 \times 10^6)\ 20' = 0.009$ ft ✓

Layer 15 30' GMA Midpt @ 185' $I_f = 0.134$ $\Delta\sigma_v = 1005$ psf

$M = 2.07 \times 10^6$ $\Delta h_{15} = (1005/2.07 \times 10^6)\ 30' = 0.015$ ft ✓

Layer 16 30' GMA Midpt @ 215' $I_f = 0.142$ $\Delta\sigma_v = 1065$ psf

$M = 2.2 \times 10^6$ $\Delta h_{16} = (1065/2.2 \times 10^6)\ 30' = 0.015$ ft ✓

CASE 2 POINT C TOTAL SETTLEMENT

Layer	Settlement	Layer	Settlement
1	.018	9	.004
2	.013	10	.008
3	.014	11	.008
4	.017	12	.009
5	.033	13	.009
6	.031	14	.009
7	.031	15	.015
8	.032	16	.015
		TOTAL	0.27 ft ✓

000486

Written by: M. GLEASON Date: 95/9/21 (YY/MM/DD) Reviewed by: JM Date: 95/10/5 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement

CASE 2 POINT D

Calculated settlements for Layers 1 and 2 are equal to settlements calculated for CASE 1 Point D layer 1 and 2

$\Delta h_{T1} = 0.274$ ✓
$\Delta h_{T2} = 0.207$ ✓

Layer 3 5' Brown Till Midpt @ 10.5' $\Delta\sigma_v = 3390$ psf

From Point A $M = 1.07 \times 10^6$ $\sigma_o = 1400$ psf $\sigma_p = 1.7 \times \sigma_o = 2380$

$\Delta h_{i3} = \left(3390/1.07 \times 10^6\right) 5' = 0.0016$ ft ✓

$\Delta h_{p3} = 0.015 \frac{5}{1+.29} \log 1.7 + 0.075 \frac{5}{1+.29} \log \frac{1400+3390}{2380}$

$\Delta h_{p3} = 0.102$ ft ✓ $\Delta h_s = 0.0015 \frac{5}{1+.22} \log 1000/10 = 0.012$ ft ✓

Layer 3 $\Delta h_T = 0.130$ ft ✓

Layer 4 5' Gray Till Midpt @ 15.5' $\Delta\sigma_v = 3310$ psf

$M = 4.2 \times 10^6$ psf $\sigma_1 = 2100$

$\Delta h_{i4} = \left(3310/4.2 \times 10^6\right) 5' = 0.004$ ft

$\Delta h_{p4} = 0.074 \frac{5}{1+.38} \log \frac{3310+2100}{2100} = 0.110$ ft ✓

$\Delta h_s = 0.0013 \frac{5}{1+.29} \log 1000/10 = 0.010$ ft ✓

Layer 4 $\Delta h_T = 0.124$ ft ✓

Layer 5 10' Gray Till Midpt @ 23' $\Delta\sigma_v = 3290$ psf $\sigma_o = 3190$ psf

$M = 5.5 \times 10^6$ psf $\Delta h_{i5} = \left(3290/5.5 \times 10^6\right) 10' = 0.006$ ft ✓

$\Delta h_{p5} = 0.074 \frac{10'}{1+.38} \log \frac{3290+3190}{3190} = 0.165$ ft ✓

$\Delta h_{s5} = 0.0013 \frac{10}{1+.29} \log 1000/10 = 0.020$ ft ✓

Layer 5 $\Delta h_T = 0.191$ ft ✓

Written by: M. GLEASON Date: 95/9/21 (YY MM DD) Reviewed by: JM Date: 95/10/4 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement
CASE 2 POINT D

Layer 6 10' Gray Till Middepth @ 33' $\Delta\sigma_v = 3290$ psf $\sigma_o = 4640$ psf

$M = 6.7\times10^6$ psf $\Delta h_i = (3290/6.7\times10^6)\,10' = 0.005$ ft ✓

$\Delta h_{p6} = 0.074 \frac{10}{1+.38} \log \frac{3290+4640}{4640} = 0.125$ ft ✓

$\Delta h_s = 0.0013 \frac{10}{1+.29} \log 1000/10 = 0.020$ ft

Layer 6 $\Delta h_T = 0.150$ ft ✓

Layer 7 10' Gray Till Midpt @ 43 ft $\Delta\sigma_v = 3270$ psf $\sigma_o = 6090$ psf

$M = 7.4\times10^6$ psf $\Delta h_i = (3270/7.4\times10^6)\,10' = 0.004$ ft ✓

$\Delta h_{p7} = 0.074 \frac{10}{1+.38} \log \left(\frac{3270+6090}{6090}\right) = 0.100$ ft ✓

$\Delta h_s = 0.020$ ft ✓

Layer 7 $\Delta h_T = 0.124$ ft ✓

Layer 8 10' Gray Till Midpt @ 53 ft $\Delta\sigma_v = 3260$ psf $\sigma_o = 7540$ psf

$M = 7.4\times10^6$ psf $\Delta h_i = (3260/7.4\times10^6)\,10' = 0.004$ ft ✓

$\Delta h_{p8} = 0.074 \frac{10}{1+.38} \log \frac{3260+7540}{7540} = 0.084$ ft ✓

$\Delta h_s = 0.020$ ft ✓

Layer 8 $\Delta h_T = 0.108$ ft ✓

Layer 9 12' GMA Soils Midpt @ 64 ft $\Delta\sigma_v = 3240$ psf

$M = \overset{1.47}{\cancel{1.25}}\times10^6$ psf $\Delta h_9 = (3240/\overset{1.47}{\cancel{1.25}}\cdot10^6)\,12' = \overset{0.026}{\cancel{0.031}}$ ft ✓

Layer 10 20' GMA Soils Midpt @ 80' $\Delta\sigma_v = 3220$

$M = 1.6\times10^6$ psf $\Delta h_{10} = (3220/1.6\times10^6)\,20' = 0.040$ ft ✓

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Foundation Stability
CASE 2 POINT D

Layer 11 20' GMA Midpt @ 100' $\Delta\sigma_v = 3130$ psf $\sigma_o = 12060$ psf

$M = 1.7 \times 10^6$ psf $\Delta h_{11} = (3130/1.7 \times 10^6)20' = 0.037$ ft ✓

Layer 12 20' GMA Midpt @ 120' $\Delta\sigma_v = 3070$ psf $\sigma_o = 13515$ psf

$M = 1.7 \times 10^6$ psf $\Delta h_{12} = (3070/1.7 \times 10^6 \text{ psf})20' = 0.036$ ft ✓

Layer 13 20' GMA Midpt @ 140' $\Delta\sigma_v = 3020$ psf $\sigma_o = 14970$ psf

$M = 1.9 \times 10^6$ psf $\Delta h_{13} = (3020/1.9 \times 10^6)20' = 0.032$ ft ✓

Layer 14 20' GMA Midpt @ 160' $\Delta\sigma_v = 2960$ psf $\sigma_o = 16400$ psf

$M = 1.98 \times 10^6$ psf $\Delta h_{14} = (2960/1.98 \times 10^6)20' = 0.030$ ft ✓

Layer 15 30' GMA Midpt @ 185' $\Delta\sigma_v = 2830$ psf $\sigma_o = 18230$ psf

$M = 2.07 \times 10^6$ psf $\Delta h_{15} = (2830/2.07 \times 10^6)30' = 0.045$ ft ✓

Layer 16 30' GMA Midpt @ 215' $\Delta\sigma_v = 2740$ psf $\sigma_o = 20,400$ psf

$M = 2.2 \times 10^6$ psf $\Delta h_{16} = (2740/2.2 \times 10^6)30' = 0.037$ ft ✓

CASE 2 POINT D TOTAL SETTLEMENT

Layer	Settlement	Layer	Settlement
1	.274	10	.040
2	.207	11	.037
3	.130	12	.036
4	.124	13	.032
5	.191	14	.030
6	.150	15	.041
7	.124	16	.037
8	.108		
9	~~.031~~ .026 ✓	TOTAL	1.59 ft ✓✓

Written by: M. GLEASON Date: 95/9/18 (YY MM DD) Reviewed by: JM Date: 95/10/5 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement

Differential Settlement, Grade Change, Tensile Strain

	CASE 1	CASE 2	
POINT A	2.26 ft	~~2.84~~ 2.83 ft	
POINT B	2.19 ft	2.74 ft	
POINT C	0.17 ft	0.27 ft	→ Point Not Important for Analysis
POINT D	1.24 ft	1.59 ft	

CASE 1 POINT A - B

Differential Settlement = 0.07 ft

Length Between Point = 130 ft (APPROXIMATE)

Change in Grade = 0.05 %

Tensile Strain $\varepsilon = 8/3 (\Delta_s/L)^2 100$ ε = very small.

POINT B - D

$\Delta_s = (2.19 - 1.24)$ ft = 0.95 ft L = 180 ft (APPX)

Grade Change = $(0.95/180) \times 100 = 0.53$ %

Tensile Strain $\varepsilon = 8/3 (\Delta_s/L)^2 \times 100 = < 0.01$ %

CASE 2

POINT A - B

$\Delta_s = (\cancel{2.84}\ 2.83 - 2.74)$ ft = ~~0.10~~ 0.09 ft L = ~~180~~ 130 ft

Grade Change = ~~0.06~~ .07 % ε = very small

POINT B - D

$\Delta_s = 2.74$ ft $- 1.59$ ft = 1.15 ft L = 180 ft

Grade Change = $(1.15/180) \times 100 = 0.64$ %

Tensile Strain $\varepsilon = 8/3 (1.15/180)^2 \times 100 = 0.01$ %

Written by: M. GLEASON Date: 95/9/18 (YY MM DD) Reviewed by: TM Date: 95/10/5 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9-9

Foundation Settlement

TIME RATE OF CONSOLIDATION

Recompacted Clay $C_v = 0.055 in^2/min$

Brown Till $C_v = 0.056 in^2/min$

Gray Till $C_v = 0.035 in^2/min$

LOWEST $C_v = 0.035 in^2/min$

C_v obtained with $\sqrt{t}$ method. Log Time method provides slightly smaller numbers in general.

Assume C_v for entire layer $= 0.02 in^2/min$

CALCULATE TIME RATE OF CONSOLIDATION.

ASSUME SINGLE DRAINAGE PATH FROM LINER SYSTEM TO GMA

CASE 1 H_{dr} = 3' clay + 5' Brown Till + 15' gray till = 23 ft ✓

CASE 2 H_{dr} = 3' clay + 10' Br. Till + 45' gray till = 58 ft ✓

TIME TO 90% CONSOLIDATION $T = 0.848$

CASE 1 $t_{90} = \frac{0.848 (23ft)^2}{0.02 in^2/min} \times \frac{144 in^2}{1 ft^2} = 6.1$ yrs ✓ (Converted from minutes to years)

CASE 2 $t_{90} = \frac{0.848 (58ft)^2}{0.02 in^2/min} \times \frac{144 in^2}{ft^2} = 39$ yrs ✓

TIME TO 95% CONSOLIDATION $T = 1.163$

CASE 1 $t_{95} = \frac{1.163 (23ft)^2}{0.02 in^2/min} \times 144 = 8.4$ yrs ✓

CASE 2 $t_{95} = \frac{1.163 (58ft)^2}{0.02 in^2/min} \times \frac{144 in^2}{ft^2} = 54$ yrs ✓

2.2 Impacted Materials Settlement

COMPUTATION COVER SHEET

SUBJECT OF CALCULATION: IMPACTED MATERIALS SETTLEMENT

Computations By: (Cognizant Engineer)
Signature: Mark H. Gleason — Date: 23 Oct '95
Printed Name and Title: MARK H. GLEASON, Assistant Project Engineer

Assumptions and Procedures Checked by: (Checker)
Signature: Saad Qureshi — Date: 23 Oct. '95
Printed Name and Title: SAAD QURESHI, PROJECT ENGINEER

Computations Checked by: (Checker)
Signature: Saad Qureshi — Date: 23 Oct '95
Printed Name and Title: SAAD QURESHI, PROJECT ENGINEER

Computations Backchecked by: (Cognizant Engineer)
Signature: Mark H. Gleason — Date: 23 Oct 95
Printed Name and Title: MARK H. GLEASON, Assistant Project Engineer

Approved by: (PDP)
Signature: Mark H. Gleason — Date: 23 Oct 95
Printed Name and Title: MARK H GLEASON, Assistant Project Engineer

Approved by: (DTL and TETL)
Signature: Rudolph Bonforte — Date: 24 Oct 95
Printed Name and Title: Rudolph Bonforte, Principal

Record of Revision (Number and initial all revisions)

Rev. No.	Reason	Date	By	Checked	Approval
A	Draft submittal to FERMCO	—	—	—	—
Ø	30% SUBMITTAL	N/A	N/A	N/A	N/A
B	Preliminary Design, EPA Submitted	14 Dec 95	[illegible]	—	—

LE3900-09.8/F9530026.CD

Written by: M. GLEASON Date: 95/10/23 Reviewed by: SR Date: 95/10/23

Client: FERMCO Project: OSDF Proj./Proposal No.: GE 3900 Task No.: 9.8

IMPACTED MATERIALS SETTLEMENT

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- Summary 45

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Client: FERMCO Project: OSDF Proj./Proposal No.: GE 3900 Task No.: 9.8

RB 95 Oct 24

IMPACTED MATERIALS SETTLEMENT

EXECUTIVE SUMMARY

The settlement of the impacted materials in the On-Site Disposal Facility (OSDF) is evaluated in this calculation package. Settlement of the impacted materials is calculated for the following two cases: (i) incremental settlement during placement of successive lifts of impacted materials; (ii) final settlement of the impacted materials due to placement of the final cover system. Settlement of the impacted materials is calculated for material assumed to be placed at optimum moisture content and at a relative compaction of 90 and 85 percent of maximum dry density as determined by ASTM D698. Both immediate and time dependent settlement of the impacted materials is calculated for several locations on the OSDF. Based on the calculations, settlement of the impacted materials will be primarily immediate settlements. In addition, differential settlement of the final cover system will not induce tensile strains and grade changes will be less than 0.2 percent. Therefore, the performance of the final cover system for the calculated settlements is acceptable.

Written by: M. GLEASON Date: 95/10/23 Reviewed by: BR Date: 95/10/23

Client: FERMLO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 9.8

RB 24 Oct 95

IMPACTED MATERIALS SETTLEMENT

PURPOSE

The purpose of this document is to provide the engineering calculations for analysis of settlement of the impacted materials placed in the On-Site Disposal Facility (OSDF). Provided in the calculations is an estimate of the settlement of the OSDF materials during filling operations and after final closure.

The results of the calculations are used to assess the total settlement and final performance of the final cover system of the OSDF. The calculations are also used to estimate settlement of the placed OSDF materials so that a prediction of volume available in the OSDF may be made.

PROCEDURE

The calculation procedure for estimating settlement of the impacted materials of the OSDF is presented in this section. Calculations for settlement of the OSDF liner system due to impacted material placement is contained in the Foundation Settlement Package (Document Number F9530021). Calculations for settlement of the OSDF impacted materials are provided for conditions during waste placement and for final conditions (i.e., long-term conditions after placement of the OSDF Final Cover System).

The engineering properties of the impacted materials used in this analysis are provided in the attached Data Verification section. Based on the estimated distribution of impacted material types to be placed in the OSDF, provided in the OSDF Required Volume Calculation Package (Document Number F9530071), approximately 80 percent of the impacted materials will be on-site near-surface soils. These on-site soils are primarily cohesive soils.

The impacted materials will be placed in the OSDF in a controlled manner (as described in the Impacted Material Placement Plan). Because approximately 80 percent of the impacted materials are the on-site cohesive soils, and the materials will be placed in a manner such that homogeneity of the impacted materials is maximized, the engineering properties of these soils will govern settlement.

The settlement of the OSDF impacted materials will be governed by the immediate compression and consolidation settlement of the impacted materials. The settlement of the OSDF impacted materials is calculated using well known geotechnical engineering equations for consolidation settlement.

Written by: M. GLEASON Date: 95/10/23 Reviewed by: SB Date: 95/10/23

Client: FERMCO Project: OSDF Proj./Proposal No.: GE 3900 Task No.: 9.8

RB 24 Oct 95

IMPACTED MATERIALS SETTLEMENT

PROCEDURE (continued)

EQUATIONS:

Total Settlement $S_t = S_i + S_p + S_s$

where S_i = immediate compression settlement
S_p = primary consolidation settlement (time and surcharge dependent)
S_s = secondary compression settlement (time dependent)

Immediate Compression and Consolidation Settlement, S_i and S_p (Δh_i and Δh_p for each layer)

$$\Delta h_p = C_r \frac{H_o}{1+e_o} \log \frac{\bar{\sigma}_p}{\bar{\sigma}_{vo}} + C_c \frac{H_o}{1+e_o} \log \frac{\sigma_{vo}+\Delta\sigma_v}{\bar{\sigma}_p}$$

where C_c = Coefficient of Compression (remolded)
C_r = Coefficient of Recompression (remolded)
e_o = initial layer void ratio
$\bar{\sigma}_{vo}$ = initial effective vertical stress
$\Delta\bar{\sigma}_v$ = additional effective vertical stress
$\bar{\sigma}_p$ = past maximum pressure due to compaction
H_o = initial layer thickness

- This equation is used for both immediate compression and for consolidation of the impacted materials. As placed, the impacted materials will not be saturated. For each layer considered, the void ratio and saturation at placement is calculated. The impacted materials are assumed to undergo immediate settlement until saturation. Once the materials have settled such that saturation is achieved, further settlement is governed by time-dependent consolidation processes. This settlement process is graphically depicted in Figure 1.

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Client: FERMLO Project: OSDF Proj./Proposal No.: GE 3900 Task No.: 9.8

RB 24 Oct 95

IMPACTED MATERIALS SETTLEMENT

PROCEDURE (continued)

Secondary Compression Settlement, S_s

- Consider Secondary Settlement for long-term conditions only. Secondary settlement is not relevant for conditions during OSDF impacted materials filling operations.

$$S_s = C_\alpha \frac{H_o}{1+e_p} \log \left[\frac{t_2}{t_1} \right]$$

where
- C_α = secondary compression index
- H_o = initial layer thickness
- P_p = void ratio at end of primary (start of secondary compression time)
- t_1 = the time from initial loading to the end of primary consolidation; assume t_1 = 1 year
- t_2 = a future time of interest for the OSDF; assume t_2 = 1,000 years (target design life)

Assumptions for Analysis

The following assumptions are made regarding OSDF cell geometry and impacted material placement:

- one cell is filled during a single construction season;
- the average construction season is 6 months;
- a 10-ft (3-m) thick impacted material layer is placed, on average, once every month;
- the cell is closed (final cover is placed) at the end of each season so that additional material is not added at the beginning of the following season;
- immediate settlement under each load increment occurs prior to placement of the next load increment;

IMPACTED MATERIALS SETTLEMENT

PROCEDURE (continued)

- the calculations are performed for one cell of the OSDF at the locations of change in grade on the final cover system as shown on Figure 2 in the Data Verification Section;
- the calculations are performed for an impacted material thickness ranging from 56-ft (17-m) thick to 45-ft (14-m) thick, and a final cover thickness (including compacted clay and contouring layer) of 9 ft (2.7 m);
- an average layer thickness of 10 ft (3 m) is assumed; and
- material compaction and engineering properties are described in the Data Verification Section.

Local Settlement and Local Deformation

Because the OSDF impacted materials will be placed following strict compaction criteria and under well-controlled conditions, with multiple passes of one or more heavy compactors, the in-place material should consist of a relatively dense, uniform mass. The OSDF impacted materials will be approximately 80 percent soils. Therefore, the potential for local deformations to occur from material heterogeneity, ravelling, chemical changes, or biodegradation are minimal.

Based on the discussion presented above, the OSDF impacted materials are expected to settle and deform as a uniform mass. Deformations due to local settlement and local waste heterogeneity are not expected.

Long-Term Settlement

Once settlements are calculated for the points indicated on Figure 2, an analysis of the final cover system integrity is made. Considered in the analysis is the differential settlement, grade change, and tensile strain in the final cover system.

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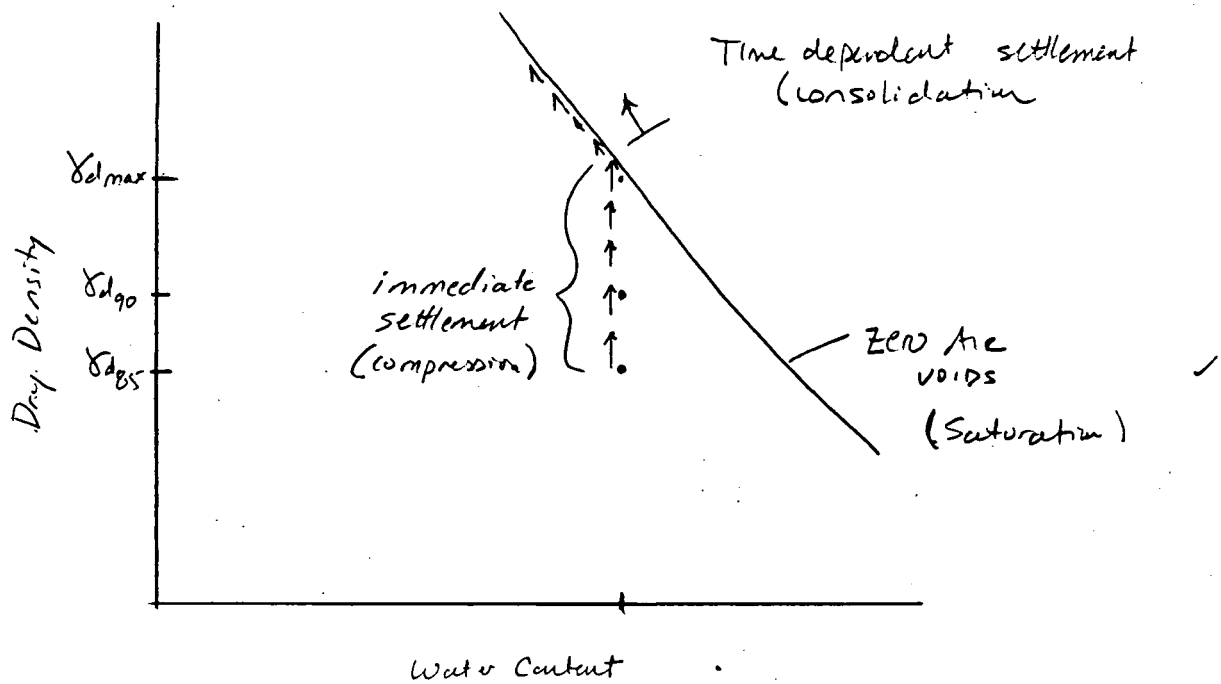
Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.8

Impacted Materials Settlement . PROCEDURES RB 24 Oct 95

FIGURE 1



Materials will undergo immediate settlement from initial state until the sample reaches the critical void ratio. (compression settlement)

The critical void ratio is defined as that void ratio (at a certain water content) at which the material is saturated.

Upon reaching the critical void ratio, further settlement will be consolidation settlement governed by the rate of expulsion of water.

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Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.8

RB 24 Oct 95

IMPACTED MATERIALS SETTLEMENT - DATA VERIFICATION

Purpose: The purpose of this section is to provide data and assumptions required to perform the impacted materials settlement calculations. The data is collected based on analysis in other calculation packages and on information in the literature as noted.

Assumptions:

The following assumptions are made regarding the material to be placed in the OSDF.

- The impacted material will be approximately 80 percent soils. Therefore, settlement parameters will be governed by the engineering properties of these soils. The remaining materials will be solid waste, demolition debris, sludge, and fly ash.
- The impacted material will be placed at its optimum moisture content as defined by ASTM D698 (Standard Proctor Compaction Test).
- The impacted material will be placed at between 85 percent and 90 percent of the Standard Proctor Maximum Dry Density. Calculations are performed for Relative Density of 85 and 90 percent.
- Settlement of the impacted materials will be immediate until the saturated void ratio is achieved. Upon reaching saturation, the settlements are governed by the consolidation rate of the materials.
- Settlements will be calculated for 10 ft lifts.
- The geometry used for the analysis is shown on the attached Figure .
- A cell will be filled in one construction season and the final cover system will be placed immediately upon filling a cell.
- Final cover system is approximately 9 ft thick, with an average unit weight of 125 pcf. ($\Delta\sigma$ = 1125 psf)

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Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.8

Impacted Materials Settlement - Data Verification RB 24 Oct 95

MATERIAL PROPERTIES:

- The following relationship for the impacted materials (soils) is obtained from PARSONS Sept 1995, PARSONS Feasibility Study (draft) for Operable Unit 5, and is summarized in OSDF Required Volume Calculation Package (Document # F9530071)

SEE ATTACHED FIGURE 3

Depth Interval (ft)	γ_d max (pcf)	% of Total	Weighted Average
0 to 0.5	109	17	18.5
0.5 to 1.5	109.5	17	18.6
1.5 to 2.5	110.3	7	7.7
2.5 to 5.5	112.8	18	20.3
5.5 to 10.5	118.0	21	24.8
10.5 to 15.5	123.5	14	17.3
15.5 to 20.5	125 +/-	6	7.5
			114.7 pcf

FOR ANALYSIS ASSUME $\gamma_{d\,max}$ = 115 pcf

- The following average values are obtained from:
  - SOURCE PARSONS, "Geotechnical Investigation Report, On-Site Disposal Facility, Operable Unit 2", 90 Percent, Revision A, Fernald Environmental Management Project, Fernald, Ohio September, 1995.
    - Optimum Moisture Content (ASTM D698) W_c = 18% (TABLE 6-7)
    - Compression Index C_c = 0.2 (Table 6-8 - Remolded Soils)
    - Recompression Index C_r = 0.035 Table 6-8 - Remolded Soils)
    - Coefficient of consolidation C_v = 0.05 in²/min - average values for loading at 4000 - 6000 psf (Table 6-8),
    - Coefficient of Secondary Compression C_α = 0.0015 (same value assumed in Foundation Settlement calculation Package - Document # F9530021)
    - Specific Gravity G_s = 2.75 (Table 6-2)

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Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.B

Impacted Materials Settlement - Data Verification RB 24 Oct 95

- Assumed Property Values
  - Due to compaction during placement the materials are assumed to exist under an increased state of vertical stress. The following values of existing pre-consolidation stress are assumed:

    For 85% Relative Compaction, assume σ_{past} = 950 psf
    For 90% Relative compaction, assume σ_{past} = 1000 psf

CALCULATE INITIAL VALUES

- At Maximum Compaction

G_s = Specific Gravity, $\gamma_{d_{max}}$ = dry unit weight (max), W_c = Moisture Content, W_w = weight of Moisture, W_s = Weight of Solids, V_s = Volume of Solids, V_w = Volume of Moisture, e = Void Ratio

$\gamma_{d_{max}}$ = 115 pcf W_c = 18% G_s = 2.75

For 1 ft³ volume: $W_s = \gamma_d V_T = 115\text{ pcf} \times 1\text{ ft}^3 = 115\text{ lb}$

$$W_w = W_c W_s = (0.18)(115\text{ lb}) = 20.7\text{ lb}$$

$$V_s = \frac{W_s}{G\gamma_w} = \frac{115\text{ lb}}{2.75(62.4)} = 0.67\text{ ft}^3 \qquad V_v = 0.33\text{ ft}^3$$

$$V_w = \frac{W_w}{\gamma_w} = \frac{20.7}{62.4} = 0.33\text{ ft}^3 \qquad V_w/V_v = 1 \text{ - Saturated Material}$$

$$e = V_v/V_s = 0.33/0.67 = 0.49$$ ← At e = 0.49 sample is saturated, consolidation starts, immediate compression stops.

- At 90% of Maximum Compaction

$$\gamma_{d_{90}} = \gamma_{d_{max}} \times 0.9 = 115\text{ pcf}(0.9) = 103.5\text{ pcf}$$

W_c = constant = 18% G_s = 2.75

For 1 cubic foot volume $W_s = \gamma_d V_T = 103.5\text{ lb}$

$$W_w = 103.5(0.18) = 18.6\text{ lb} \qquad V_w = \frac{18.6}{62.4} = 0.30$$

$$V_s = \frac{W_s}{G\gamma_w} = \frac{103.5}{2.75(62.4)} = 0.60$$

Written by: M. GLEASON Date: 95/10/22 (YY MM DD) Reviewed by: SR Date: 95/10/23 (YY MM DD)

Client: FERMIO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.8

Impacted Materials Settlement - Data Verification RB 24 Oct 95

Initial Values cont.

Voids = $1 - V_s = 0.4$ Saturation = $V_w/V_v = 0.3/0.4 = 75\%$

$e = V_v/V_s = 0.4/0.6 = 0.66$ $V_{gas} = 0.1$ ft or 10%

For soil compacted at 90% of γ_{dmax} at Optimum Moisture content, immediate settlement will occur until 10% volume change (until gas is gone) and $e = 0.49$.

For 85% of Maximum Compaction

$\gamma_{d85} = \gamma_{dmax} \times .85 = 115$ pcf $(.85) = 97.8$ pcf

Water content = 18% $G_s = 2.75$

For 1 ft³ volume $W_s = 97.8$ lb $W_w = 97.8(.18) = 17.6$ lb

$V_s = \frac{W_s}{G_s \gamma_w} = \frac{97.8}{2.75(62.4)} = 0.57$ ft³ $V_v = 1 - V_s = 0.43$ ft³

$V_w = \frac{W_w}{\gamma_w} = 0.28$ ft³ $V_{AIR} = 0.15$ ft³

Saturation = $V_w/V_v = 65\%$ $e = V_v/V_s = 0.75$

$e = 0.75$ corresponds to values presented in Parsons, Sept 95 table 6-8 for 85% compaction of remolded samples.

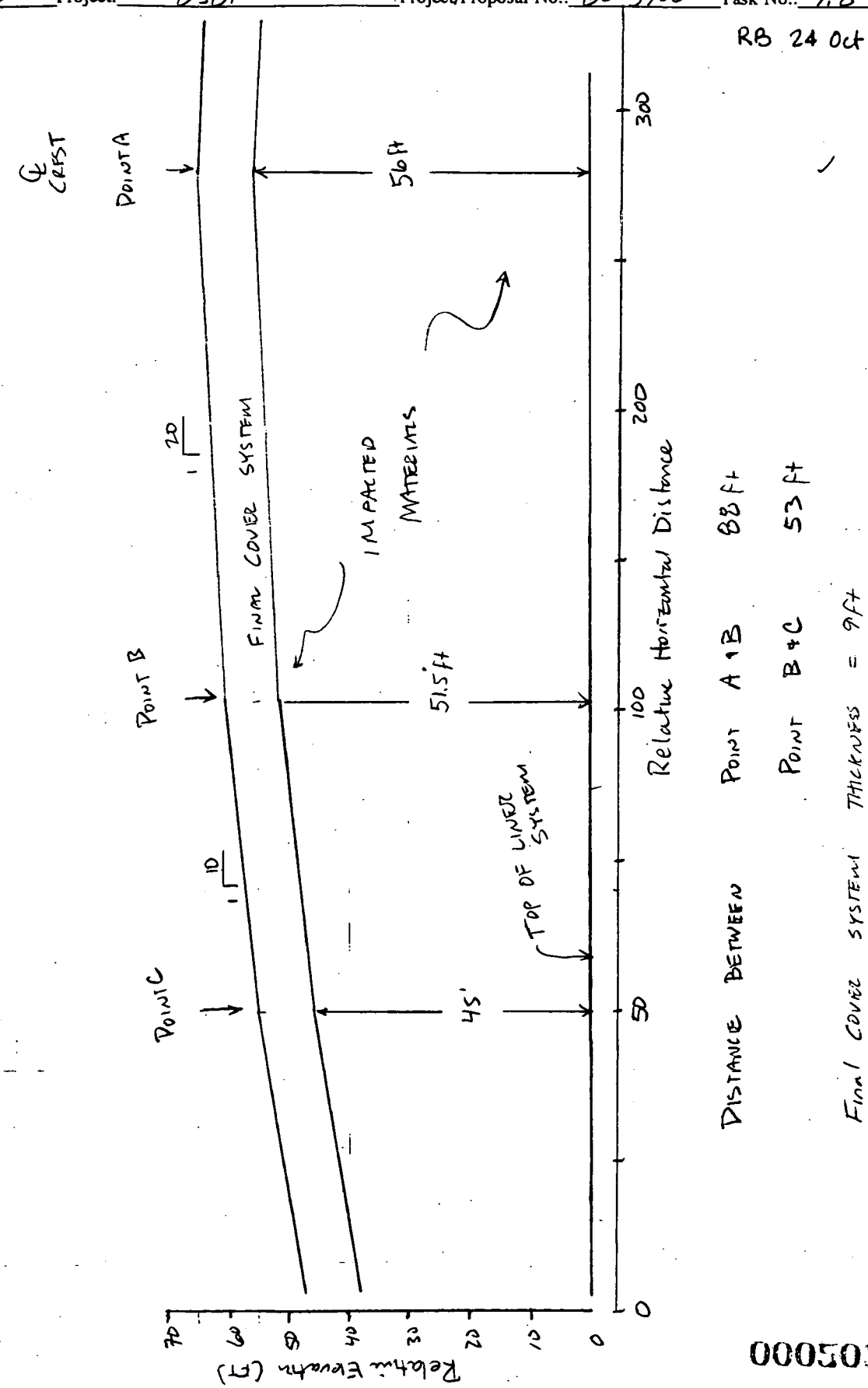
For soil compacted at 85% of γ_{dmax} at Optimum Moisture Content, immediate settlement will occur until 15% volume change (15% of initial volume is air) and $e = 0.49$.

Written by: M. GLEASON Date: 95/10/22 (YY MM DD) Reviewed by: SQ Date: 95/10/23 (YY MM DD)

Client: FERMILAB Project: OSDF Project/Proposal No.: 6E 3900 Task No.: 9.8

RB 24 Oct 95

FIGURE 2
EAST - WEST SECTION OF OSDF
FROM ℄ OF CREST



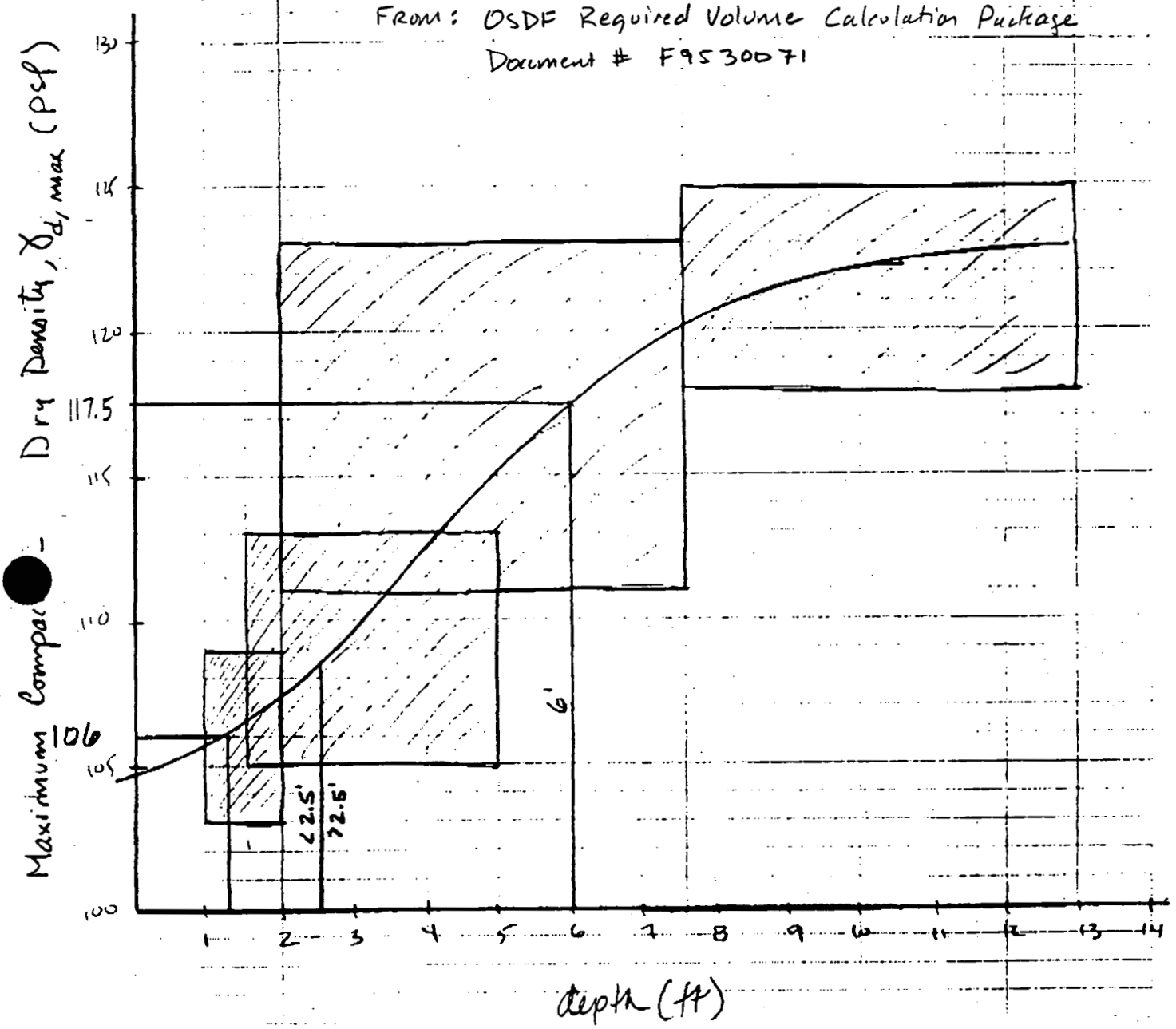
Written by: VANDERLINDE Date: 95/10/7 (YY MM DD) Reviewed by: [illegible] Date: 95/10/7 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: B-12

RB 24 Oct 95 13/46

FIGURE 3

FROM: OSDF Required Volume Calculation Package
Document # F9530071



Ref.: Geotechnical Investigation Report, OSDF, Sept 1995, pg 4-13 to 4-16 and Appendix I

~~FIGURE 2~~ MHB

Written by: M. GLEASON Date: 95/10/22 (YY MM DD) Reviewed by: SR Date: 95/10/23 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: 6E 3900 Task No.: 9.8

IMPACTED MATERIALS SETTLEMENT

SETTLEMENT CALCULATION.

MATERIAL PLACED AT 90% RELATIVE COMPACTION

POINT A - CREST

IMPACTED MATERIAL THICKNESS = 56 ft $\gamma_T = 103.5(1.18) = 122$ pcf

Calculate settlement, new e of layer 1 after each successive layer is placed

- Layer 1 Placed - 10 ft - No settlements
- Layer 2 Placed 10 ft thick $\Delta\sigma_v = 10(122\text{ pcf}) = 1220$ psf

σ_o @ 5 ft = 122(5) = 610 psf $\sigma_p = 1000$ psf

$C_c = 0.2$ $C_r = 0.035$ $e_o = 0.66$ (See Data Verification)

$$\Delta h = C_r \frac{H_o}{1+e_o} \log \frac{\sigma_p}{\sigma_o} + C_c \frac{H_o}{1+e_o} \log \frac{\Delta\sigma_v + \sigma_o}{\sigma_p}$$

$$\Delta h_{1_2} = 0.035 \frac{10}{1+0.66} \log \frac{1000}{610} + 0.2 \frac{10}{1.66} \log \frac{1220+610}{1000}$$

$\Delta h_{1_2} = 0.36$ ft → 3.6% settlement of lift 1

New e for Layer 1

3.6% volume change < 10% so settlement is immediate and change in volume is loss/compression of air.

New Volumes $V_{w_{1_2}} = V_{w_o} \times 1.036 = 0.3 \times 1.036 = 0.31$

* V_{wo} & V_{so} from data verification section

$V_{s_{1_2}} = V_{s_o} \times 1.036 = 0.6 \times 1.036 = 0.625$

$V_{v_{1_2}} = 1 - 0.625 = 0.375$

$e_{1_2} = 0.375/0.625 = 0.6$ $S_{1_2} = 0.31/0.375 = 83\%$

Written by: M. GLEASON Date: 95/10/22 (YY MM DD) Reviewed by: SR Date: 95/10/23 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.8

IMPACTED MATERIALS SETTLEMENT - CALCULATIONS

POINT A - 90% RC..

- Layer 3 Placed 10 ft thick $\Delta\sigma_v = 1220$ psf
  - Immediate settlement of Layer 2 = 0.36 ft (same conditions for placement of Layer 2 on layer 1) ✓
  - Settlement of Layer 1
    - Because settlement of Layer 1 after placement of Layer 2 is immediate, the total (new) thickness of Layer 1 remains at 10 ft. Actual placement for Layer 2 then is 10 ft + settlement of Layer 1 (0.36 ft) = 10.36 ft.
      → Impacted material thickness at time of Layer 3 placement is 20 ft.

$$\sigma_{o_{1_3}} = 122\text{ pcf}\,(15\text{ ft}) = 1830\text{ psf}$$ → VIRGIN COMPRESSION

$$\Delta h_{1_3} = C_c \frac{H_o}{1+e_o} \log \frac{\sigma_o' + \Delta\sigma_v'}{\sigma_o'}$$

$$= 0.2 \frac{10}{1+0.6} \log \frac{1830+1220}{1830} = 0.28\text{ ft}$$ ✓

New e for Layer 1

Additional 2.8% volume change for 10 ft Layer compression is still immediate.

New Volumes $V_{w_{1_3}} = V_{w_{1_2}} \times 1.028 = 0.31 \times 1.028 = 0.32$

$V_{s_{1_3}} = V_{s_{1_2}} \times 1.028 = 0.625 \times 1.028 = 0.64$

$V_{v_{1_3}} = 0.36$

$e_{1_3} = 0.36/0.64 = 0.56 > 0.49$ ✓

$S_{1_3} = 0.32/0.36 = 89\%$

Written by: M. GLEASON Date: 95/10/22 (YY MM DD) Reviewed by: SQ Date: 95/10/23 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.8

IMPACTED MATERIALS SETTLEMENT - CALCULATIONS

POINT A - 90% RC

- Layer 4 Placed - 10 ft thick layer. $\Delta\sigma_v = 1220$ psf
  - Immediate Settlement of Layer 3 = 0.36 ft
    (Same as Layer 1 after Layer 2 & Layer 2 after Layer 3) ✓
  - Immediate Settlement of Layer 2 = 0.28 ft
    (Same as Layer 1 after placement of Layer 3) ✓
  - Settlement of Layer 1

$$\sigma_o = 122 \text{ pcf } (25 \text{ ft}) = 3050 \text{ psf}$$

$$\Delta h_{1_4} = 0.2 \frac{10 \text{ ft}}{1 + 0.56} \log \frac{3050 + 1220}{3050}$$

$$\Delta h_{1_4} = 0.19 \text{ ft}$$ ✓

New e for Layer 1

Additional 1.9% volume change for 10 ft Layer

New Volumes

$$V_{W1_4} = V_{W1_3} \times 1.019 = 0.32 \times 1.019 = 0.326$$

$$V_{S1_4} = V_{S1_3} \times 1.019 = 0.64 \times 1.019 = 0.652$$

$$V_{V1_4} = 0.348$$

$$e_{1_4} = 0.348/0.652 = 0.53$$ - COMPRESSION IS STILL IMMEDIATE.

$$S = 0.326/0.348 = 94\%$$ ✓

Written by: M. GLEASON Date: 95/10/22 Reviewed by: SD Date: 95/10/23

Client: FERMILO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.8

IMPACTED MATERIALS SETTLEMENT - CALCULATIONS

POINT A · 90% RC

· LAYER 5 Placed 10 ft Layer $\Delta\sigma_v$ = 1220 psf

- Immediate Settlement of Layer 4 = 0.36 ft (layer 1 after layer 2)
- Immediate Settlement of Layer 3 = 0.28 ft (layer 1 after layer 3)
- Immediate Settlement of Layer 2 = 0.19 ft (layer 1 after layer 4)
- Settlement of Layer 1

$$\sigma_o = 35\text{ft}(122\text{ pcf}) = 4270\text{psf}$$

$$\Delta h_{15} = 0.2 \frac{10}{1+0.53} \log \frac{4270+1220}{4270}$$

$$\Delta h_{15} = 0.14\text{ ft}$$ ✓

Additional 1.4% Settlement

New Volume

$$V_{W_{15}} = V_{W_{14}} \times 1.014 = 0.326 \times 1.014 = 0.33$$

$$V_{S_{15}} = V_{S_{14}} \times 1.014 = 0.652 \times 1.014 = 0.66$$

$$V_{V_{15}} = 0.34$$ ✓

$$e_{15} = 0.34/0.66 = 0.515$$ → Compression from Layer 5 is Immediate.

$$S = 0.33/0.34 = 97\%$$ ✓

Written by: M. Gleason Date: 95/10/22 Reviewed by: SR Date: 95/10/23

Client: Fernco Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.8

Impacted Materials Settlement – Calcs.

Point A 90% Rc

- Layer 6 placed. 6 ft @ 122pcf = 732 psf = $\Delta\sigma_v$

Settlement of Layer 1 σ_o = 122pcf × 45 ft = 5490 psf

$$\Delta h_{1_6} = 0.2 \frac{10}{1+0.515} \log \frac{5490+732}{5490}$$

Δh_{1_6} = 0.07 ft 0.7 % Additional Settlement ✓

New Volumes $V_{w_{1_6}} = V_{w_{1_5}} \times 1.007 = 0.33 \times 1.007 = 0.332$

$V_{s_{1_6}} = V_{s_{1_5}} \times 1.007 = 0.66 \times 1.007 = 0.665$

$V_{v_{1_6}} = 0.335$ ✓

$e_{1_6} = 0.335/0.665 = 0.50$ Compression from Layer 6 is Immediate.

$S_{1_6} = .332/.335 = 99\%$ Assume Additional Settlement is Consolidation (time dependent)

Settlement of Layer 2

σ_o = 35 ft × 122 pcf = 4270 $e_{2_5} = e_{1_4} = 0.53$

$$\Delta h_{2_6} = 0.2 \frac{10}{1.53} \log \frac{4270+732}{4270} = 0.09 \text{ ft}$$ ✓

New Volumes $V_{w_{2_5}} = V_{w_{1_4}} = 0.326$ $V_{s_{2_5}} = V_{s_{1_4}} = 0.652$

$V_{w_{2_6}} = V_{w_{2_5}} \times 1.009 = 0.335$ $V_{s_{2_6}} = V_{s_{2_5}} \times 1.009 = 0.659$

$V_{v_{2_6}} = 0.341$

$e_{2_6} = .341/.659 = 0.517$ $S = 0.335/.341 = 98\%$ ✓

Written by: M. Gleason Date: 95/10/22 Reviewed by: SQ Date: 95/10/23

Client: Fermco Project: OSDF Project/Proposal No.: 6E 3900 Task No.: 9.8

Impacted Materials Settlement - Calcs

Point A - 90%

· Layer 6 cont. $\Delta\sigma_v = 732$ psf

· Settlement at Layer 3

$\sigma_0 = 25' \times 122$ pcf $= 3050$ psf $\quad e_{3_5} = e_{1_3} = 0.56$

$$\Delta h_{3_6} = 0.2 \frac{10}{1+0.56} \log \frac{3050+732}{3050} = 0.12 \text{ ft} \quad 1.2\% \text{ Settlement}$$

New Volumes $V_{W_{3_5}} = V_{W_{1_3}} = 0.32 \quad V_{S_{3_5}} = V_{S_{1_3}} = 0.64$

$V_{W_{3_6}} = 0.32 \times 1.012 = 0.324$

$V_{S_{3_6}} = 0.64 \times 1.012 = 0.648 \quad V_{V_{3_6}} = 0.352$

$e_{3_6} = .352/.648 = 0.54$

$S_{3_6} = .324/.352 = 92\%$

> Immediate Settlements

Settlement at Layer 4

$\sigma_0 = 15\text{ft} \times 122\text{pcf} = 1830$ psf $\quad e_{4_5} = e_{1_2} = 0.6$

$$\Delta h_{4_6} = 0.2 \frac{10}{1+0.6} \log \frac{1830+732}{1830} = 0.18\text{ft} \quad 1.8\% \text{ settlement}$$

New Volumes $V_{W_{4_6}} = V_{W_{1_2}} = 0.31 \quad V_{S_{4_6}} = V_{S_{1_2}} = 0.625$

$V_{W_{4_6}} = 0.31 \times 1.018 = 0.316$

$V_{S_{4_6}} = 0.625 \times 1.018 = 0.636 \quad V_{V_{4_6}} = 0.364$

$e_{4_6} = .364/.636 = 0.572$

$S_{4_6} = .316/.364 = 87\%$

Written by: M. Gleason Date: 95/10/22 (YY MM DD) Reviewed by: SQ Date: 95/10/23 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.8

Impacted Material Settlement - Calcs

Point A - 90%

Layer 6 cont. $\Delta\sigma_v = 732$

· Settlement of Layer 5 $e_{5_6} = e_1 = 0.66$ $\sigma_0 = 5 \times 122 = 610$ psf

$$\Delta h_{5_6} = 0.035 \frac{10}{1.66} \log \frac{1000}{610} + 0.2 \frac{10}{1.66} \log \frac{610+732}{1000}$$

$\Delta h_{5_6} = 0.2$ ft 2 % settlement of Layer ✓

New Volumes $V_{w_{5_6}} = V_{w_1} = 0.3$ $V_{s_{5_6}} = V_{s_1} = 0.6$

$V_{w_{5_6}} = 0.3 \times 1.02 = 0.306$

$V_{s_{5_6}} = 0.6 \times 1.02 = 0.612$ $V_{v_{5_6}} = .388$

$e_{5_6} = .388/0.612 = 0.634$

PLACEMENT OF FINAL COVER (Layer 7)

9 ft thick @ 125 pcf $\Delta\sigma_v = 1125$ psf

Layer 1

$\sigma_0 = 51$ ft $\times$ 122 pcf $= 6222$ psf $e_{1_6} = 0.5$

$$\Delta h_{1_7} = 0.2 \frac{10}{1.5} \log \frac{1125+6222}{6222} = 0.1 \text{ ft}$$ ✓ - Time Dependent

Layer 2

$\sigma_0 = 41$ ft $\times$ 122 pcf $= 5002$ $e_{2_6} = 0.517$

$$\Delta h_{2_7} = 0.2 \frac{10}{1.517} \log \frac{5002+1125}{5002} = 0.12 \text{ ft}$$ Time Dependent

Written by: M. Gleason Date: 95/10/22 (YY/MM/DD) Reviewed by: SQ Date: 95/10/23 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.8

Impacted Material Settlement - Calcs

Point A - 90% RC. Final Cover $\Delta\sigma_v = 1125$ psf

Layer 3

$\sigma_o = 31\text{ft} \times 122 = 3782$ $e_{3_6} = 0.54$

$\Delta h_{3_7} = 0.2 \frac{10}{1.54} \log \frac{3782+1125}{3782} = 0.15\text{ ft}$ immediate

Layer 4

$\sigma_o = 21\text{ft} \times 122 = 2562\text{ psf}$ $e_{4_6} = 0.572$

$\Delta h_{4_7} = 0.2 \frac{10}{1.572} \log \frac{2562+1125}{2562} = 0.20\text{ ft}$ immediate

Layer 5

$\sigma_o = 11' \times 122\text{pcf} = 1342\text{ psf}$ $e_{5_6} = 0.634$

$\Delta h_{5_7} = 0.2 \frac{10}{1.634} \log \frac{1125+1342}{1342} = 0.32\text{ ft}$ immediate

Layer 6

$\sigma_o = 3 \times 122\text{pcf} = 366\text{ psf}$ $e_6 = e_1 = 0.66$

$\Delta h_{6_7} = 0.035 \frac{10}{1+.66} \log \frac{1000}{366} + 0.2 \frac{10}{1.66} \log \frac{1125+366}{1000}$

$\Delta h_{6_7} = 0.30\text{ ft}$

TOTAL SECONDARY SETTLEMENT

$\Delta h_s = C_{\alpha\epsilon} \frac{H_o}{1+e_p} \log t_1/t_2$

Assume $t_1 = 1\text{ yr}$
$t_2 = 1000\text{ yr}$
$H_o = 56\text{ ft}$
$e_p = 0.5$ avg.
$C_{\alpha\epsilon} = 0.0015$

$\Delta h_s = 0.0015 \frac{56}{1+.5} \log 1000$

$\Delta h_s = 0.17\text{ ft}$

IMPACTED MATERIAL SETTLEMENTS

POINT A - 90% Relative Compaction Summary

	Layer Placed	CALCULATED SETTLEMENTS (FT)						
		Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	TOTAL
10ft	Layer 1	–	–	–	–	–	–	–
10ft	Layer 2	0.36	–	–	–	–	–	0.36
10ft	Layer 3	0.28	0.36	–	–	–	–	0.64
10ft	Layer 4	0.19	0.28	0.36	–	–	–	0.83
10ft	Layer 5	0.14	0.19	0.28	0.36	–	–	0.97
6ft	Layer 6	0.07	0.09	0.12	0.18	0.2	–	0.66
	TOTAL	1.04	0.92	0.76	0.54	0.2	–	3.46

Immediate Settlement During Placement of Impacted Materials = 3.46 ft

9 ft	FINAL COVER	*0.10	*0.12	0.15	0.20	0.32	0.30	1.19 ft
						Secondary Settlement		0.17 ft
						TOTAL		1.36 ft

* Time Dependent

Total Post Closure Settlement = 1.36 ft
Immediate Post Closure Settlement = 1.19 - 0.22 = 0.97 ft

Written by: M. GLEASON Date: 95/10/22 (YY MM DD) Reviewed by: SQ Date: 95/10/23 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: 6E 3900 Task No.: 9.8

IMPACTED MATERIALS Settlement Calcs

90% Relative Compaction

Point B - Total Material Thickness = 51.5 ft

- Layer 1 Placed - (10')
- Layer 2 Placed (10') Layer 1 settles as in Point A $\Delta h_{12} = 0.36$ ft
- Layer 3 Placed
  - Layer 1 as in Point A $\Delta h_{13} = 0.28$ ft ✓
  - Layer 2 as in Point A $\Delta h_{23} = 0.36$ ft ✓
- Layer 4 Placed
  - Layer 1 as in Point A $\Delta h_{14} = 0.19$ ft ✓
  - Layer 2 as in Point A $\Delta h_{24} = 0.28$ ft ✓
  - Layer 3 as in Point A $\Delta h_{34} = 0.36$ ft ✓
- Layer 5 Placed

Assume $H = 11.5$ ft $\Delta\sigma_v = 11.5 \times 122 = 1403$ psf

- Layer 1

$\sigma_o = 35' \times 122$ pcf $= 4270$ psf $e_{14} = 0.53$ (From Pt A)

$$\Delta h_{15} = 0.2 \frac{10}{1.53} \log \frac{1403 + 4270}{4270} = 0.16 \text{ ft}$$ ✓ 1.6% Settlement

Volumes $V_{W_{14}} = 0.326$ (Pt A) $V_{S_{14}} = 0.652$ (Pt A)

$V_{W_{15}} = .326 \times 1.016 = 0.331$ $V_{S_{15}} = .652 \times 1.016 = 0.662$

$V_{V_{15}} = 0.338$

$e_{15} = .338/.662 = 0.51$ - Immediate Settlements. ✓

For the remaining analyses, saturation is not calculated. The soils are considered unsaturated until the void ratio e equals the critical void ratio.

Written by: M. GLEASON Date: 95/10/22 (YY MM DD) Reviewed by: SR Date: 95/10/23 (YY MM DD)

Client: FERMCO Project: DSDF Project/Proposal No.: GE 3900 Task No.: 9.8

Impacted Materials Settlement - Calcs

Point B - 90% R.C.

- Placement of Layer 5 $\Delta\sigma_v = 1403$ - Layer 5 placed.
  - Layer 2

$\sigma_0 = 25' \times 122 pcf = 3050 psf$ $e_{2_4} = e_{1_3} = 0.56$

$\Delta h_{2_5} = 0.2 \frac{10}{1+.56} \log \frac{3050+1403}{3050} = 0.21 ft$ 2.1% Settlement

$V_{W_{2_4}} = V_{W_{1_3}} = 0.32$ $V_{S_{2_4}} = V_{S_{1_3}} = 0.64$ (From Point A)

$V_{W_{2_5}} = 0.32 \times 1.021 = .327$

$V_{S_{2_5}} = .64 \times 1.021 = .653$ $V_{V_{2_5}} = .347$

$e_{2_5} = .347/.653 = .53$

- Layer 3

$\sigma_0 = 15' \times 122 pcf = 1830 psf$ $e_{3_4} = e_{1_2} = 0.6$

$\Delta h_{3_5} = 0.2 \frac{10}{1.6} \log \frac{1830+1403}{1830} = 0.31 ft$ 3.1% Settlement

$V_{W_{3_4}} = V_{W_{1_2}} = .31$ $V_{S_{3_4}} = V_{S_{1_2}} = .625$ (From Point A)

$V_{W_{3_5}} = .31 \times 1.031 = 0.320$ $V_{S_{3_5}} = 0.625 \times 1.031 = 0.644$ $V_{V_{3_5}} = .356$

$e_{3_5} = .356/.644 = 0.55$

- Layer 4 $\sigma_0 = 5' \times 122 pcf = 610 psf$ $e_4 = e_1 = 0.66$

$\Delta h_{4_5} = 0.035 \frac{10}{1+.66} \log \frac{1000}{610} + 0.2 \frac{10}{1.66} \log \frac{610+1403}{1000}$

$\Delta h_{4_5} = 0.41$ - 4.1% Settlement

$V_{W_4} = V_{0_1} = 0.3$ $V_{S_4} = V_{S_1} = 0.6$ (From Point A)

$V_{W_{45}} = 0.3(1.041) = 0.312$ $V_{S_{45}} = 0.625$ $V_{V_{45}} = 0.375$

$e_{4_5} = .375/.625 = 0.60$

Written by: M. GLEASON Date: 95/10/22 (YY/MM/DD) Reviewed by: SQ Date: 95/10/23 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: 6E 3900 Task No.: 9.8

Impacted Materials Settlement

Point B - 90% Relative Compaction

- Placement of Final Cover (→ Layer 6) $\Delta\sigma_v = 9ft \times 125pcf = 1125 psf$

- Layer 1 $\sigma_o = 46.5ft \times 122pcf = 5673 psf$ $e_{1_5} = 0.51$

$$\Delta h_{1_6} = 0.2 \frac{10}{1+.51} \log \frac{5673+1125}{5673}$$

$$\Delta h_{1_6} = 0.1 ft$$

- Layer 2 $\sigma_o = 36.5ft \times 122pcf = 4453 psf$ $e_{2_5} = 0.53$

$$\Delta h_{2_6} = 0.2 \frac{10}{1.53} \log \frac{4453+1125}{4453}$$

$$\Delta h_{2_6} = 0.13 ft$$

- Layer 3 $\sigma_o = 26.5ft \times 122pcf = 3233psf$ $e_{3_5} = 0.55$

$$\Delta h_{3_6} = .2 \frac{10}{1.55} \log \frac{3233+1125}{3233}$$

$$\Delta h_{3_6} = 0.17 ft$$

- Layer 4 $\sigma_o = 16.5ft \times 122pcf = 2013 psf$ $e_{4_5} = 0.60$

$$\Delta h_{4_6} = .2 \frac{10}{1.6} \log \frac{2013+1125}{2013}$$

$$\Delta h_{4_6} = 0.24 ft$$

- Layer 5 $\sigma_o = 5.75ft \times 122pcf = 702psf$ $e_5 = e_1 = 0.66$

$$\Delta h_{5_6} = 0.035 \frac{11.5}{1.66} \log \frac{1000}{702} + 0.2 \frac{11.5}{1.66} \log \frac{702+1125}{1000}$$

$$\Delta h_{5_6} = 0.40 ft$$

SECONDARY $H_o = 51.5'$

$$\Delta H_s = 0.0015 \frac{51.5}{1.5} \log 1000/1. = 0.15 ft$$

Impacted Material Settlement

Point B - 90% Relative Compaction Summary

	Layer Placed	CALCULATED SETTLEMENT (FT) Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	TOTAL ft
10'	Layer 1	–	–	–	–	–	–
10'	Layer 2	.36	–	–	–	–	.36
10'	Layer 3	.28	.36	–	–	–	.64
10'	Layer 4	.19	.28	.36	–	–	.83
11.5'	Layer 5	.16	.21	.31	.41	–	1.09
	TOTAL	.99	.85	.67	.41	–	2.92 ft

Immediate Settlement During Impacted Materials Placement = 2.92 ft

9ft	FINAL COVER	0.10*	0.13	0.17	0.24	0.40	1.04 ft
						Secondary	0.15 ft
							1.19 ft

* Time Dependent

Total Post Closure settlement = 1.19 ft

Immediate Post Closure Settlement = 1.04 - 0.10 = 0.94 ft

Written by: M. Gleason Date: 95/10/22 (YY/MM/DD) Reviewed by: SQ Date: 95/10/23 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.8

Impacted Materials Settlement

90% Relative Compaction

Point C Total Material Thickness = 45 ft

- Layer 1 Placed (10') - no settlement
- Layer 2 Placed (10')
  - Layer 1 Δh_{12} = 0.36 ft (From Pt A)
- Layer 3 Placed (10')
  - Layer 1 Δh_{13} = 0.28 ft (Pt A)
  - Layer 2 Δh_{23} = 0.36 ft (Pt A)
- Layer 4 Placed (10')
  - Layer 1 Δh_{14} = 0.19 ft
  - Layer 2 Δh_{24} = 0.28 ft (Pt A)
  - Layer 3 Δh_{34} = 0.36 ft
- Layer 5 Placed 5 ft

$$\Delta\sigma_v = 5\text{ft} \times 122\text{pcf} = 610 \text{ psf}$$

- Layer 1

$$\sigma_o = 35' \times 122\text{pcf} = 4270 \text{ psf} \qquad e_{1_4} = 0.53 \text{ (Pt A)}$$

$$\Delta h_{1_5} = 0.2 \frac{10}{1.53} \log \frac{4270+610}{4270}$$

$$\Delta h_{1_5} = 0.08 \text{ ft} = 0.8\% \text{ Settlement}$$

$$V_{w_{1_4}} = 0.326 \qquad V_{s_{1_4}} = 0.652 \quad \text{(From Pt A)}$$

$$V_{w_{1_5}} = .326 \times 1.008 = 0.329 \qquad V_s = .652 \times 1.008 = 0.657$$

$$V_{v_{1_5}} = .343$$

$$e_{1_5} = .343/.657 = 0.52$$

Written by: M. Gleason Date: 95/10/23 (YY/MM/DD) Reviewed by: SR Date: 95/10/23 (YY/MM/DD)

Client: FERMCO Project: USDF Project/Proposal No.: GE 3900 Task No.: 9.8

Impacted Materials Settlement

POINT C - 90%

Layer 5 placed $\Delta\sigma_v = 610$ psf

- Layer 2 $\sigma_o = 25' \times 122$ pcf $= 3050$ psf $e_{2_4} = e_{1_3} = 0.526$

$$\Delta h_{2_5} = 0.2 \frac{10}{1.56} \log \frac{3050 + 610}{3050} = 0.10 \text{ ft} \quad - 1\%$$

$V_{W_{2_4}} = 0.32$ $V_{S_{2_4}} = 0.64$ (Point B, Point A)

$V_{W_{2_5}} = .32 \times 1.01 = 0.323$ $V_{S_{2_5}} = .64 \times 1.01 = 0.646$

$V_{V_{2_5}} = .354$ $e_{2_5} = .354/.646 = 0.55$

- Layer 3 $\sigma_o = 15' \times 122$ pcf $= 1830$ psf $e_{3_4} = e_{1_2} = 0.6$

$$\Delta h_{3_5} = 0.2 \frac{10}{1.6} \log \frac{1830 + 610}{1830} = 0.16 \text{ ft} \quad 1.6\% \text{ Settlement}$$

$V_{W_{3_4}} = 0.31$ $V_{S_{3_4}} = 0.625$ (Pt A, Pt B)

$V_{W_{3_5}} = .31 \times 1.016 = 0.315$ $V_{S_{3_5}} = .625 \times 1.016 = 0.635$

$V_{V_{3_5}} = 0.365$ $e_{3_5} = .365/.635 = 0.57$

- Layer 4 $\sigma_o = 5 \times 122 = 610$ psf $e_4 = e_1 = 0.66$

$$\Delta h_{4_5} = 0.035 \frac{10}{1.66} \log \frac{1000}{610} + 0.2 \frac{10}{1.66} \log \frac{610 + 610}{1000}$$

$\Delta h_{4_5} = 0.15$ ft - 1.5% Settlement

$V_{W_4} = 0.3$ $V_{S_4} = 0.6$ (Pt A, Pt B)

$V_{W_{4_5}} = .3 \times 1.015 = .305$ $V_{S_{4_5}} = .6 \times 1.015 = 0.609$

$V_{V_{4_5}} = 0.391$ $e_{4_5} = .391/.609 = 0.64$

Written by: M. GLEASON Date: 95/10/23 (YY MM DD) Reviewed by: SQ Date: 95/10/23 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.8

Impacted Materials Settlement

Point C - 90% Relative Compaction

- Placement of Final Cover - Layer 6 $\Delta\sigma_v = 9ft \times 125pcf = 1125 psf$

  - Layer 1 $\sigma_o = 40' \times 122 = 4880 psf$ $e_{1_5} = 0.52$

    $\Delta h_{1_6} = .2 \frac{10}{1.52} \log \frac{4880 + 1125}{4880}$ ✓

    $\Delta h_{1_6} = 0.12 ft$

  - Layer 2 $\sigma_o = 30' \times 122 = 3660 psf$ $e_{2_5} = 0.55$

    $\Delta h_{2_6} = .2 \frac{10}{1.55} \log \frac{3660 + 1125}{3660}$ ✓

    $\Delta h_{2_6} = 0.15 ft$

  - Layer 3 $\sigma_o = 20' \times 122 pcf = 2440 psf$ $e_{3_5} = 0.57$

    $\Delta h_{3_6} = .2 \frac{10}{1.57} \log \frac{2440 + 1125}{2440}$ ✓

    $\Delta h_{3_6} = 0.21 ft$

  - Layer 4 $\sigma_o = 10' \times 122 psf = 1220 psf$ $e_{4_5} = 0.64$

    $\Delta h_{4_6} = .2 \frac{10}{1.64} \log \frac{1220 + 1125}{1220}$ ✓

    $\Delta h_{4_6} = 0.32 ft$

  - Layer 5 $\sigma_o = 2.5' \times 122 psf = 305 psf$ $e_5 = e_1 = 0.66$

    $\Delta h_{5_6} = 0.035 \frac{5}{1.66} \log \frac{1000}{305} + 0.2 \frac{15}{1.66} \log \frac{305 + 1125}{1000}$

    $\Delta h_{5_6} = 0.15 ft$ ✓

SECONDARY $H_o = 45'$

$\Delta H_s = 0.0015 \frac{45'}{1.5} \log 1000/1 \doteq 0.14 ft$

IMPACTED MATERIAL SETTLEMENT

POINT C 90% Relative Compaction - Summary

CALCULATED SETTLEMENT (FT)

	Layer Placed	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Total (ft)
10'	Layer 1	—	—	—	—	—	—
10'	Layer 2	.36	—	—	—	—	.36
10'	Layer 3	.28	.36	—	—	—	.64
10'	Layer 4	.19	.28	.36	—	—	.83
5'	Layer 5	.08	.10	.16	.15	—	.49
	Total	.91	.74	.52	.15	—	2.32 ft

Immediate Settlement During Placement = 2.32 ft

9 ft	Final Cover	*.12	.15	.21	.32	.15	0.95

*Some time dependent settlement

Secondary Settlement 0.14 ft

1.09 ft

Total Post Closure Settlement = 1.09 ft

Immediate Settlement = 0.82 ft

Written by: M. Gleason Date: 95/10/23 (YY/MM/DD) Reviewed by: SR Date: 95/10/23 (YY/MM/DD)

Client: FEZMCO Project: OSDF Project/Proposal No.: 6F 3600 Task No.: 9.8

Impacted Materials Settlement

MATERIAL PLACED AT 85% RELATIVE COMPACTION

POINT A

- Impacted Material Thickness = 56 ft

$\gamma_{d_{85}} = 97.8$ pcf $W_c = 18\%$ $\gamma_T = \gamma_d(1+w_c) = 115$ pcf

Calculate Settlement, new e after each layer is placed

- Layer 1 placed (10' thick) - no settlement
- Layer 2 placed (10' thick) - Follow Assumptions Made for Point A
  - Layer 1 Settlement $\Delta\sigma_v = 10(115) = 1150$ psf

$\sigma_o = 5\text{ft} \times 115\text{pcf} = 575$ psf $\sigma_p = 950$ psf $V_{s_1} = 0.57\text{ft}^3$ per ft^3

$C_c = 0.2$ $C_r = 0.035$ $e_o = 0.75$ (Data Verification)

$$\Delta h_{1_2} = 0.035 \frac{10}{1.75} \log \frac{950}{575} + 0.2 \frac{10}{1.75} \log \frac{575+1150}{950}$$

$\Delta h_{1_2} = 0.34$ ft 3.4% Volume change - settlement

$V_{s_{1_2}} = 0.57 \times 1.034 = 0.59$ $V_{v_{1_2}} = 0.41$

$e_{1_2} = .41/.59 = 0.696$ - immediate settlement

- Layer 3 placed (10' thick) $\Delta\sigma_v = 10(115) = 1150$ psf
  - Layer 2 Settlement $\Delta h_{2_3} = \Delta h_{1_2} = 0.34$ ft
  - Layer 1 Settlement $\sigma_o = 15\text{ft} \times 115\text{pcf} = 1725$ psf

$$\Delta h_{1_3} = 0.2 \frac{10}{1.696} \log \frac{1725+1150}{1725}$$

$\Delta h_{1_3} = 0.26$ ft - 2.6% Settlement

$V_{s_{1_3}} = V_{s_{1_2}} \times 1.026 = 0.59 \times 1.026 = 0.605$ $V_{v_{1_3}} = 0.395$

$e_{1_3} = .395/.605 = 0.652$ - Immediate Settlement

Written by: M. Gleason Date: 95/10/23 (YY MM DD) Reviewed by: SR Date: 95/10/23 (YY MM DD)

Client: FEMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.8

Impacted Materials Settlement

Point A 85% RC.

- Layer 4 placed (10' thick) $\Delta\sigma_v = 1150$ psf
  - Layer 3 $\Delta h_{3_4} = \Delta h_{1_2} = \Delta h_{2_3} = 0.34$ ft
  - Layer 2 $\Delta h_{2_4} = \Delta h_{1_3} = 0.26$ ft
  - Layer 1

$$\sigma_o = 25\text{ft} \times 115\text{pcf} = 2875 \text{ psf}$$

$$\Delta h_{1_4} = 0.2 \frac{10}{1.652} \log \frac{2875 + 1150}{2875}$$

$\Delta h_{1_4} = 0.18$ ft 1.8% Settlement

$V_{s_{1_4}} = V_{s_{1_3}} \times 1.018 = 0.605 \times 1.018 = 0.616$ $V_{v_{1_4}} = 0.384$

$e_{1_4} = .384/.616 = 0.624$ - Immediate Settlements

- Layer 5 Placed (10' thick) $\Delta\sigma_v = 1150$ psf
  - Layer 4 $\Delta h_{4_5} = \Delta h_{1_2} = 0.34$ ft
  - Layer 3 $\Delta h_{3_5} = \Delta h_{1_3} = 0.26$ ft
  - Layer 2 $\Delta h_{2_5} = \Delta h_{1_4} = 0.18$ ft
  - Layer 1

$$\sigma_o = 35\text{ft} \times 115\text{pcf} = 4025 \text{ psf}$$

$$\Delta h_{1_5} = 0.2 \frac{10}{1.624} \log \frac{4025 + 1150}{4025}$$

$\Delta h_{1_5} = 0.13$ ft - 1.3% Settlement

$V_{s_{1_5}} = V_{s_{1_4}} \times 1.013 = 0.616 \times 1.013 = 0.624$ $V_{v_{1_5}} = 0.376$

$e_{1_5} = .376/.624 = 0.603$

Written by: M. Gleason Date: 95/10/23 (YY/MM/DD) Reviewed by: SB Date: 95/10/23 (YY/MM/DD)

Client: Fernco Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.8

Impacted Material Settlement

Point A 85% R.C.

Layer 6 Placed (6' thick) $\Delta\sigma_v = 6ft \times 115 pcf = 690 psf$

- Layer 1

$\sigma_0 = 45' \times 115 pcf = 5175 psf$

$\Delta h_{1_6} = 0.2 \frac{10}{1.603} \log \frac{5175 + 690}{5175}$

$\Delta h_{1_6} = 0.07 ft$ 0.7 % Settlement ✓

$Vs_{1_6} = Vs_{1_5} \times 1.007 = 0.624 \times 1.007 = 0.628$ $Vv_{1_6} = 0.372$

$e_{1_6} = .372/.628 = 0.592$ - Immediate Settlement ✓

- Layer 2

$\sigma_0 = 35' \times 115 pcf = 4025 psf$ $e_{2_5} = e_{1_4} = 0.624$

$\Delta h_{2_6} = 0.2 \frac{10}{1+.624} \log \frac{4025 + 690}{4025}$

$\Delta h_{2_6} = 0.08 ft$ 0.8 % Settlement ✓

$Vs_{2_5} = Vs_{1_4} = .616$ $Vs_{2_6} = Vs_{2_5} \times 1.008 = .616 \times 1.008 = 0.62$

$Vv_{1_6} = 0.38$ $e_{2_6} = .38/.62 = 0.61$ - Immediate Settlements ✓

- Layer 3

$\sigma_0 = 25' \times 115 pcf = 2875 psf$ $e_{3_5} = e_{1_3} = 0.652$

$\Delta h_{3_6} = 0.2 \frac{10}{1+.652} \log \frac{2875 + 690}{2875}$

$\Delta h_{3_6} = 0.11 ft$ 1.1 % Settlement ✓

$Vs_{3_5} = Vs_{1_3} = 0.605$ $Vs_{3_6} = Vs_{3_5} \times 1.011 = 0.605 \times 1.011 = 0.612$

$Vv_{3_6} = .388$ $e_{3_6} = .388/.612 = .634$ ✓

Written by: M. Gleason Date: 95/10/23 (YY/MM/DD) Reviewed by: SR Date: 95/10/23 (YY/MM/DD)

Client: Fernco Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.8

Impacted Material Settlement

Point A 85% R.C.

Layer 6 Placed $\Delta\sigma_v = 690$ psf

- Layer 4

$\sigma_0 = 15\text{ft} \times 115\text{pcf} = 1725\text{psf}$ $e_{4_5} = e_{1_2} = 0.696$

$\Delta h_{4_6} = .2 \frac{10}{1+.696} \log \frac{1725+690}{1725}$

$\Delta h_{4_6} = 0.17$ ft 1.7 % Settlement

$Vs_{4_5} = Vs_{1_2} = 0.59$ $Vs_{4_6} = Vs_{4_5} \times 1.017 = 0.59 \times 1.017 = 0.60$

$Vv_{4_6} = 0.40$ $e_{4_6} = .40/.60 = 0.667$

- Layer 5

$\sigma_0 = 5\text{ft} \times 115\text{pcf} = 575\text{psf}$ $e_5 = e_1 = 0.75$

$\Delta h_{5_6} = 0.035 \frac{10}{1.75} \log \frac{950}{575} + 0.2 \frac{10}{1.75} \log \frac{575+690}{950}$

$\Delta h_{5_6} = 0.19$ ft = 1.9 % Settlement

$Vs_5 = Vs_1 = 0.57$ $Vs_{5_6} = Vs_5 \times 1.019 = 0.57 \times 1.019 = 0.581$

$Vv_{5_6} = 0.419$ $e_{5_6} = 0.72$

FINAL COVER (LAYER 7)

9 ft thick @ 125 pcf = 1125 psf

- Layer 1

$\sigma_0 = 51' \times 115\text{pcf} = 5865\text{psf}$ $e_{1_6} = 0.592$

$\Delta h_{1_7} = 0.2 \frac{10}{1.592} \log \frac{5865+1125}{5865}$

$\Delta h_{1_7} = 0.10$ ft - immediate

Written by: M. Gleason Date: 95/10/23 (YY/MM/DD) Reviewed by: SA Date: 95/10/23 (YY/MM/DD)

Client: Femco Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.8

Impacted Materials Settlement

Point A 85% R.C.

Final Cover Placed $\Delta\sigma_v = 1125$ psf

- Layer 2 $\sigma_o = 41' \times 115$ pcf $= 4715$ psf $e_{2_6} = 0.61$

$$\Delta h_{2_7} = 0.2 \frac{10}{1.61} \log \frac{4715+1125}{4715}$$

$$\Delta h_{2_7} = 0.12 \text{ ft}$$

- Layer 3 $\sigma_o = 31' \times 115$ pcf $= 3565$ $e_{3_6} = .634$

$$\Delta h_{3_7} = 0.2 \frac{10}{1.634} \log \frac{3565+1125}{3565}$$

$$\Delta h_{3_7} = 0.15 \text{ ft}$$

- Layer 4 $\sigma_o = 21' \times 115$ pcf $= 2415$ psf $e_{4_6} = .667$

$$\Delta h_{4_7} = 0.2 \frac{10}{1.667} \log \frac{2415+1125}{2415}$$

$$\Delta h_{4_7} = 0.20 \text{ ft}$$

- Layer 5 $\sigma_o = 11' \times 115$ pcf $= 1265$ psf $e_{5_6} = 0.72$

$$\Delta h_{5_7} = 0.2 \frac{10}{1.72} \log \frac{1265+1125}{1265}$$

$$\Delta h_{5_7} = 0.32 \text{ ft}$$

- Layer 6 $\sigma_o = 3' \times 115$ pcf $= 345$ psf $e_6 = e_o = 0.75$

$$\Delta h_{6_7} = 0.035 \frac{6}{1.75} \log \frac{950}{345} + 0.2 \frac{6}{1.75} \log \frac{1125+345}{950}$$

$$\Delta h_{6_7} = 0.18 \text{ ft}$$

SECONDARY SETTLEMENT

FROM POINT A for 90% R.C.

$$\Delta H_s = 0.17 \text{ ft}$$

Impacted Materials Settlements

Point A 85% Relative Compaction - Summary

CALCULATED SETTLEMENTS (FT)

	Layer Placed	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	TOTAL
10'	Layer 1	—	—	—	—	—	—	—
10'	Layer 2	.34	—	—	—	—	—	.34
10'	Layer 3	.26	.34	—	—	—	—	.60
10'	Layer 4	.18	.26	.34	—	—	—	.78
10'	Layer 5	.13	.18	.26	.34	—	—	.91
6'	Layer 6	.07	.08	.11	.17	.19	—	.62
	TOTALS	.98	.86	.71	.51	.19	—	3.25

Total Immediate Settlement During Material Placement = 3.25 ft

9'	Final Cover	.10	.12	.15	.20	.32	.18	1.07
							Secondary Settlement	0.17
								1.24 ft

POST CLOSURE SETTLEMENT = 1.24 ft

Immediate Settlement Post Closure = 1.07 ft.

GEOSYNTEC CONSULTANTS

Written by: M. Gleason Date: 95/10/23 (YY MM DD) Reviewed by: SQ Date: 95/10/23 (YY MM DD)

Client: Femco Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.8

Impacted Materials Settlement

85% Relative Compaction

POINT B – TOTAL MATERIAL THICKNESS = 51.5 ft

- Layer 1 Placed 10' – no settlement
- Layer 2 Placed 10'
  - Layer 1 $\Delta h_{1_2} = 0.34$ ft (As in Point A)
- Layer 3 Placed 10'
  - Layer 1 $\Delta h_{1_3} = 0.26$ ft (As in Point A)
  - Layer 2 $\Delta h_{2_3} = 0.34$ ft (As in Point A)
- Layer 4 Placed 10'
  - Layer 1 $\Delta h_{1_4} = 0.18$ ft
  - Layer 2 $\Delta h_{2_4} = 0.26$ ft
  - Layer 3 $\Delta h_{3_4} = 0.34$ ft

  } As in Point A
- Layer 5 Placed H = 11.5'

$\Delta\sigma_v = 11.5' \times 115$ pcf $= 1322$ psf

- Layer 1 $\sigma_0 = 35' \times 115$ pcf $= 4025$ psf $e_{1_4} = .624$ (Pt A)

$$\Delta h_{1_5} = .2 \frac{10}{1.624} \log \frac{1322 + 4025}{4025}$$

$\Delta h_{1_5} = 0.15$ ft 1.5% Settlement

$V_{s_{1_4}} = 0.6016$ (Pt A) $V_{s_{1_5}} = V_{s_{1_4}} \times 1.015 = 0.625$ $V_{v_{1_5}} = 0.1375$

$e_{1_5} = .375/.625 = 0.60$

- Layer 2 $\sigma_0 = 25' \times 115$ pcf $= 2875$ psf $e_{2_4} = e_{1_3} = 0.652$

$$\Delta h_{2_5} = 0.2 \frac{10}{1.652} \log \frac{2875 + 1322}{2875}$$

$\Delta h_{2_5} = 0.20$ ft 2.0 percent settlement

$V_{s_{2_4}} = V_{s_{1_3}} = 0.605$ (Pt A) $V_{s_{2_5}} = V_{s_{2_4}} \times 1.02 = 0.617$

$V_{v_{2_5}} = .383$ $e_{2_5} = .383/.617 = 0.62$

Written by: M. Gleason Date: 95 / 10 / 23 (YY MM DD) Reviewed by: SR Date: 95 / 10 / 23 (YY MM DD)

Client: Fernco Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.8

Impacted Materials Settlement

Point B - 85% R.C.
Layer 5 Placed $\Delta\sigma_v = 1322$ psf

- Layer 3. $\sigma_0 = 15' \times 115$ pcf $= 1725$ psf $e_{3_4} = e_{1_2} = 0.696$

$$\Delta h_{3_5} = 0.2 \frac{10}{1.696} \log \frac{1725 + 1322}{1725}$$

$\Delta h_{3_5} = 0.29$ ft 2.9 % Settlement

$V_{s_{3_4}} = V_{s_{1_2}} = 0.59$ $V_{s_{3_5}} = V_{s_{3_4}} \times 1.029 = 0.607$

$V_{v_{3_5}} = 0.393$ $e_{3_5} = .393/.607 = 0.647$

- Layer 4 $\sigma_0 = 5' \times 115 = 575$ psf $e_4 = e_1 = 0.75$

$$\Delta h_{4_5} = 0.035 \frac{10}{1.75} \log \frac{950}{575} + 0.2 \frac{10}{1.75} \log \frac{575 + 1322}{950}$$

$\Delta h_{4_5} = 0.39$ ft 3.9 % Settlement

$V_{s_4} = V_{s_1} = 0.57$ $V_{s_{4_5}} = 0.57 \times 1.039 = 0.592$

$V_{v_{4_5}} = 0.408$ $e_{4_5} = .408/.592 = 0.69$

FINAL COVER (LAYER 6) 9' @ 125 pcf $\Delta\sigma_v = 1125$ psf

- Layer 1 $\sigma_0 = 46.5' \times 115$ pcf $= 5348$ psf $e_{1_5} = 0.60$

$$\Delta h_{1_6} = 0.2 \frac{10}{1+.6} \log \frac{5348 + 1125}{5348}$$

$\Delta h_{1_6} = 0.10$ ft

- Layer 2 $\sigma_0 = 36.5' \times 115$ pcf $= 4198$ psf $e_{2_5} = 0.62$

$$\Delta h_{2_6} = 0.2 \frac{10}{1+.62} \log \frac{4198 + 1125}{4198}$$

$\Delta h_{2_6} = 0.13$ ft

Written by: M. Gleason Date: 95/10/23 (YY MM DD) Reviewed by: SR Date: 95/10/23 (YY MM DD)

Client: Fernco Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.8

Impacted Materials Settlement

Point B 85% R.C.

$\Delta\sigma_v = 1125$ psf

Final Cover

- Layer 3 $\sigma_0 = 26.5 \times 115$ pcf $= 3048$ psf $e_{3_5} = 0.647$

$$\Delta h_{3_6} = 0.2 \frac{10}{1.647} \log \frac{3048 + 1125}{3048}$$

$$\Delta h_{3_6} = 0.17 \text{ ft}$$

- Layer 4 $\sigma_0 = 16.5 \times 115$ pcf $= 1898$ psf $e_{4_5} = 0.69$

$$\Delta h_{4_6} = 0.2 \frac{10}{1.69} \log \frac{1898 + 1125}{1898}$$

$$\Delta h_{4_6} = 0.24 \text{ ft}$$

- Layer 5 $\sigma_0 = 5.75$ ft $\times 115$ pcf $= 661$ psf $e_5 = e_1 = 0.75$

$$\Delta h_{5_6} = 0.035 \frac{11.5}{1.75} \log 950/661 + 0.2 \frac{11.5}{1.75} \log \frac{661 + 1125}{950}$$

$$\Delta h_{5_6} = 0.40 \text{ ft}$$

Secondary Settlement

$$\Delta H_s = 0.0015 \frac{51.5}{1.5} \log 1000/1 = 0.15 \text{ ft}$$

Written by: M. Gleason Date: 95/10/23 (YY MM DD) Reviewed by: SR Date: 95/10/23 (YY MM DD)

Client: Fermco Project: OSDF Project/Proposal No.: GE 3900 Task No.: 2.8

Impacted Materials Settlement

Point B 85% Relative Compaction - Summary

CALCULATED SETTLEMENT (FT)

	Layer Placed	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Totals (ft)
10'	Layer 1	–	–	–	–	–	–
10'	Layer 2	0.34	–	–	–	–	0.34
10'	Layer 3	0.26	0.34	–	–	–	0.60
10'	Layer 4	0.18	0.26	0.34	–	–	0.78
11.5'	Layer 5	0.15	0.20	0.29	0.39	–	1.03
	TOTALS	0.93	0.80	0.63	0.39		2.75 ft

Immediate Settlement During Impacted Materials Placement = 2.75 ft

9'	FINAL COVER	0.10	0.13	0.17	0.24	0.40	1.04 ft
						Secondary Settlement	0.15 ft
							1.19 ft

Total Post Closure Settlement = 1.19 ft

Immediate Post Closure Settlement = 1.04 ft.

Written by: M. Gleason Date: 95/10/23 (YY MM DD) Reviewed by: SQ Date: 95/10/23 (YY MM DD)

Client: Femco Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.8

Impacted Materials Settlement

Point C 85% Relative Compaction

Total Material Thickness = 45 ft

- Layer 1 Placed 10' - no settlement
- Layer 2 Placed 10'
  - Layer 1 $\Delta h_{12} = 0.34$ ft (Pt A)
- Layer 3 Placed 10'
  - Layer 1 $\Delta h_{13} = 0.26$ ft (Pt A)
  - Layer 2 $\Delta h_{23} = 0.34$ ft (Pt A)
- Layer 4 Placed 10'
  - Layer 1 $\Delta h_{14} = 0.18$ ft
  - Layer 2 $\Delta h_{24} = 0.26$ ft
  - Layer 3 $\Delta h_{34} = 0.34$ ft

  (As in Pt A, Pt B)
- Layer 5 Placed 5'

$\Delta\sigma_v = 5\text{ft} \times 115\text{pcf} = 575\text{psf}$

- Layer 1 $\sigma_o = 35' \times 115\text{pcf} = 4025\text{psf}$ $e_{1_4} = .624$ (Pt A)

$$\Delta h_{1_5} = 0.2 \frac{10}{1.624} \log \frac{4025 + 575}{4025}$$

$\Delta h_{1_5} = 0.07$ 0.7 % Settlement

$V_{s_{1_4}} = 0.616$ (Pt A) $V_{s_{1_5}} = V_{s_{1_4}} \times 1.007 = 0.62$ $V_{v_{1_5}} = 0.38$

$e_{1_5} = .38/.62 = 0.613$

- Layer 2 $\sigma_o = 25' \times 115\text{pcf} = 2875\text{psf}$ $e_{2_4} = e_{1_3} = 0.652$

$$\Delta h_{2_5} = 0.2 \frac{10}{1.652} \log \frac{2875 + 575}{2875}$$

$\Delta h_{2_5} = 0.10$ ft 1% Settlement

$V_{s_{2_4}} = 0.605$ (Pt A) $V_{s_{2_5}} = V_{s_{1_4}} \times 1.01 = 0.611$ $V_{v_{2_5}} = 0.389$

$e_{2_5} = .389/.611 = 0.637$

Written by: M. Gleason Date: / / YY MM DD Reviewed by: SQ Date: 95 / 10 / 23 YY MM DD

Client: Femco Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.8

Impacted Materials Settlement

Point C 85% R.C.

Layer 5 Placed $\Delta\sigma_v = 575$ psf

• Layer 3 $\sigma_o = 15' \times 115$ pcf $= 1725$ psf $e_{3_4} = e_{1_2} = 0.696$ (Pt A)

$$\Delta h_{3_5} = 0.2 \frac{10}{1.696} \log \frac{1725 + 575}{1725}$$

$\Delta h_{3_5} = 0.15$ ft 1.5 % Settlement – immediate ✓

$V_{s_{3_4}} = 0.59$ (Pt A) $V_{s_{3_5}} = V_{s_{3_4}} \times 1.015 = 0.60$ $V_{v_{3_5}} = 0.40$

$e_{3_5} = .4/.6 = 0.667$

• Layer 4 $\sigma_o = 5' \times 115$ pcf $= 575$ psf $e_4 = e_o = 0.75$

$$\Delta h_{4_5} = 0.035 \frac{10}{1.75} \log \frac{950}{575} + 0.2 \frac{10}{1.75} \log \frac{575 + 575}{950}$$

$\Delta h_{4_5} = 0.14$ ft 1.4 % Settlement ✓

$V_{s_4} = 0.57$ $V_{s_{4_5}} = V_{s_4} \times 1.014 = 0.58$ $V_{v_{4_5}} = 0.42$

$e_{4_5} = .42/.58 = 0.724$

FINAL COVER PLACED (Layer 6) $\Delta\sigma_v = 1125$ psf (9' @ 125 pcf)

• Layer 1 $\sigma_o = 40' \times 115$ pcf $= 4600$ psf $e_{1_5} = .613$

$$\Delta h_{1_6} = 0.2 \frac{10}{1.613} \log \frac{4600 + 1125}{4600}$$ ✓

$\Delta h_{1_6} = 0.12$ ft

• Layer 2 $\sigma_o = 30' \times 115$ pcf $= 3450$ psf $e_{2_5} = 0.637$

$$\Delta h_{2_6} = 0.2 \frac{10}{1.637} \log \frac{3450 + 1125}{3450}$$ ✓

$\Delta h_{2_6} = 0.15$ ft

Written by: M. GLEASON Date: 95 / 10 / 23 (YY MM DD) Reviewed by: SQ Date: 95 / 10 / 23 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.8

Impacted Materials Settlement

POINT C 85% R.C.

FINAL COVER PLACED $\Delta\sigma_v = 1125$ pcf

- Layer 3 $\sigma_o = 20' \times 115$ pcf $= 2300$ psf $e_{3_5} = 0.667$

$$\Delta h_{3_6} = .2 \frac{10}{1.667} \log \frac{2300 + 1125}{2300}$$

$$\Delta h_{3_6} = 0.21 \text{ ft}$$

- Layer 4 $\sigma_o = 10' \times 115$ pcf $= 1150$ psf $e_{4_5} = 0.724$

$$\Delta h_{4_6} = .2 \frac{10}{1.724} \log \frac{1150 + 1125}{1150}$$

$$\Delta h_{4_6} = 0.34 \text{ ft}$$

- Layer 5 $\sigma_o = 2.5' \times 115$ pcf $= 288$ psf $e_5 = e_o = 0.75$

$$\Delta h_{5_6} = 0.035 \frac{5}{1.75} \log \frac{950}{288} + 0.2 \frac{5}{1.75} \log \frac{288 + 1125}{950}$$

$$\Delta h_{5_6} = 0.15 \text{ ft}$$

SECONDARY SETTLEMENT $H_o = 45'$

$$\Delta H_s = 0.0015 \frac{45'}{1.5} \log 1000/1 = 0.14 \text{ ft}$$

IMPACTED MATERIAL SETTLEMENT

POINT C 85% RELATIVE COMPACTION - SUMMARY

CALCULATED SETTLEMENT (FT)

	Layer Placed	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	TOTAL
10'	Layer 1	—	—	—	—	—	—
10'	Layer 2	.34	—	—	—	—	.34
10'	Layer 3	.26	.34	—	—	—	.60
10'	Layer 4	.18	.26	.34	—	—	.78
5'	Layer 5	.07	.10	.15	.14	—	.46
	TOTALS	.85	.70	.49	.14	—	2.18

Immediate Settlement During Material Placement = 2.18 ft

9'	FINAL COVER	.12	.15	.21	.34	.15	0.97 ft
						Secondary Settlement	0.14 ft
							1.11 ft

Total Post Closure Settlement = 1.11 ft

Immediate Closure Settlement = 0.97 ft

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Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.8

Impacted Materials Settlement

Summary of Settlements

- Immediate Settlement During Material Placement

	Point A	Point B	Point C
90% Relative Compaction	3.46 ft	2.92 ft	2.32 ft
85% Relative Compaction	3.25 ft	2.75 ft	2.18 ft

These settlements are immediate and will occur during material placement. Therefore they will not affect grading for the final cover system.
The settlements provide an estimate of the settlement during waste placement for materials placed at Std. Proctor Optimum Moisture Content. Placement at higher water content will affect results. Material placed at a higher water content may saturate quicker and thus undergo less immediate settlement.

Settlement From Final Cover System

90% Relative Compaction

	Immediate ft	Time Dependent ft	Total ft
Point A	0.97	0.39	1.36
Point B	0.94	0.25	1.19
Point C	0.95	0.14	1.09

85% Relative Compaction

Point A	1.07	0.17	1.24
Point B	1.04	0.15	1.19
Point C	0.97	0.14	1.11

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Client: Fernco Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.8

Impacted Material Settlement

Summary - cont.

- Settlement due to placement of the Final Cover is relatively uniform.

  Maximum differential Settlement

  90% RC = 1.36 - 1.09 = 0.27 ft

  85% R.C. = 1.24 - 1.11 = 0.15 ft

- Differential Settlements result in compression (shortening) of the cover system components

  ∴ No tensile strains are calculated for the Final Cover System

- Differential Settlements result in less than 0.2 percent grade change

  90% R.C. Pt A - Pt B $= \frac{1.36 - 1.19}{88 ft} \times 100 = 0.19\ \%$

  85% R.C. Pt B - Pt C $\frac{1.19' - 1.11'}{53'} \times 100 = 0.15\ \%$

  ∴ Grade Changes do not affect cover system performance or integrity.

- Impact of Foundation Settlement.

  Foundation Soils Settlement as calculated in the foundation settlement package will contribute to Final Cover Settlement. Foundation settlements are greater at the location of the most materials. Therefore, foundation settlements will add to the overall compression of the Final Cover System. Grade changes of the Final Cover from Foundation Settlement are expected to be less than 0.5 %.

SECTION 3

3. SLOPE STABILITY

3.1 Foundation Stability
3.2 Short-Term Liner System Stability on Side Slopes
3.3 Interim/Final Waste Slope Stability
3.4 Cover System Stability
3.5 Perimeter Access Corridor
3.6 Borrow Area Cut Slope Stability

3.1 Foundation Stability

COMPUTATION COVER SHEET

SUBJECT OF CALCULATION: FOUNDATION STABILITY

Computations By: (Cognizant Engineer)
Signature [signature] Date 6 OCT 95
Printed Name and Title ROBERT S COBLE II, STAFF ENGINEER

Assumptions and Procedures Checked by: (Checker)
Signature [signature] Date 06 OCT 95
Printed Name and Title SAAD QURESHI, PROJECT ENGINEER

Computations Checked by:
Signature [signature] Date 06 OCT 95
Printed Name and Title SAAD QURESHI, PROJECT ENGINEER

Computations Backchecked by: (Cognizant Engineer)
Signature [signature] Date 06 OCT 95
Printed Name and Title ROBERT S COBLE II, STAFF ENGINEER

Approved by: (PDP)
Signature [signature] Date 06 OCT 95
Printed Name and Title MARK H. GLEASON, ASSISTANT PROJECT ENGINEER

Approved by: (DTL and TETL)
Signature [signature] Date 07 Oct 95
Printed Name and Title Rudolph Bonaparte, Principal

Record of Revision (Number and initial all revisions)

NO.	REASON	DATE	BY	CHECKED	APPROVAL
B	Preliminary Design EPA Submittal	14 Dec 95	[illegible]		

Signature: _____
Number: _____
Registration Stamp (if applicable)

Written by: M. Gleason Date: 95 / 12 / 14 Reviewed by: SQ Date: 95 / 12 / 14

Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 9.4

14Dec95

FOUNDATION STABILITY

EXECUTIVE SUMMARY

Purpose

This calculation package contains analyses for static foundation stability of the OSDF for Final and Interim landfill configurations. The stability of the OSDF is calculated for failure surfaces that pass through the waste mass and along the soils beneath the OSDF.

Procedure

Calculations are performed for the Final OSDF Configuration and for the Interim (between cell) OSDF Configuration as shown on Figures 1 and 2. For the interim configuration, both short-term and long-term material properties are considered. For the Final OSDF Configuration, only long-term material properties are considered.

Minimum Acceptable Factors of Safety (FS) based on UMTRA Technical Approach Document (DOE, 1989) are as follows: (i) long-term stability, FS $\geq$ 1.5; and (ii) end of construction (interim/short-term) stability, FS $\geq$ 1.3.

The stability analyses are performed using established geotechnical procedures for calculating slope stability.

Results

	Minimum FS	
• Interim Conditions - 3H:1V slope		
· short-term strengths	1.5	acceptable
· long-term strengths	1.8	acceptable
• Final Conditions - 6H:1V slope	3.0	acceptable

All factors of safety meet the established criteria.

Written by: R. Coble Date: 95/10/05 (YY MM DD) Reviewed by: SR Date: 95/10/06 (YY MM DD)

Client: Fernco Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.4

RB 95/10/5

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Written by: M. GLEASON Date: 95/10/5 (YY MM DD) Reviewed by: SG Date: 95/10/06 (YY MM DD)

Client: FERNCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.4

RB 95/10/5

FOUNDATION STABILITY

SUMMARY OF CALCULATIONS

This calculation package contains analyses for foundation stability at the OSDF for Final and Interim landfill configurations. The stability of the OSDF is calculated for failure surfaces that pass through the waste mass and along the soils beneath the OSDF.

Calculations are performed for the Final OSDF Configuration and for the Interim (between cell) OSDF Configuration as shown on Figures 1 and 2. For the interim configuration, both short-term and long-term material properties are considered. For the final OSDF Configuration, only long-term material properties are considered.

Minimum Acceptable Factors of Safety (FS) based on UMTRA Technical Approach Document (DOE, 1989) are as follows:

LONG-TERM STABILITY · FS ≥ 1.5
END OF CONSTRUCTION
(INTERIM / SHORT-TERM) STABILITY FS ≥ 1.3

RESULTS FOR FOUNDATION STABILITY

INTERIM CONDITIONS - 3H:1V SLOPE

		MINIMUM FS	
SHORT-TERM	STRENGTHS	1.5	ACCEPTABLE
LONG-TERM	STRENGTHS	1.8	ACCEPTABLE ✓
FINAL CONDITIONS	6H:1V SLOPE	3.0	ACCEPTABLE. ✓

ALL FACTORS OF SAFETY MEET THE ESTABLISHED CRITERIA

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Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.4

95/10/5

FOUNDATION STABILITY - DATA COLLECTION AND VERIFICATION

PURPOSE: The purpose of this document is to describe the engineering procedures used to collect data for use in the analysis for Foundation Stability of the OSDF. The data thus collected is provided for verification.

SCOPE: Collect Engineering Data for the foundation stability analysis of the OSDF. Data required includes engineering properties of the subsurface soils including the brown till, the gray till, and the soils of the Great Miami Aquifer. Engineering data may be found based on site-specific information, and published correlations for material properties.

DESIGN: Material properties are required for failure surfaces that pass through the waste and through the subsurface soils beneath the OSDF. Analysis approach is discussed in the Engineering Procedures. Material shear strength properties are required for undrained analysis and drained analysis for short-term and long-term conditions

PARAMETERS FOR DESIGN

BROWN TILL Thickness ranges from approximately 8 to 15 ft
Average unit weight γ_T = 135 pcf Reference 1 table 4-3

Undrained Shear Strength - from unconfined compression testing performed by Parsons (Reference 1, TABLE 4-5)

Boring	Material	Depth	S_u	Axial strain
11470B	ML	8-10.5	780	7%
11472	CL	3.5-6.0	4400	12.9%
11473	CL	6.5-8.5	4058	10.4%
11477	CL	3.5-6.0	652	7.7%
11481	CL	6.5-9.0	4458	11.7%
11480	CL	0.5-3.0	2127	4.32

Failure at small strain may be indicative of brittle failure in unconfined test.

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Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.4

RB 95/10/5

FOUNDATION STABILITY DATA COLLECTION AND VERIFICATION

PARAMETERS - BROWN TILL cont.

UNDRAINED STRENGTH - Su = 780 psf and Su = 652 psf are not representative of the material described for the brown till. (ie stiff silty clay).
For analysis assume Su = 1200 psf
This assumption is conservative based on the available unconfined compression test results.

DRAINED SHEAR STRENGTH
- From Consolidated Undrained Triaxial Tests with measurement of pore pressure ($\bar{R}$ tests) by Parsons (Reference 1, Table 4-6)
- Use effective shear strengths only.

BORING	Material	Depth (ft)	$\bar{c}$ (psf)	$\bar{\phi}$ (deg)
11468	CL	9.0-11.5	525	28
11469	CL	3.0-5.5	500	25
11470B	ML	8.0-10.5	0	35
11475	CL	11.0-13.5	125	34
11478	CL	3.5-6.0	375	26

For the analysis assume $\bar{c} = 0$ and $\bar{\phi} = 25°$

GRAY TILL Thickness ranges from approximately 15 to 45 ft

Average Unit Weight = 145 pcf Reference 1 Table 4-3

Undrained Shear Strength from UC tests Reference 1 Table 4-5

BORING	MATERIAL	DEPTH ft	Su (psf)	Axial Strain %
11468	CL	15-17.5	2738	15
11469	CL	15.5-18	2650	15
11471	CL	17-19.5	3733	14.6
11473	CL	15.5-18	2975	15
11474	CL	14-16.5	3647	11.6
11475	CL	15.5-18	4818	10
11476	CL-ML	9.5-12.0	2635	15
11479	CL	18.5-21.0	1974	15

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Client: FERMILO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.4

RB 95/10/5

FOUNDATION STABILITY - DATA COLLECTION AND VERIFICATION

PARAMETERS - GRAY TILL, CONT.

UNDRAINED STRENGTH -

Su strengths for analysis

Low	1974 psf	use 1900 psf for analysis
High	4848 psf	
Average	3150 psf	

DRAINED SHEAR STRENGTH

- FROM Consolidated-Undrained Triaxial tests with measurement of pore pressure ($\bar{R}$ tests) by Parsons (Ref 1 table 4-6). Effective stress analysis only.

BORING	MATERIAL	DEPTH (ft)	$\bar{c}$ psf	$\bar{\phi}$ (deg)
11472	CL	23-25.5	150	30
11476	SC-SM	14.0-16.5	0	38
11477	CL	14.0-16.5	180	32
11481	CL	15.5-18.0	250	32

For the analysis assume $\bar{c} = 0$. $\bar{\phi}$ ranges from a low of 30° to a high of 38° $\bar{\phi}_{AVG} = 33°$.
FOR ANALYSIS ASSUME $\bar{\phi} = 30°$

GREAT MIAMI AQUIFER (GMA)

- GMA soils are granular silty sand soils and are medium dense to very dense and are dense to very dense directly below the till.
- The soils are unsaturated directly beneath the gray till layer.
- The ground-water table is approximately 80-90 ft below the ground surface.

For the stability analysis assume the following parameters to be used in both drained and undrained analyses:

$\gamma_T = 135$ pcf $\phi = 35°$ (Reference 2).
↳ low range for dense sands

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Client: FERMCO Project: OSDF Project/Proposal No.: 6E 3900 Task No.: 09.4

FOUNDATION STABILITY DATA COLLECTION/VERIFICATION RB 95/10/5

PARAMETERS FOR DESIGN

LINER SYSTEM - 3ft THICK LAYER OF RECOMPACTED BROWN TILL

- ASSUME BROWN TILL will be compacted at a minimum dry density of 95% of STANDARD PROCTOR OPTIMUM (ASTM D698), and at a water content 2 to 4 percent of optimum

From information provided by Parsons (Ref 1) (table 4-8)

MAXIMUM DRY DENSITY (ASTM D698) = 118 pcf average

OPTIMUM MOISTURE CONTENT = 13.7% average

At 95% dry density $\gamma_d = 118(.95) = 112$ pcf

At 2% wet of optimum $w_c = 15.7$ & 4% $w_c = 17.7\%$

Total unit weight $\gamma_T = \gamma_d(1+w_c)$

LOW $\gamma_T = 112(1+0.157) = 129.6$ pcf

HIGH $\gamma_T = 112(1+0.177) = 131.8$ pcf

Assume $\gamma_T = 130$ pcf ✓

UNDRAINED SHEAR STRENGTH - Su

No test data is available for Su of remolded brown till (which is assumed to be the liner material).

Presented in Ref 5 Fig 12.8 is a relationship between LI (Liquidity Index) and Remolded Shear Strength.

From Ref 1 Figure 4-12 For Samples of Brown Till obtained at depths of 0-5 ft (Assume clay beneath 5 is not used in liner). (Discard one point at high and low end of scale)

Weighted Average Range of LL Max = 51% Min = 28% Avg ≈ 38%

Weighted Average Range of PI Max = 32% Min = 13% Avg ≈ 21%

corresponding PL = LL-PI; PL Max = 19 Min = 15% Avg = 17%

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Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.4

Foundation Stability Data Collection / Verification

RB 95/10/5

PARAMETERS

LINER SYSTEM - Recompacted Clay Liner Cont.

UNDRAINED STRENGTH

$$LI = \frac{W_n - PL}{PI}$$

At Average 3% wet of optimum, $W_c = 15.7\%$

use max values

$$LI = \frac{15.7\% - 19}{32} = -0.1$$

min

$$LI = \frac{15.7 - 15}{13} = 0.05$$

AVERAGE

$$LI = \frac{15.7 - 17}{21} = -0.06$$

FROM FIGURE 12.8 (Ref 5)

S_u min $= 0.6$ kg/cm² $\quad 0.6 \text{ kg/cm}^2 \times \frac{929 \text{ cm}^2}{\text{ft}^2} \times \frac{2.205 \text{ lb}}{\text{kg}} = 1229$ lb/ft²

S_u max $= 2$ kg/cm² $\quad 2 \text{ kg/cm}^2 \times \frac{929 \text{ cm}^2}{\text{ft}^2} \times \frac{2.205 \text{ lb}}{\text{kg}} = 4096$ lb/ft²

For S_u of compacted clay liner use 1200 lb/ft² ✓

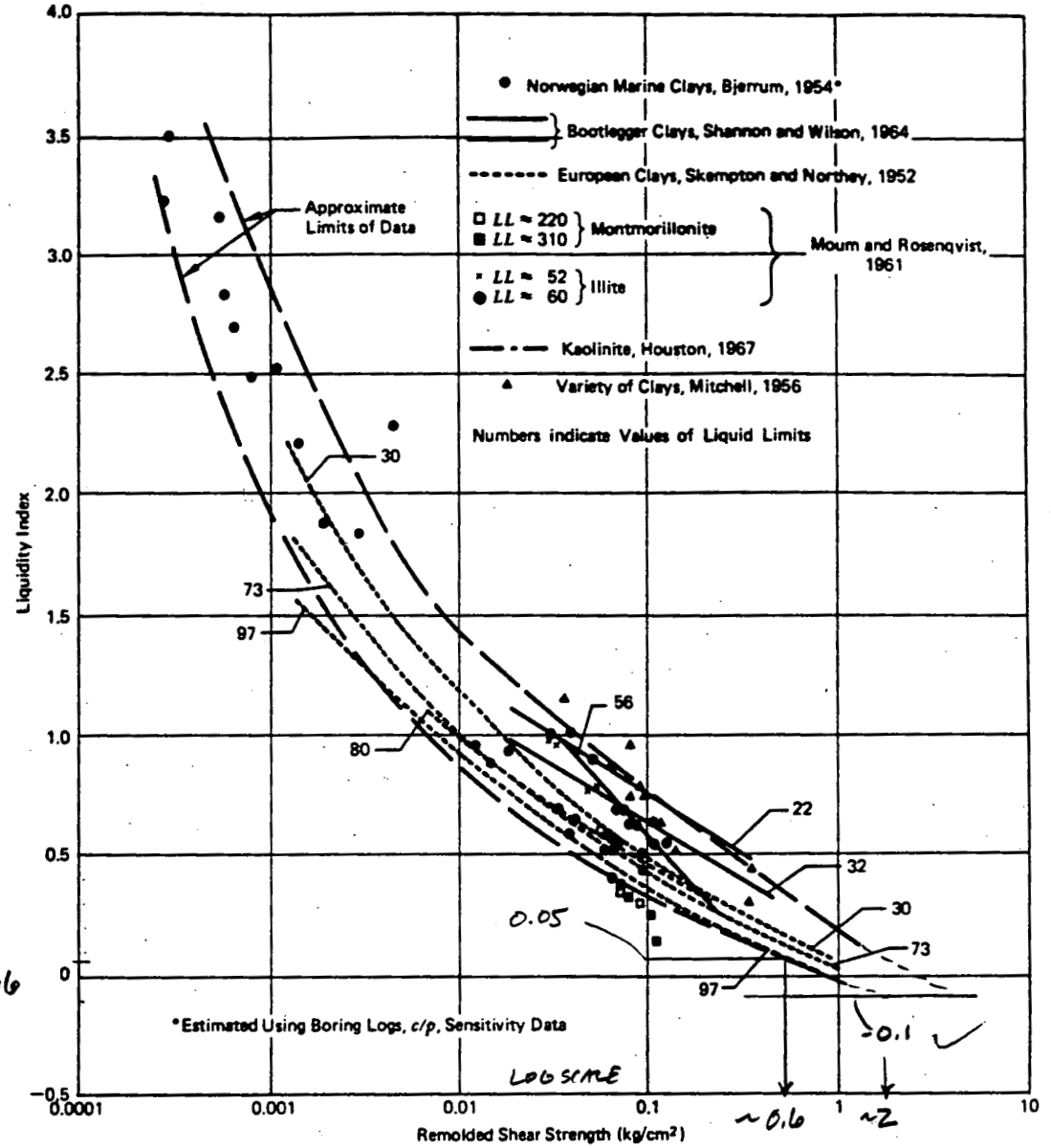
DRAINED STRENGTH - Presented below is a summary of consolidated-undrained triaxial tests on remolded Brown Till (Ref 1 Table 4-9).

Boring	Material	Depth	$\bar{c}$ psf	$\bar{\Phi}$ degrees	
11468	CL	2-6.5	325	29	at optimum W_c
11472	CL	9-12	100	29	"
11474	CL	3-7.5	200	30	"
11478	CL	3-7.5	400	23	"
11478	CL	3-7.5	175	28	3% Dry of opt
11478	CL	3-7.5	250	25	4% Wet of optimum
				Inconclusive	

Average $\bar{\Phi}$ for samples at optimum $\bar{\Phi} = 27.8$

Assume ~10% decrease in strength for samples 2-4% wet of optimum W_c

$\therefore$ Assume $\bar{\Phi} = 27.8 - 0.1(27.8) = 25°$ ✓



FROM MITCHELL, 1976 (Ref 5)

Fig. 12.8 Remolded shear strength vs. liquidity index relationships for several clays.

percent, the strengths in the two directions were the same. This was consistent with the finding that as the density increased the intensity of preferred orientation decreased.

The sample stiffness, as measured by the ratio of stress to shear displacement, at 50 percent of peak strength was about twice as high for shear across the direction of preferred orientation than parallel to it.

The results of direct shear tests on Leighten Buzzard sand, which contains rounded particles, (Arthur and Menzies, 1972) gave a maximum shear to normal stress ratio 24 percent greater for samples poured through the side or end of the shear box than for samples prepared in the normal way. Additional tests were done on the same sand at a porosity of 34 percent using a cubical triaxial cell in which samples could be tilted to the direction of pouring. The results, shown in Fig. 12.12 in terms of effective principal strains, indicate strength variations of about 10 percent of maximum σ_1'/σ_3' for different orientations of σ_1' and σ_3' relative to the direction of pouring. The variations of peak effective stress ratio and effective stress friction angle ϕ' are shown in Fig. 12.12*d*.

Figures 12.12 *b* and *c* show also that the strain

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Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.4

RB 95/10/5

FOUNDATION STABILITY - DATA COLLECTION CONT.

PARAMETERS FOR DESIGN

WASTE MATERIAL - OSDF WASTE -

- BASED ON PROJECT SCOPE OF WORK, WASTE MATERIAL IS EXPECTED TO INCLUDE THE FOLLOWING:
  - contaminated soil;
  - municipal solid waste;
  - fly ash;
  - lime sludge; and
  - demolition debris.

BECAUSE OF THE EXTREME VARIABILITY, THE MATERIAL PROPERTIES ARE EXPECTED TO VARY CONSIDERABLY.
Waste will be placed under well-controlled conditions
Estimate a range of properties:

Unit weight γ_T = 80 pcf Low - including liner and cover materials
γ_T = 125 pcf high - " "

Shear strength: Assume lime sludge will be mixed with demolition debris or soils so that it is not placed in one location in significant quantities

For Municipal Waste Estimate $\phi = 33°$ (Reference 3)
- estimate demolition debris and soil (compacted in place have at least this strength.

For Ash - $\bar{\phi} = 34°$ (Reference 4)
similar to bottomash. based on tests performed for Delmarva Power (EPRI)

FOR ANALYSIS ASSUME THE FOLLOWING PROPERTIES

UNIT WEIGHT γ_{waste} = 125 pcf

SHORT-TERM STRENGTHS C = 200 psf $\phi = 25°$ ✓

LONG-TERM STRENGTHS $\bar{\phi} = 25°$

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RB 95/10/5

FOUNDATION STABILITY - DATA COLLECTION

PARAMETERS FOR DESIGN

GRANULAR COMPONENT OF FINAL COVER SYSTEM AND LINER SYSTEM

FINAL COVER GRANULAR COMPONENTS:

- 6" TOPSOIL,
- 21" Common Soil for Vegetative Support,
- 6" Sand Filter Layer,
- 36" COBBLE Layer - (Biotic Barrier), and
- 12" Pea Gravel (Drainage Layer)

LINER SYSTEM GRANULAR COMPONENTS:

- 12" Pea Gravel - Leachate collection layer, and
- 12" Pea Gravel - Leachate detection layer

- FOR FOUNDATION STABILITY, THE GEOSYNTHETICS COMPONENTS OF THE FINAL COVER AND LINER SYSTEMS ARE NOT RELEVANT

ASSUME THAT THE GRANULAR MATERIALS HAVE UNIFORM PROPERTIES

WITH γ_T = 125 pcf ✓

ϕ = 30 degrees

Written by: R. COBLE Date: 95/09/15 (YY/MM/DD) Reviewed by: SQ Date: 95/10/06 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.4

FOUNDATION STABILITY CALCULATION PACKAGE

PURPOSE: THE PURPOSE OF THIS DOCUMENT IS TO PROVIDE THE ENGINEERING CALCULATIONS FOR FOUNDATION STABILITY OF THE OSDF. THE CALCULATIONS PROVIDE AN ANALYSIS OF THE RESISTANCE TO FAILURE OF THE OSDF FOR SURFACES THAT PASS THROUGH THE WASTE MASS AND THE SOILS BENEATH THE OSDF. THE ANALYSES WERE PERFORMED FOR BOTH INTERIM AND FINAL CONFIGURATIONS OF THE LANDFILL. THE INTERIM CONFIGURATIONS MODEL THE CONDITIONS EXPECTED TO OCCUR WHILE THE LANDFILL IS BEING FILLED. THE INTERIM CONFIGURATIONS WERE ANALYSED FOR BOTH SHORT-TERM (UNDRAINED) AND LONG-TERM (DRAINED) SOIL STRENGTH PARAMETERS.

PROCEDURE: THE CALCULATION PROCEDURES FOR FOUNDATION STABILITY ANALYSIS IS DESCRIBED IN DETAIL IN THE DESIGN CRITERIA PACKAGE, AND IS SUMMARIZED HERE. THE DATA USED FOR THE ANALYSIS (I.E. UNIT WEIGHTS, UNDRAINED SHEAR STRENGTHS, AND DRAINED SHEAR STRENGTHS) ARE PROVIDED IN THE DATA VERIFICATION PACKAGE.

THE COMPUTER PROGRAM XSTABL (SHARMA, 1994) WAS USED TO PERFORM THE STABILITY ANALYSES. CIRCULAR AND WEDGE-TYPE FAILURE SURFACES WERE EXAMINED. CIRCULAR FAILURE SURFACES WERE ANALYSED USING BISHOP'S SIMPLIFIED METHOD (BISHOP, 1955). WEDGE FAILURE SURFACES WERE ANALYSED USING SPENCER'S METHOD (SPENCER, 1967).

ANALYSIS:

I. XSTABL COMPUTER MODEL NOTES

A. THE STABILITY OF THE FOUNDATION SOILS AND THE ASSOCIATED FACTORS OF SAFETY AGAINST FOUNDATION FAILURE WERE ANALYSED USING THE PROGRAM XSTABL, VERSION 5.

B. FOR CIRCULAR FAILURE ANALYSES, THE PROGRAM REQUIRES THE OPERATOR TO PROVIDE 2 RANGES OF X-VALUES DELINEATING WHERE THE CIRCULAR FAILURE SURFACES CAN ORIGINATE AND TERMINATE IN ADDITION TO THE CROSS-SECTIONAL GEOMETRY OF THE SLOPE AND THE MATERIAL STRENGTH PARAMETERS. THE USER MUST, ALSO, PROVIDE A SPACING BETWEEN THE FAILURE INITIATION POINTS AND THE NUMBER OF CIRCULAR FAILURE PLANES TO TEST FOR FROM EACH INITIATION POINT.

Written by: R. COBLE Date: 95/09/15 Reviewed by: SQ Date: 95/10/06

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.4

C. WEDGE FAILURE ANALYSES REQUIRE THE OPERATOR TO PROVIDE ONE OR MORE "BOXES" WITHIN THE MODEL, THROUGH WHICH ALL OF THE FAILURE SURFACES MUST PASS.

II. METHODOLOGY FOR CRITICAL FAILURE PLANE SEARCH

A. CIRCULAR FAILURE PLANES

1. INITIATION POINTS FOR THE CIRCULAR FAILURE SURFACE SEARCH WERE INITIALLY SPACED AT 10 FT. INTERVALS. X-VALUES FOR THE INITIATION POINTS WERE ALLOWED TO RANGE FROM THE WASTE / TOE BERM INTERSECTION TO THE LIMITS OF THE MODEL.

2. THE FAILURE CIRCLES WERE ALLOWED TO TERMINATE ANYWHERE WITHIN THE WASTE MASS.

3. TEN FAILURE CIRCLES WERE EXAMINED FOR EACH INITIATION POINT.

4. FROM THE HUNDREDS OF FAILURE CIRCLES GENERATED, THE 10 CIRCLES WITH THE LOWEST FACTOR OF SAFETY AGAINST FAILURE WERE PLOTTED. (NOTE: SINCE THIS WAS AN EXAMINATION OF THE FOUNDATION MATERIALS, ANY FAILURE PLANES THAT DID NOT PASS INTO THE FOUNDATION SOILS WERE DISREGARDED).

5. THE RANGES OF INITIATION AND TERMINATION POINTS FOR THE 10 FAILURE CIRCLES WITH THE LOWEST FACTORS OF SAFETY WERE THEN RE-ENTERED INTO THE MODEL AS THE NEW LIMITS FOR THE INVESTIGATION.

6. THE FAILURE PLANE INITIATION POINT SPACING WAS THEN REDUCED TO 5 FEET.

7. THE FAILURE CIRCLE WITH THE LOWEST FACTOR OF SAFETY GENERATED IN THE SECOND RUN WAS TAKEN AS THE CRITICAL CIRCLE.

B. WEDGE - TYPE FAILURE PLANES

1. TWO BOXES WERE DESIGNATED WITHIN THE MODEL. THE FIRST BOX WAS SIZED TO CONTAIN AS MUCH OF THE FOUNDATION SOILS LOCATED UNDER THE WASTE MASS AS

THE COMPUTER MODEL WOULD ALLOW. THE SECOND BOX WAS LOCATED AND SIZED TO CONTAIN THE REMAINDER OF THE FOUNDATION SOILS THAT WERE NOT LOCATED UNDER THE WASTE MASS.

2. ONE HUNDRED FAILURE SURFACES WERE THEN GENERATED THROUGH THE 2 INITIAL BOXES.

3. THE 10 MOST CRITICAL FAILURE PLANES WERE PLOTTED.

4. BOTH BOXES WERE THEN REDUCED IN SIZE AND REPOSITIONED TO CONTAIN THE INFLECTION POINTS OF THE 10 MOST CRITICAL FAILURE PLANES.

5. STEPS 2 THROUGH 4, ABOVE, WERE REPEATED UNTIL A SINGLE, MINIMUM FACTOR OF SAFETY AGAINST FAILURE WAS OBTAINED FOR 2 CONSECUTIVE RUNS, OR THE FACTOR OF SAFETY BEGAN TO INCREASE.

6. AS A CHECK, THE WEDGE FAILURE PLANES WERE GENERATED USING BOTH THE RANKINE AND BLOCK FAILURE THEORIES.

7. THE FINAL FACTOR OF SAFETY AGAINST A WEDGE FAILURE WAS DERIVED BY USING SPENCER'S METHOD ON THE WEDGE FAILURE PLANES GENERATED IN STEPS 1 THROUGH 6.

III INTERIM LANDFILL CONDITIONS

A. LANDFILL GEOMETRY

THE INTERIM CONDITIONS EXAMINED ARE EXPECTED TO OCCUR PRIOR TO CAPPING, WHILE THE LANDFILL IS BEING FILLED. DURING FILLING OPERATIONS, IT IS ASSUMED THAT:

- THE MAXIMUM HEIGHT OF WASTE WILL BE ~~APPROXIMATELY~~ 60 ft;
- ANY OPEN FACE WILL HAVE A TEMPORARY MAXIMUM SLOPE OF 3H : 1V ; AND
- ADJACENT CELLS MAY BE EXCAVATED UP TO 10 FT. IN DEPTH.

SEE FIG. 1, ON THE FOLLOWING PAGE, FOR THE INTERIM MODEL GEOMETRY

GEOSYNTEC CONSULTANTS

Written by: Rob Cosce Date: 95/09/15 (YY/MM/DD) Reviewed by: SQ Date: 95/10/06 (YY/MM/DD)

Client: Fernco Project: OSDF Project/Proposal No.: GE 9500 Task No.: 9

INTERIM CONDITIONS
FOUNDATION STABILITY MODEL

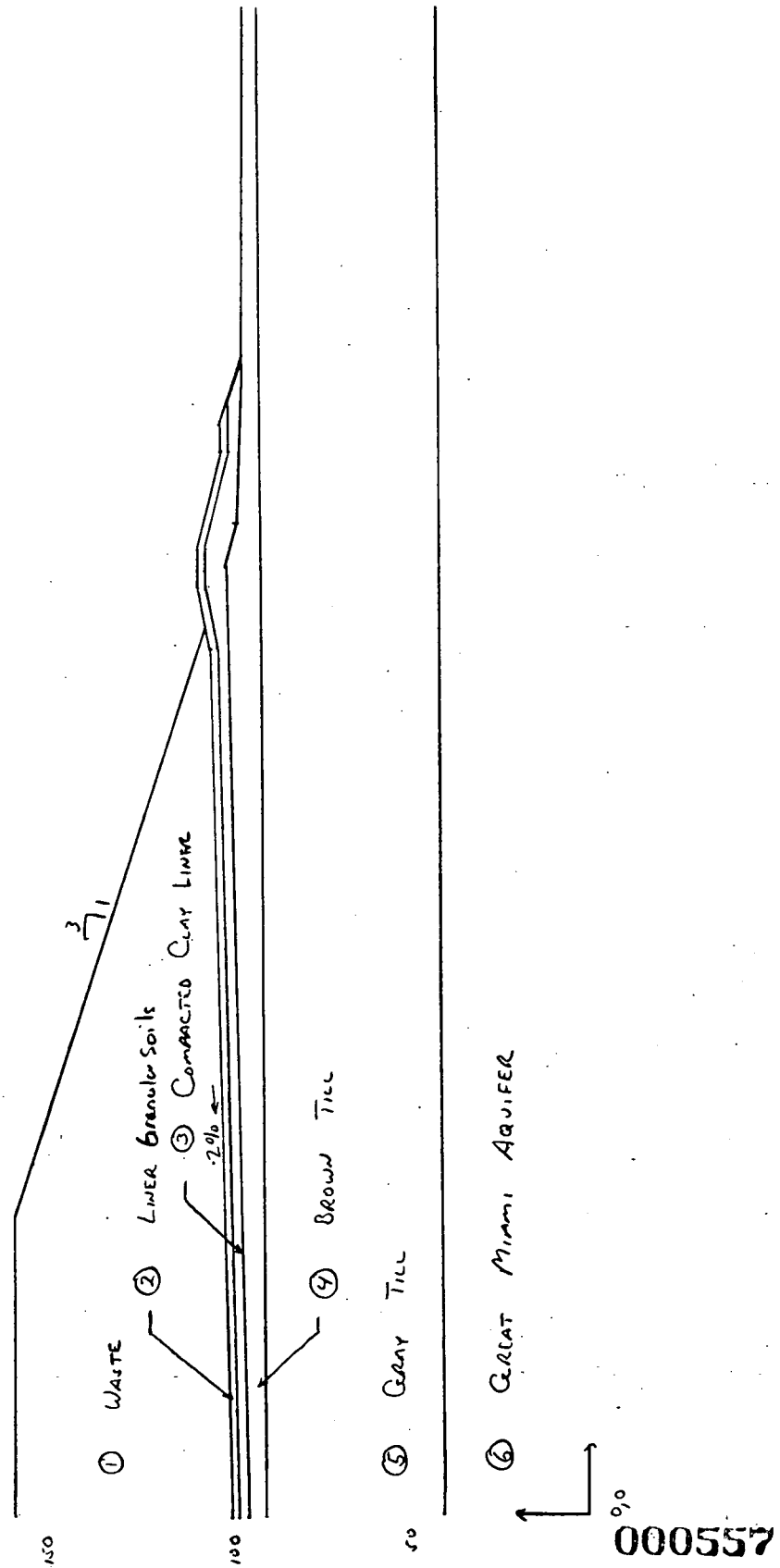

FIG. 1

Written by: R. COBLE Date: 95 / 09 / 15 (YY / MM / DD) Reviewed by: SG Date: 95 / 10 / 06 (YY / MM / DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.4

B. MATERIAL STRENGTH PARAMETERS

1. SHORT TERM STRENGTH

a) STABILITY ANALYSES WERE PERFORMED FOR CIRCULAR AND WEDGE FAILURES IN THE SUBGRADE MATERIALS. THE ANALYSES USED THE WEAKEST UNDRAINED STRENGTHS FOR BROWN AND GRAY TILLS.

b) MATERIAL PARAMETERS USED

MATERIAL	WEIGHT (γ_T) (PCF)	S_u (PSF)	ϕ (DEGREES)
① WASTE	125	200	25
② LINER (Granular Soils)	125	–	30
③ COMPACTED CLAY LINER	130	1200	–
④ BROWN TILL	135	1200	–
⑤ GRAY TILL	145	1900	–
⑥ GREAT MIAMI AQUIFER	135	–	35

2. LONG TERM STRENGTH

a) STABILITY ANALYSES WERE PERFORMED FOR CIRCULAR AND WEDGE FAILURES IN THE SUBGRADE MATERIALS USING THE DRAINED STRENGTHS FOR THE BROWN AND GRAY TILLS.

Written by: R. Cobb Date: 95 / 09 / 15 (YY / MM / DD) Reviewed by: SA Date: 95 / 10 / 06 (YY / MM / DD)

Client: Fernco Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.4

b) MATERIAL PARAMETERS USED

MATERIAL	WEIGHT (γ) (PCF)	ϕ' (DEGREES)	c' (PSF)
① WASTE	125	25	0
② LINER (Granular Soils)	125	30	0
③ COMPACTED CLAY	130	25	0
④ BROWN TILL	135	25	0
⑤ GRAY TILL	145	30	0
⑥ GREAT MIAMI AQUIFER	135	35	0

IV FINAL LANDFILL CONDITIONS

A. LANDFILL GEOMETRY

THE FINAL CONDITIONS EXAMINED WILL OCCUR AFTER THE LANDFILL HAS BEEN CLOSED AND CAPPED. SEE FIG. 2, ON THE FOLLOWING PAGE, FOR THE FINAL MODEL GEOMETRY.

GEOSYNTEC CONSULTANTS

Written by: R. COBLE Date: 95/10/05 (YY/MM/DD) Reviewed by: [illegible] Date: 95/10/06 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.4

FINAL CONFIGURATION

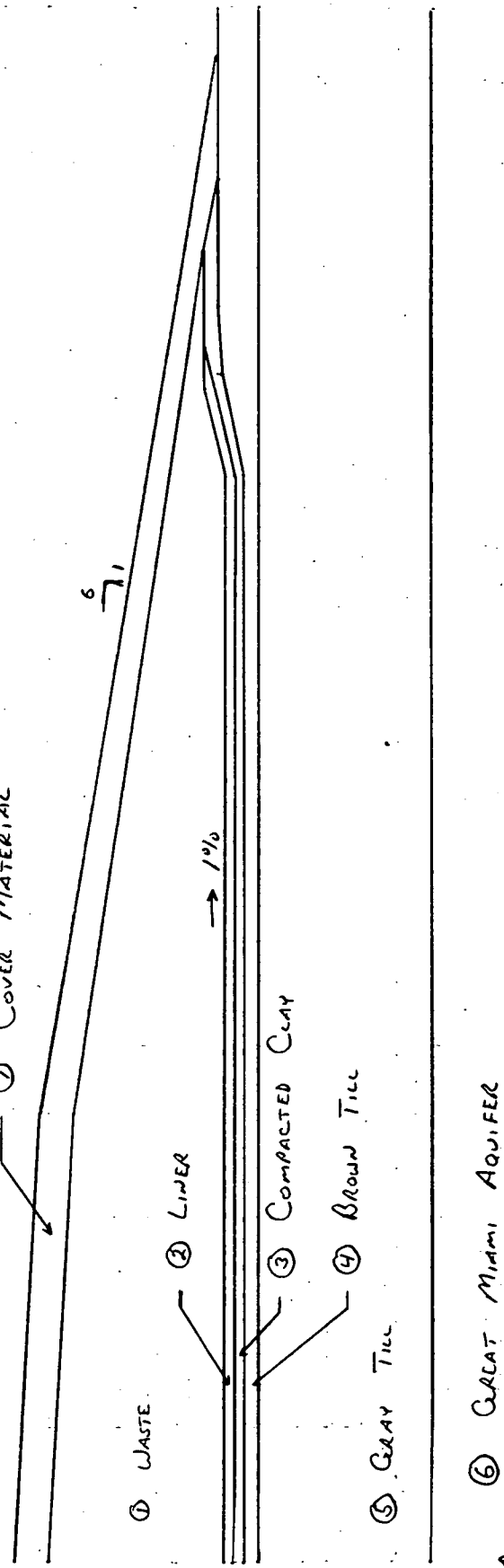

FIGURE 2

Written by: R. Coble Date: 95 / 09 / 16 (YY MM DD) Reviewed by: SE Date: 95 / 10 / 06 (YY MM DD)

Client: Fernco Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.4

B. MATERIAL STRENGTH PARAMETERS

1. STABILITY ANALYSES WERE PERFORMED FOR CIRCULAR AND WEDGE FAILURES IN THE SUBGRADE MATERIALS USING THE DRAINED STRENGTHS FOR THE BROWN AND GRAY TILLS.

2. MATERIAL PARAMETERS USED

	MATERIAL	WEIGHT (γ) (PCF)	ϕ' (DEGREES)	c' (PSF)
1	WASTE	125	25	0
2	LINER	125	30	0
3	COMPACTED CLAY	130	25	0
4	BROWN TILL	135	25	0
5	GRAY TILL	145	30	0
6	GREAT MIAMI AQUIFER	135	35	0
7	COVER MATERIAL	125	30	0

Written by: R. Coble Date: 95 / 10 / 05 (YY MM DD) Reviewed by: [illegible] Date: 95 / 10 / 06 (YY MM DD)

Client: Fernco Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.4

V. SUMMARY OF RESULTS

THE MINIMUM ACCEPTABLE FACTORS OF SAFETY AGAINST SLOPE FAILURE ARE: (UMTRA, 1989) (REF 9)

1.5 FOR LONG TERM CONDITIONS; AND
1.3 FOR INTERIM - END OF CONSTRUCTION CONDITIONS.

THE CRITICAL FACTORS OF SAFETY AGAINST SLOPE FAILURE OBTAINED FROM THE CALCULATIONS ARE:

- INTERIM CONDITIONS - SHORT TERM -

  1.5 AGAINST CIRCULAR FAILURE
  1.8 AGAINST WEDGE FAILURE. ✓

- INTERIM CONDITIONS - LONG TERM -

  1.8 AGAINST CIRCULARE FAILURE
  2.4 AGAINST WEDGE FAILURE ✓

- FINAL CONFIGURATION -

  3.0 AGAINST CIRCULAR FAILURE
  3.8 AGAINST WEDGE FAILURE. ✓

ALL FACTORS OF SAFETY MEET THE ESTABLISHED CRITERIA

Written by: M. GLEASON Date: 95/5/6 (YY MM DD) Reviewed by: SS Date: 95/10/06 (YY MM DD)

Client: FEEMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.4

FOUNDATION STABILITY REFERENCES

REFERENCES

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Written by: R Cooke Date: 95/10/05 (YY MM DD) Reviewed by: SA Date: 95/10/06 (YY MM DD)

Client: Franco Project: OSDF Project/Proposal No.: G2 3900 Task No.: 09.41

9. US DEPT. OF ENERGY, "URANIUM MINE TAILINGS REMEDIATION CONTROL ACT, REMEDIAL ACTION DESIGN", TECHNICAL APPROACH DOCUMENT, REVISION 2, DECEMBER, 1989,

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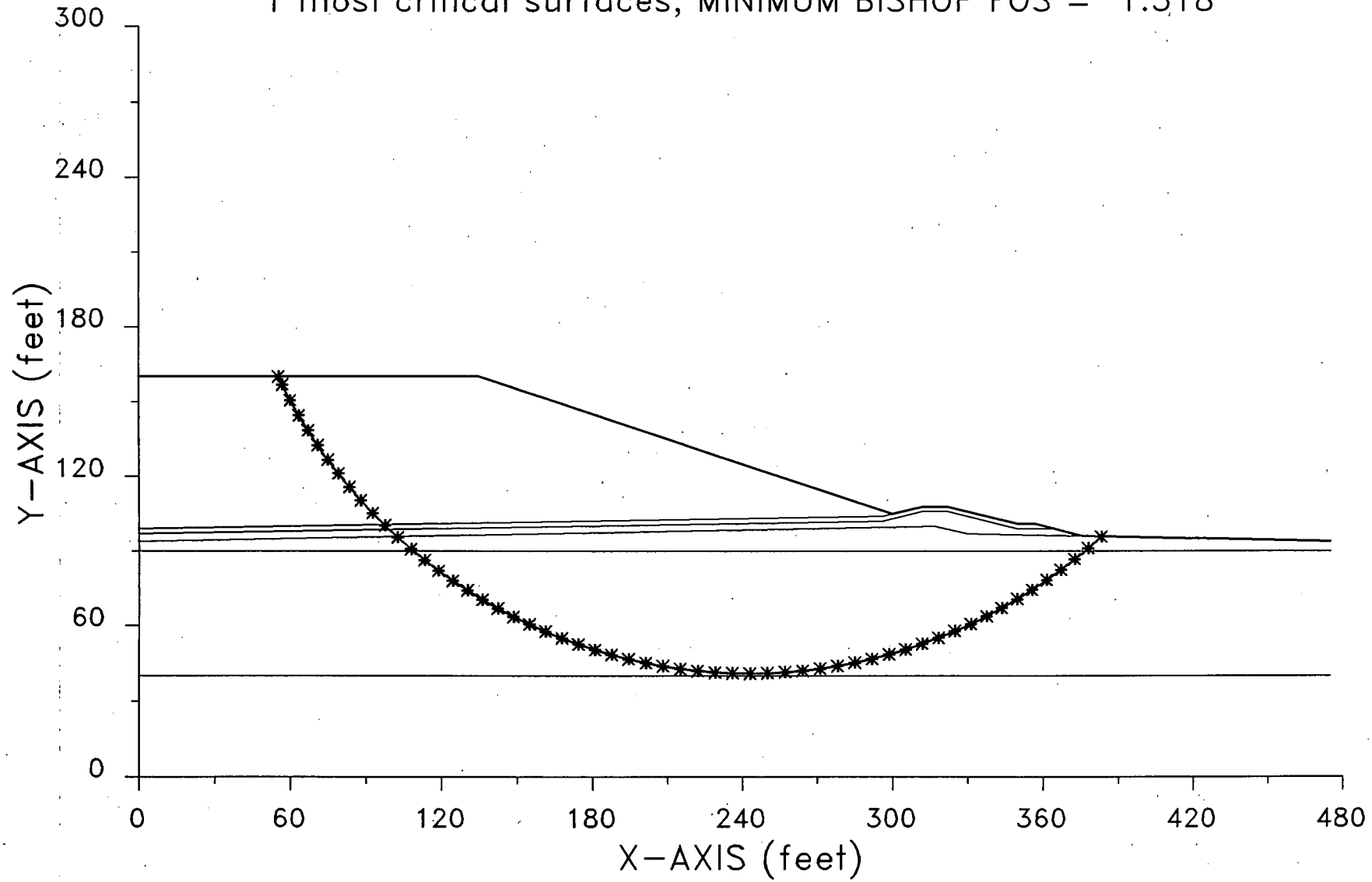
FERMCO/INTERMED. CONFIG./SHORT TERM

1 most critical surfaces, MINIMUM BISHOP FOS = 1.518



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Problem Description : FERMCO/INTERMED. CONFIG./SHORT TERM

SEGMENT BOUNDARY COORDINATES
---

8 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	160.0	135.0	160.0	1
2	135.0	160.0	300.0	105.0	1
3	300.0	105.0	312.0	108.0	2
4	312.0	108.0	322.0	108.0	2
5	322.0	108.0	350.0	101.0	2
6	350.0	101.0	357.0	101.0	2
7	357.0	101.0	376.0	96.0	2
8	376.0	96.0	475.0	94.0	4

14 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	99.0	296.0	104.0	2
2	296.0	104.0	300.0	105.0	2
3	.0	97.0	296.0	102.0	3
4	296.0	102.0	312.0	106.0	3
5	312.0	106.0	322.0	106.0	3
6	322.0	106.0	350.0	99.0	3
7	350.0	99.0	365.0	99.0	3
8	365.0	99.0	374.0	96.0	3
9	.0	94.0	317.0	100.0	4
10	317.0	100.0	330.0	97.0	4
11	330.0	97.0	374.0	96.0	4

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12	374.0	96.0	376.0	96.0	4
13	.0	90.0	475.0	90.0	5
14	.0	40.0	475.0	40.0	6

ISOTROPIC Soil Parameters
---

6 Soil unit(s) specified

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	125.0	125.0	200.0	25.00	.000	.0	0
2	125.0	125.0	.0	30.00	.000	.0	0
3	130.0	130.0	1200.0	.00	.000	.0	0
4	135.0	135.0	1200.0	.00	.000	.0	0
5	145.0	145.0	1900.0	.00	.000	.0	0
6	135.0	135.0	.0	35.00	.000	.0	0

A critical failure surface searching method, using a random technique for generating CIRCULAR surfaces has been specified.

100 trial surfaces will be generated and analyzed.

10 Surfaces initiate from each of 10 points equally spaced along the ground surface between x = 350.0 ft
and x = 400.0 ft

Each surface terminates between x = .0 ft
and x = 100.0 ft

Unless further limitations were imposed, the minimum elevation at which a surface extends is y = .0 ft

* * * * * DEFAULT SEGMENT LENGTH SELECTED BY XSTABL * * * * *

7.0 ft line segments define each trial failure surface.

ANGULAR RESTRICTIONS :

The first segment of each failure surface will be inclined within the angular range defined by :

Lower angular limit := -45.0 degrees
Upper angular limit := (slope angle - 5.0) degrees

Factors of safety have been calculated by the :

* * * * * SIMPLIFIED BISHOP METHOD * * * * *

The most critical circular failure surface is specified by 57 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	383.33	95.85
2	378.11	91.19
3	372.73	86.71
4	367.20	82.42
5	361.53	78.31
6	355.73	74.40
7	349.79	70.69
8	343.74	67.18
9	337.56	63.88
10	331.28	60.78
11	324.90	57.90
12	318.43	55.24
13	311.87	52.80
14	305.23	50.58
15	298.52	48.59
16	291.75	46.83
17	284.92	45.29
18	278.04	43.99
19	271.12	42.92
20	264.17	42.08
21	257.20	41.48
22	250.21	41.12
23	243.21	40.99
24	236.21	41.10
25	229.22	41.45
26	222.24	42.03
27	215.29	42.84
28	208.37	43.90
29	201.49	45.18
30	194.65	46.70
31	187.88	48.44
32	181.16	50.42
33	174.51	52.62
34	167.95	55.04
35	161.47	57.69
36	155.08	60.55
37	148.79	63.63
38	142.61	66.92
39	136.55	70.41
40	130.60	74.11
41	124.79	78.00
42	119.11	82.09
43	113.57	86.37
44	108.18	90.84
45	102.94	95.48

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46	97.86	100.30
47	92.95	105.29
48	88.21	110.44
49	83.65	115.75
50	79.26	121.21
51	75.07	126.81
52	71.07	132.56
53	67.26	138.43
54	63.66	144.43
55	60.26	150.55
56	57.06	156.78
57	55.55	160.00

**** Simplified BISHOP FOS = 1.518 ****

The following is a summary of the TEN most critical surfaces

Problem Description : FERMCO/INTERMED. CONFIG./SHORT TERM

	FOS (BISHOP)	Circle Center x-coord (ft)	Circle Center y-coord (ft)	Radius (ft)	Initial x-coord (ft)	Terminal x-coord (ft)	Resisting Moment (ft-lb)
1.	1.518	242.94	248.07	207.08	383.33	55.55	1.434E+08
2.	1.541	224.09	283.16	242.21	377.78	15.56	1.822E+08
3.	1.543	232.36	232.78	189.96	366.67	56.92	1.253E+08
4.	1.549	227.78	304.48	263.68	388.89	7.21	2.072E+08
5.	1.552	228.41	227.76	184.27	361.11	57.09	1.193E+08
6.	1.561	211.47	241.83	201.48	355.56	27.37	1.398E+08
7.	1.566	215.81	242.13	198.61	355.56	35.01	1.339E+08
8.	1.567	216.89	287.98	246.18	372.22	6.60	1.862E+08
9.	1.570	255.76	227.72	183.48	383.33	85.27	1.168E+08
10.	1.574	223.45	268.24	222.12	366.67	29.50	1.554E+08

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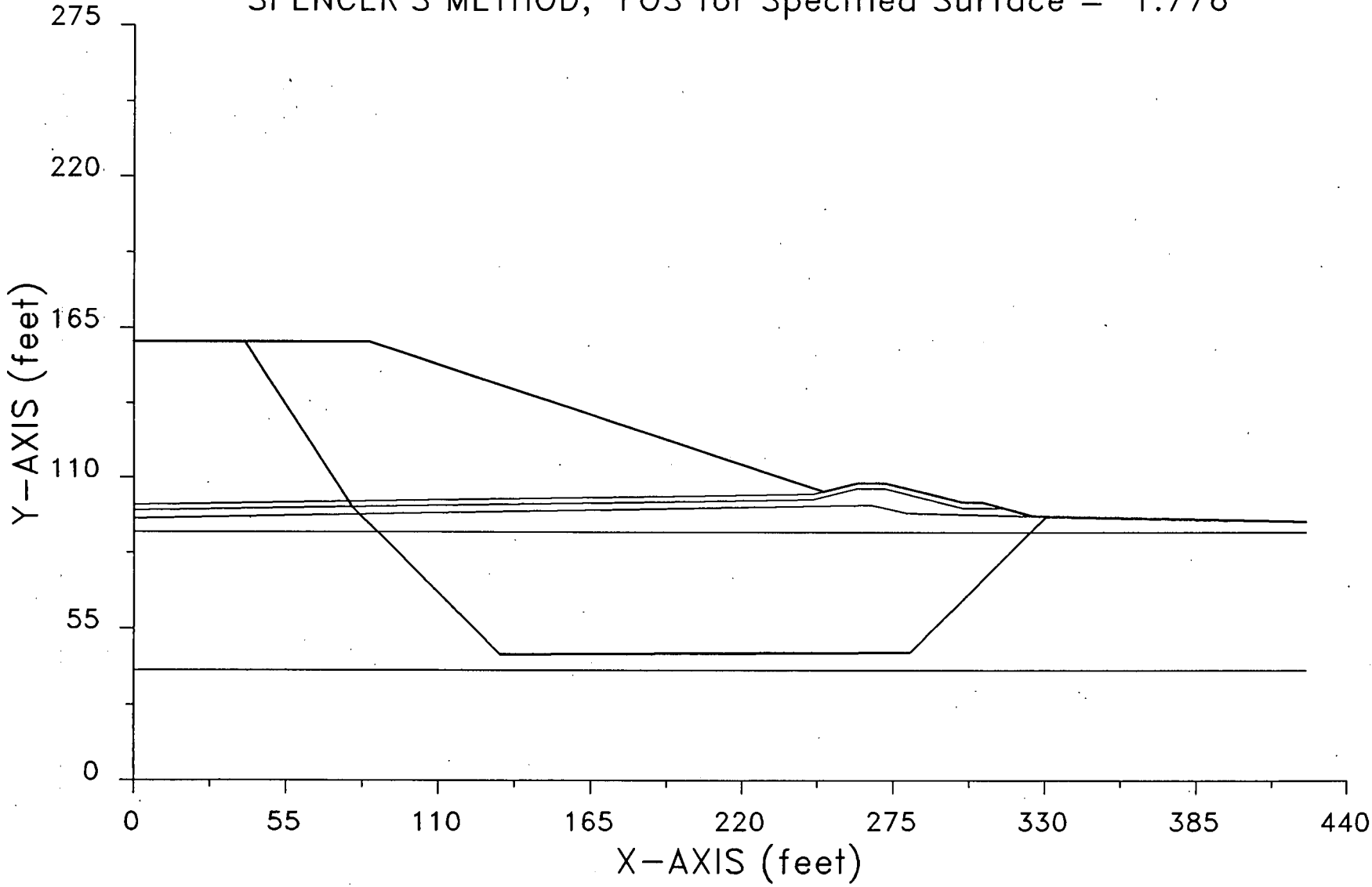
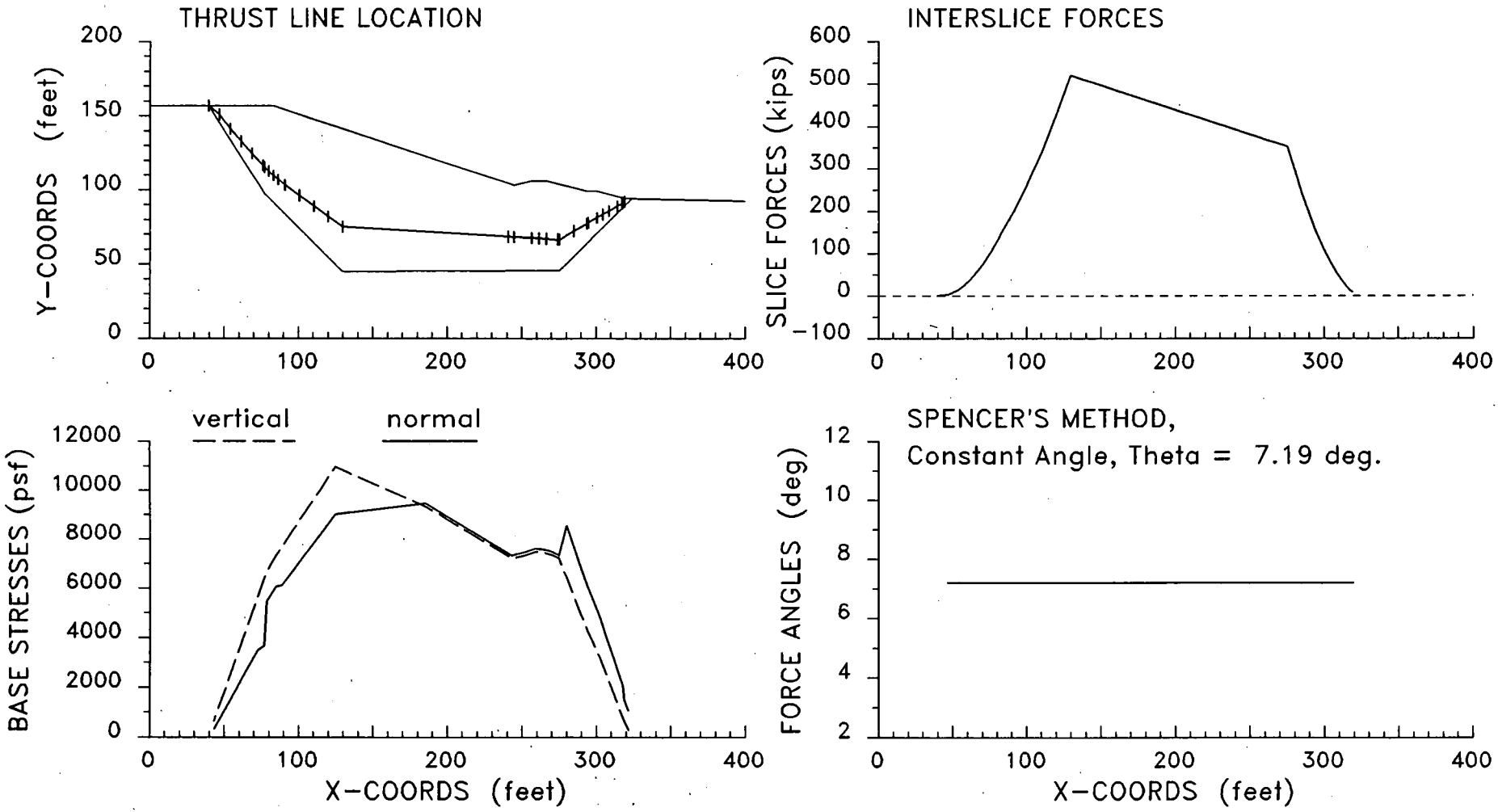
FERMCO/INTERMED. CONFIG./SHORT TERM
SPENCER'S METHOD, FOS for Specified Surface = 1.776





FERMCO/INTERMED. CONFIG./SHORT TERM
SPENCER'S METHOD, FOS for Specified Surface = 1.776

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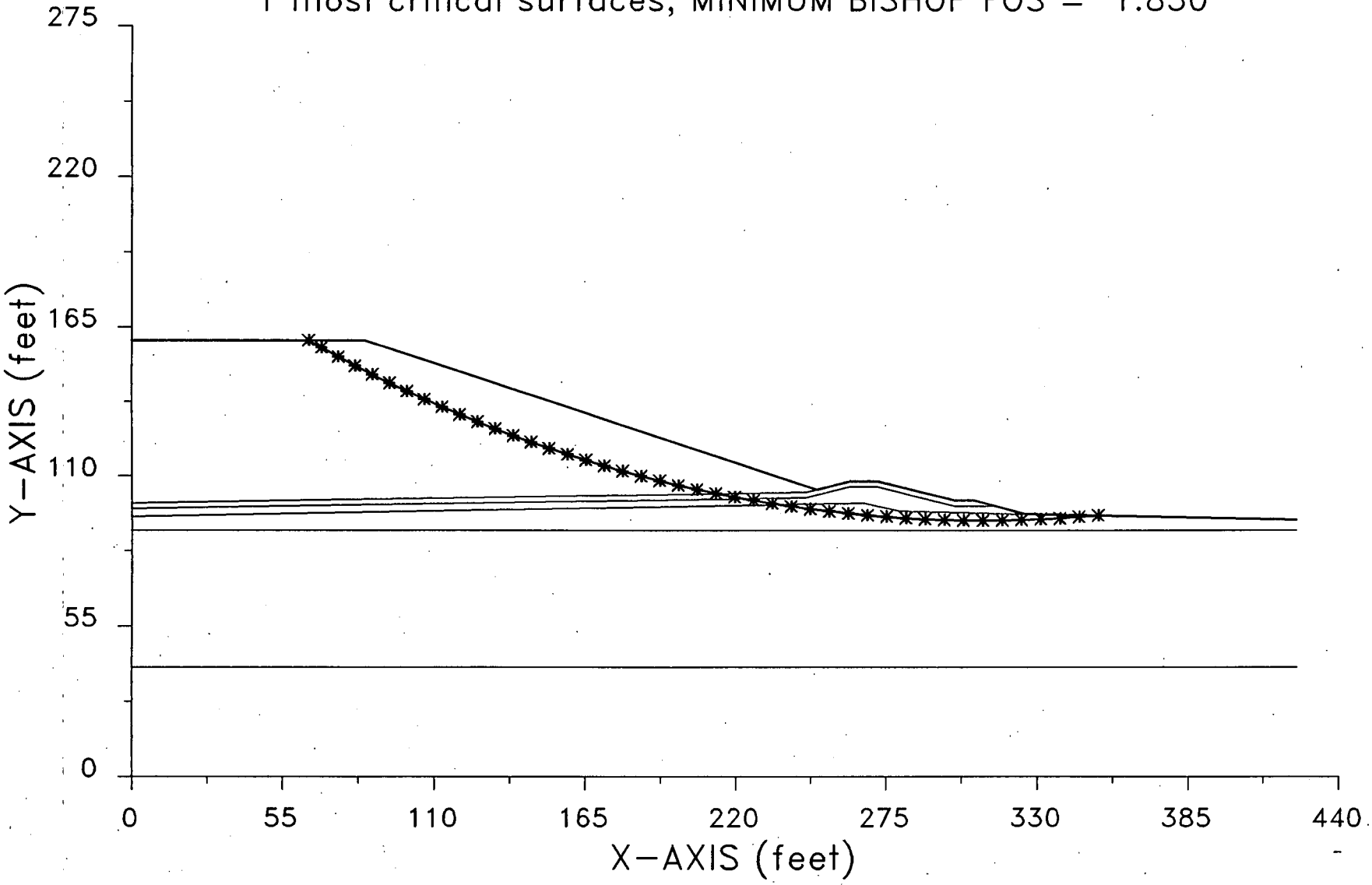
FERMCO/INTERMED. CONFIG./LONG TERM

1 most critical surfaces, MINIMUM BISHOP FOS = 1.830



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Problem Description : FERMCO/INTERMED. CONFIG./LONG TERM

SEGMENT BOUNDARY COORDINATES
---

8 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	160.0	85.0	160.0	1
2	85.0	160.0	250.0	105.0	1
3	250.0	105.0	262.0	108.0	2
4	262.0	108.0	272.0	108.0	2
5	272.0	108.0	300.0	101.0	2
6	300.0	101.0	307.0	101.0	2
7	307.0	101.0	326.0	96.0	2
8	326.0	96.0	425.0	94.0	4

14 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	100.0	246.0	104.0	2
2	246.0	104.0	250.0	105.0	2
3	.0	98.0	246.0	102.0	3
4	246.0	102.0	262.0	106.0	3
5	262.0	106.0	272.0	106.0	3
6	272.0	106.0	300.0	99.0	3
7	300.0	99.0	315.0	99.0	3
8	315.0	99.0	324.0	96.0	3
9	.0	95.0	267.0	100.0	4
10	267.0	100.0	280.0	97.0	4
11	280.0	97.0	324.0	96.0	4

12	324.0	96.0	326.0	96.0	4
13	.0	90.0	425.0	90.0	5
14	.0	40.0	425.0	40.0	6

ISOTROPIC Soil Parameters
---

6 Soil unit(s) specified

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	125.0	125.0	.0	25.00	.000	.0	0
2	125.0	125.0	.0	30.00	.000	.0	0
3	130.0	130.0	.0	25.00	.000	.0	0
4	135.0	135.0	.0	25.00	.000	.0	0
5	145.0	145.0	.0	30.00	.000	.0	0
6	135.0	135.0	.0	35.00	.000	.0	0

A critical failure surface searching method, using a random technique for generating CIRCULAR surfaces has been specified.

120 trial surfaces will be generated and analyzed.

10 Surfaces initiate from each of 12 points equally spaced along the ground surface between x = 325.0 ft
and x = 385.0 ft

Each surface terminates between x = .0 ft
and x = 250.0 ft

Unless further limitations were imposed, the minimum elevation at which a surface extends is y = .0 ft

* * * * * DEFAULT SEGMENT LENGTH SELECTED BY XSTABL * * * * *

7.0 ft line segments define each trial failure surface.

ANGULAR RESTRICTIONS :

The first segment of each failure surface will be inclined within the angular range defined by :

Lower angular limit := -45.0 degrees
Upper angular limit := (slope angle - 5.0) degrees

Factors of safety have been calculated by the :

* * * * * SIMPLIFIED BISHOP METHOD * * * * *

The most critical circular failure surface is specified by 44 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	352.27	95.47
2	345.29	94.93
3	338.31	94.49
4	331.32	94.16
5	324.32	93.92
6	317.32	93.78
7	310.32	93.74
8	303.32	93.80
9	296.32	93.96
10	289.33	94.22
11	282.34	94.58
12	275.35	95.04
13	268.37	95.60
14	261.41	96.26
15	254.45	97.01
16	247.50	97.87
17	240.56	98.82
18	233.64	99.88
19	226.74	101.03
20	219.85	102.28
21	212.98	103.63
22	206.13	105.07
23	199.31	106.62
24	192.50	108.26
25	185.72	110.00
26	178.97	111.83
27	172.24	113.76
28	165.54	115.79
29	158.87	117.91
30	152.22	120.12
31	145.62	122.43
32	139.04	124.84
33	132.50	127.33
34	126.00	129.92
35	119.53	132.61
36	113.11	135.38
37	106.72	138.25
38	100.38	141.20
39	94.07	144.25
40	87.82	147.39
41	81.60	150.61
42	75.44	153.92
43	69.32	157.32
44	64.66	160.00

**** Simplified BISHOP FOS = 1.830 ****

The following is a summary of the TEN most critical surfaces

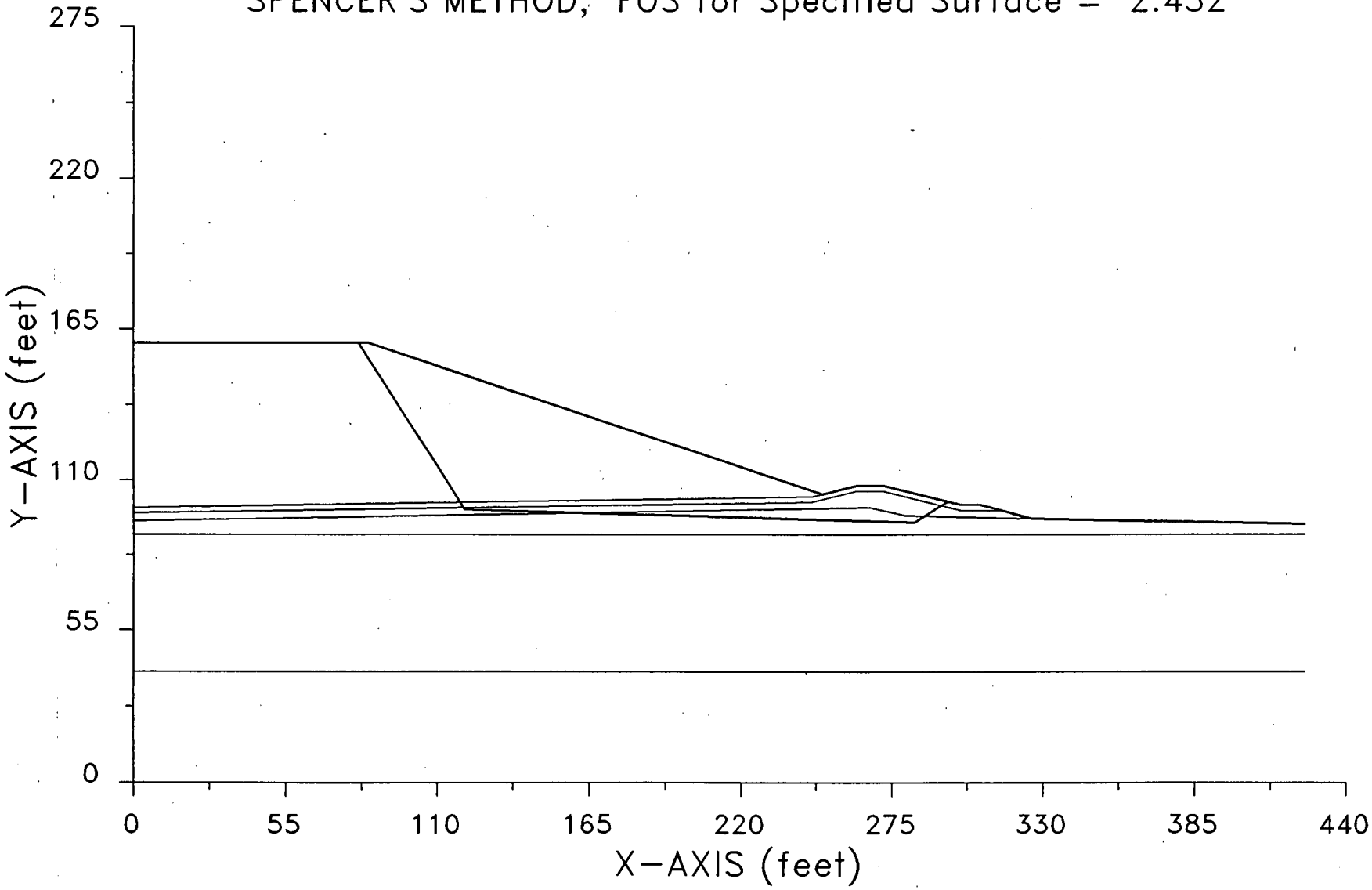
Problem Description : FERMCO/INTERMED. CONFIG./LONG TERM

	FOS (BISHOP)	Circle x-coord (ft)	Center y-coord (ft)	Radius (ft)	Initial x-coord (ft)	Terminal x-coord (ft)	Resisting Moment (ft-lb)
1.	1.830	311.07	585.11	491.37	352.27	64.66	9.210E+07
2.	1.895	297.67	654.48	558.88	325.00	37.22	1.392E+08
3.	1.976	288.50	571.61	481.26	357.73	39.15	1.579E+08
4.	2.070	292.03	383.21	289.86	330.45	124.10	3.399E+07
5.	2.125	473.12	1697.20	1607.78	325.00	2.00	3.100E+08
6.	2.142	248.99	380.87	294.58	325.00	54.10	1.228E+08
7.	2.153	302.82	613.20	524.87	385.00	38.09	1.914E+08
8.	2.195	258.19	445.34	359.41	341.36	39.70	1.648E+08
9.	2.202	288.58	491.76	405.85	374.09	54.83	1.549E+08
10.	2.352	287.85	438.42	355.53	379.55	66.79	1.449E+08

* * * END OF FILE * * *

RS 10-05-95 12:17

FERMCO/INTERMED. CONFIG./LONG TERM
SPENCER'S METHOD, FOS for Specified Surface = 2.432



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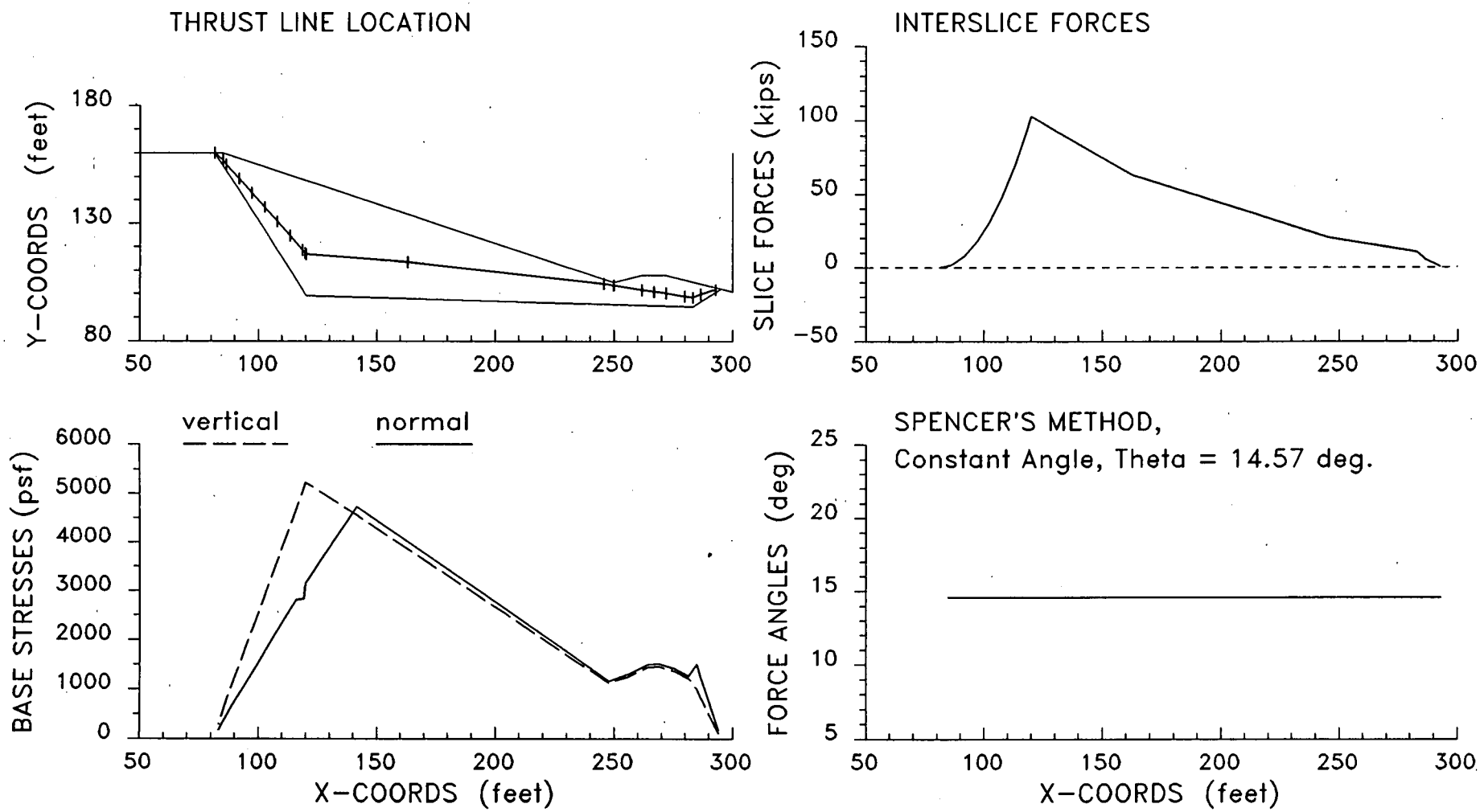
95/10/06 34/42

10/5/95

000577



FERMCO/INTERMED. CONFIG./LONG TERM
SPENCER'S METHOD, FOS for Specified Surface = 2.432

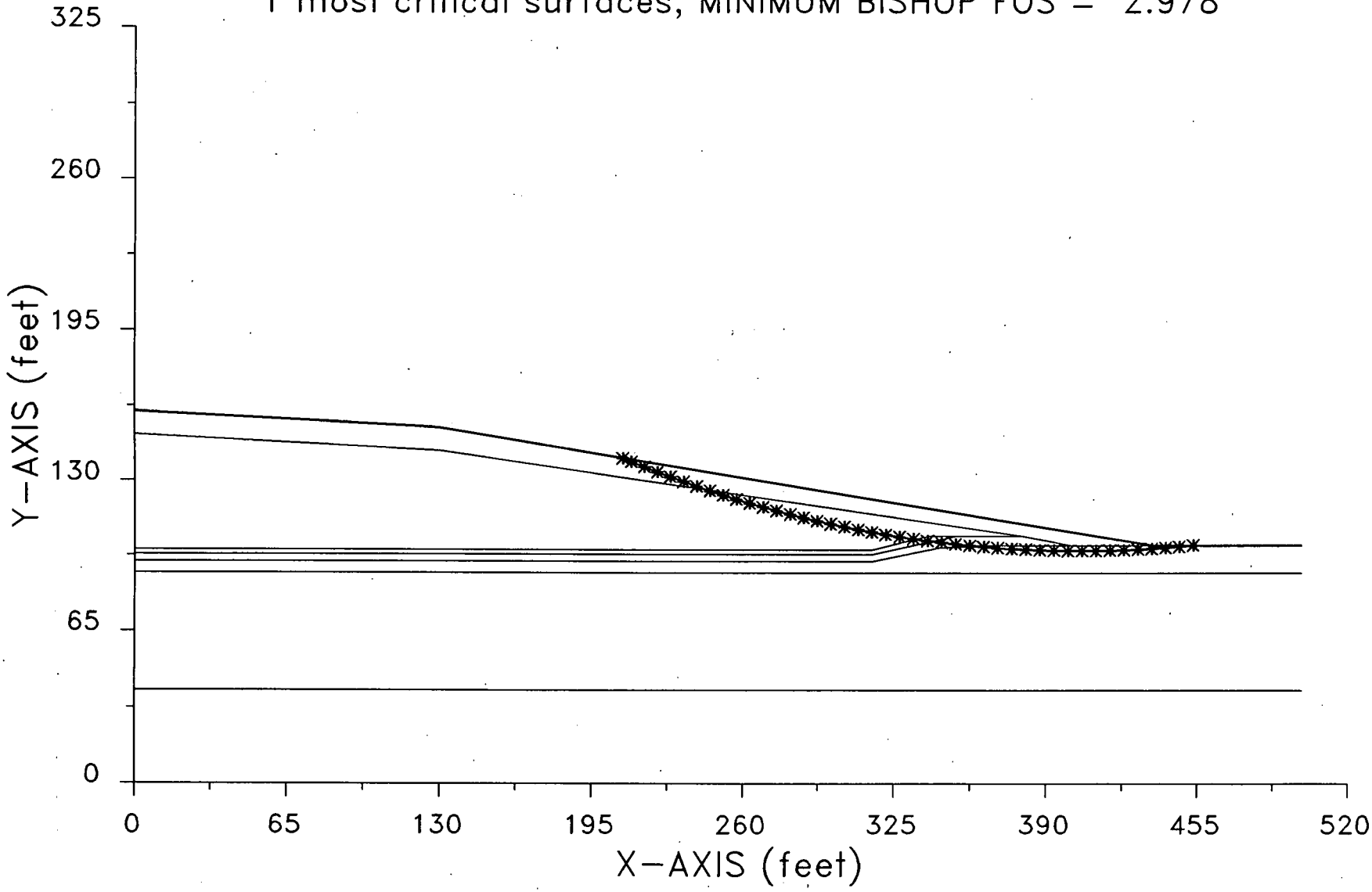
000578

186 35/42

10-05-95 13:08

FREMCO/ FINAL CONFIG./ DRAINED

1 most critical surfaces, MINIMUM BISHOP FOS = 2.978



000579

186 36/42

AM 10/5/95 SQ 95/10/00

186 37/42

XSTABL File: FC 10-05-95 13:08

```
*****************************************
*              X S T A B L              *
*                                       *
*        Slope Stability Analysis       *
*               using the               *
*            Method of Slices           *
*                                       *
*         Copyright (C) 1992 á 94       *
*   Interactive Software Designs, Inc.  *
*        Moscow, ID 83843, U.S.A.       *
*                                       *
*          All Rights Reserved          *
*                                       *
*  Ver. 5.100                95 á 1305  *
*****************************************
```

Problem Description : FREMCO/ FINAL CONFIG./ DRAINED

SEGMENT BOUNDARY COORDINATES
---

3 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	160.0	130.0	153.0	7
2	130.0	153.0	436.0	102.0	7
3	436.0	102.0	500.0	102.0	4

17 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	150.0	130.0	143.0	1
2	130.0	143.0	380.0	106.0	1
3	.0	100.0	316.0	100.0	2
4	316.0	100.0	340.0	106.0	2
5	340.0	106.0	352.0	106.0	2
6	.0	98.0	316.0	98.0	3
7	316.0	98.0	352.0	106.0	3
8	352.0	106.0	380.0	106.0	3
9	380.0	106.0	401.0	102.0	3
10	.0	95.0	316.0	95.0	4
11	316.0	95.0	345.0	101.0	4
12	345.0	101.0	364.0	102.0	4
13	364.0	102.0	401.0	102.0	4
14	401.0	102.0	436.0	102.0	4
15	436.0	102.0	500.0	102.0	4
16	.0	90.0	500.0	90.0	5

17	.0	40.0	500.0	40.0	6

ISOTROPIC Soil Parameters
---

7 Soil unit(s) specified

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	125.0	125.0	.0	25.00	.000	.0	0
2	125.0	125.0	.0	30.00	.000	.0	0
3	130.0	130.0	.0	25.00	.000	.0	0
4	135.0	135.0	.0	25.00	.000	.0	0
5	145.0	145.0	.0	30.00	.000	.0	0
6	135.0	135.0	.0	35.00	.000	.0	0
7	125.0	125.0	.0	30.00	.000	.0	0

A critical failure surface searching method, using a random technique for generating CIRCULAR surfaces has been specified.

100 trial surfaces will be generated and analyzed.

10 Surfaces initiate from each of 10 points equally spaced along the ground surface between x = 440.0 ft
and x = 500.0 ft

Each surface terminates between x = 10.0 ft
and x = 350.0 ft

Unless further limitations were imposed, the minimum elevation at which a surface extends is y = .0 ft

* * * * * DEFAULT SEGMENT LENGTH SELECTED BY XSTABL * * * * *

6.0 ft line segments define each trial failure surface.

ANGULAR RESTRICTIONS :

The first segment of each failure surface will be inclined within the angular range defined by :

Lower angular limit := -20.0 degrees
Upper angular limit := (slope angle - 5.0) degrees

Factors of safety have been calculated by the :

* * * * * SIMPLIFIED BISHOP METHOD * * * * *

The most critical circular failure surface is specified by 43 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	453.33	102.00
2	447.36	101.46
3	441.38	100.98
4	435.39	100.58
5	429.40	100.25
6	423.40	100.00
7	417.41	99.81
8	411.41	99.70
9	405.41	99.66
10	399.41	99.69
11	393.41	99.80
12	387.41	99.98
13	381.42	100.22
14	375.43	100.54
15	369.44	100.94
16	363.46	101.40
17	357.48	101.94
18	351.51	102.55
19	345.55	103.23
20	339.60	103.98
21	333.65	104.80
22	327.72	105.70
23	321.80	106.66
24	315.89	107.70
25	309.99	108.81
26	304.11	109.99
27	298.24	111.24
28	292.39	112.56
29	286.55	113.95
30	280.73	115.41
31	274.93	116.94
32	269.15	118.54
33	263.39	120.21
34	257.64	121.95
35	251.92	123.75
36	246.22	125.63
37	240.55	127.57
38	234.89	129.59
39	229.27	131.67
40	223.66	133.81
41	218.09	136.03
42	212.54	138.31
43	208.93	139.84

**** Simplified BISHOP FOS = 2.978 ****

The following is a summary of the TEN most critical surfaces

Problem Description : FREMCO/ FINAL CONFIG./ DRAINED

	FOS (BISHOP)	Circle Center x-coord (ft)	Circle Center y-coord (ft)	Radius (ft)	Initial x-coord (ft)	Terminal x-coord (ft)	Resisting Moment (ft-lb)
1.	2.978	405.09	598.62	498.96	453.33	208.93	6.711E+07
2.	2.996	385.00	796.40	699.18	466.67	108.62	2.208E+08
3.	3.033	410.47	269.29	169.88	440.00	330.07	6.819E+06
4.	3.054	394.37	749.25	653.79	486.67	125.67	1.990E+08
5.	3.062	358.09	690.34	594.97	446.67	99.21	2.315E+08
6.	3.083	410.35	497.68	399.67	466.67	244.99	4.613E+07
7.	3.089	353.35	659.51	566.41	453.33	96.27	2.463E+08
8.	3.090	402.66	899.65	803.56	500.00	101.81	2.696E+08
9.	3.093	342.39	604.72	512.11	440.00	97.95	2.280E+08
10.	3.100	392.80	332.07	236.29	446.67	271.26	2.755E+07

* * * END OF FILE * * *

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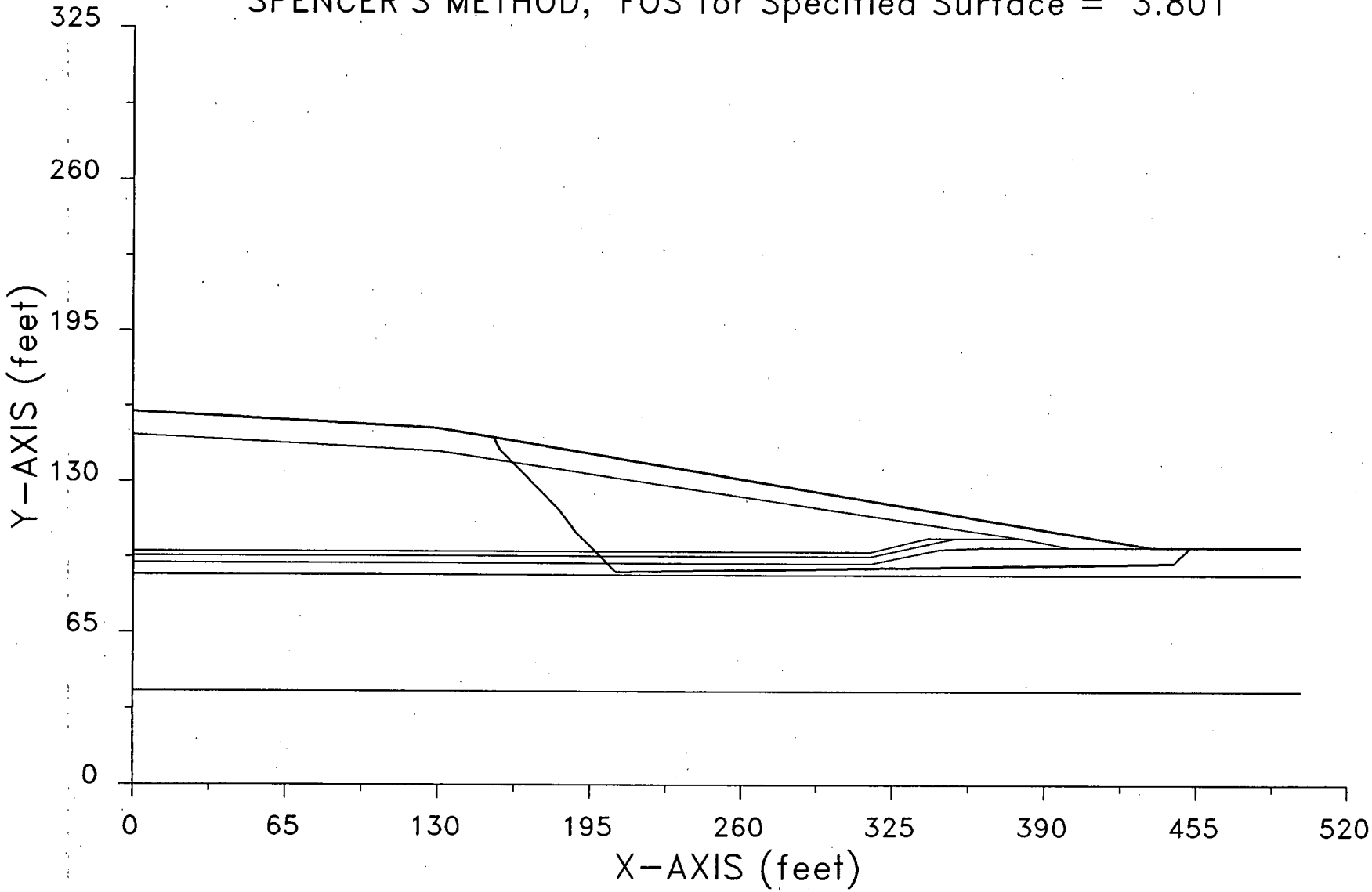
FREMCO/ FINAL CONFIG./ DRAINED

SPENCER'S METHOD, FOS for Specified Surface = 3.801



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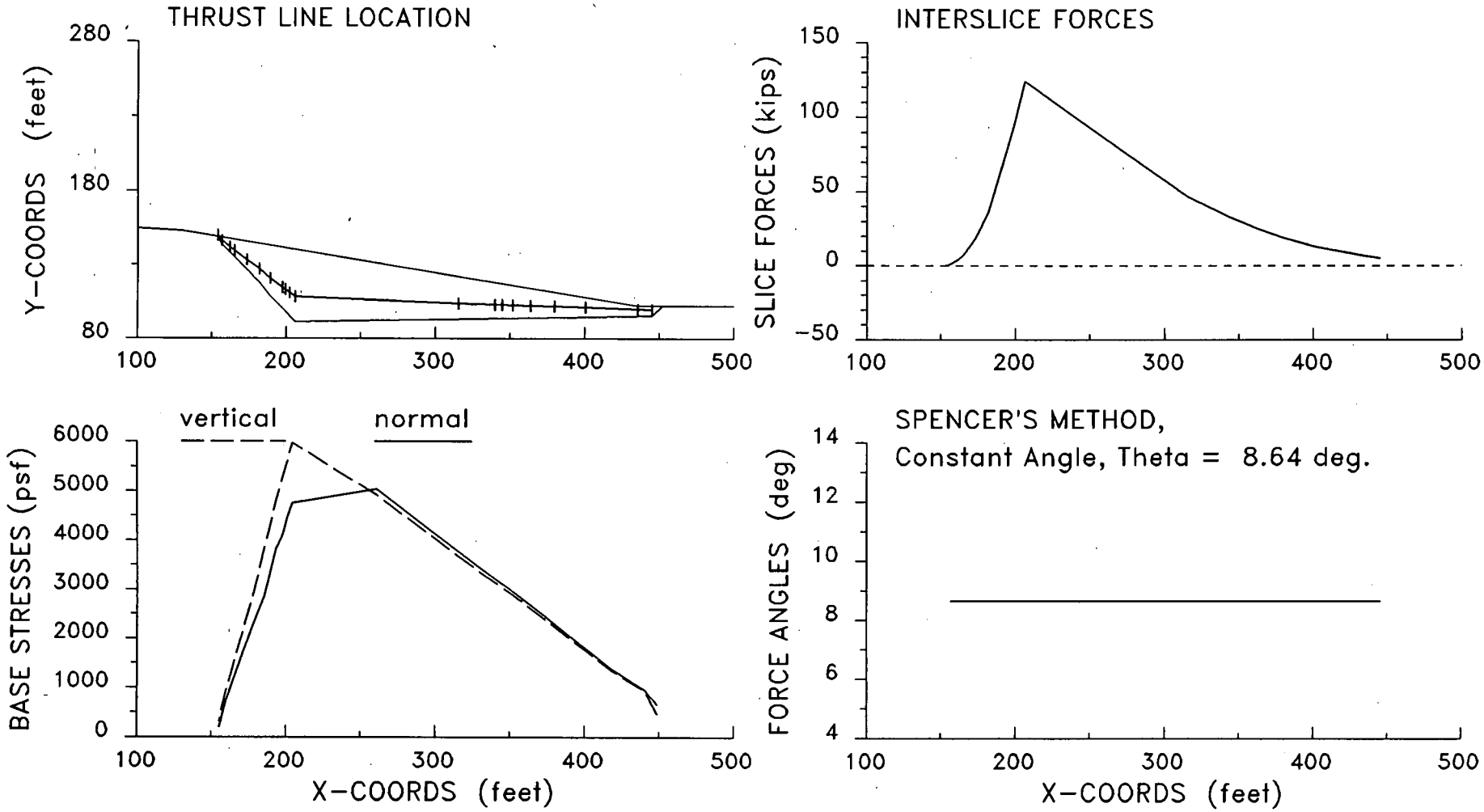

FREMCO/ FINAL CONFIG./ DRAINED
SPENCER'S METHOD, FOS for Specified Surface = 3.801

000585

1 of 1
10/5/95
SK 95/10/06
1100
42/42

APPENDIX A

COMPUTER SOFTWARE USED TO PREPARE CALCULATION PACKAGE

XSTABL - Version 5

Sharma, S., "*XSTABL: An Integrated Slope Stability Analysis Program for Personal Computers, Version 5*," Interactive Software Designs, Moscow, ID, 1994.

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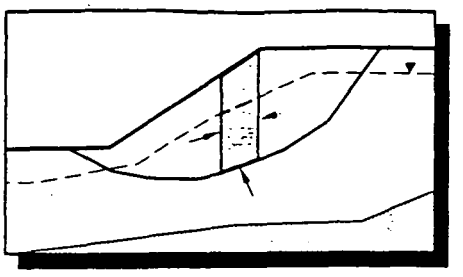

XSTABL©

An Integrated Slope Stability Analysis Program for Personal Computers

Reference Manual

Version 5

prepared by

Sunil Sharma

for

Interactive Software Designs, Inc
953 N. Cleveland Street
Moscow, ID 83843, U.S.A.

XSTABL

VERSION 5.00

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The user is also specifically advised, and cautioned, to exercise careful engineering judgement in the correct interpretation of the final results.

License No.
1202a

XSTABL
License Agreement

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READ BEFORE USING

WARNING: Carefully read this license agreement before using the **XSTABL** program. Use of the program indicates your acceptance of the terms of this license.

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Without the written consent of *INTERACTIVE SOFTWARE DESIGNS, Inc.*, YOU MAY NOT :

1. Make copies of **XSTABL** with the intent to supply other users,
2. Transmit **XSTABL** via any electronic media,
3. Duplicate the **XSTABL** Reference Manual,
4. Attempt to disassemble the **XSTABL** machine-code for any purpose whatsoever.

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CHAPTER 1

1.0 INTRODUCTION

XSTABL is a fully integrated slope stability analysis program designed to operate on an IBM personal computer, or close compatible. It permits the engineer to develop the slope geometry interactively and perform the slope analysis from within a single program. The slope analysis portion of **XSTABL** uses a modified version of the popular STABL program, originally developed at Purdue University.

XSTABL performs a two dimensional limit equilibrium analysis to compute the factor of safety for a layered slope according to:

(a) General Limit Equilibrium (GLE) Method,

(b) Janbu's Generalized Procedure of Slices (GPS),

(c) Simplified Bishop,

(d) Simplified Janbu.

If the program is used to search for the most critical surface, only the simplified Bishop and Janbu methods are available for calculating the factor of safety. The program can be used to search for the most critical surface or the factor of safety may be determined for specific surfaces. **XSTABL**, version 5.0, is programmed to handle:

1. heterogenous soil systems with up to 20 soil units,
2. The strength of a soil unit may be defined using:
   (a) conventional, c-ϕ parameters,
   (b) undrained strengths as a function of vertical effective stress,
   (c) a nonlinear Mohr-Coulomb envelop.
3. Anisotropic soil strength properties,

4. Reinforced slopes,
5. Pore water pressures for effective stress analysis using:
   (a) phreatic and piezometric surfaces
   (b) pore pressure grid
   (c) R_u factor
   (d) constant pore water pressure
6. Pseudo-static earthquake loading,
7. Surcharge boundary loads,
8. Automatic generation and analysis of an unlimited number of circular, noncircular and block-shaped failure surfaces,
9. Analysis of right-facing slopes,
10. Both SI and Imperial units.

1.1 Summary of Interactive Features of XSTABL

XSTABL is intended for use on an IBM-PC, or near compatible, suitably equipped for screen graphics. The program uses menus and data-tables to "guide" the potential user through the many options available for performing a slope stability analysis. The interactive features of **XSTABL** include:

1. Selection of options via intuitive, easy to understand menus,
2. Context sensitive help information,
3. All numeric data is entered through prompts into a table,
4. Error checking during data entry phase,
5. Slope geometry may be readily reviewed on-screen,
6. Previously entered data can be edited,
7. Single failure surfaces may be analyzed using several rigorous procedures that satisfy force and moment equilibrium,
8. Previously saved files can be edited and saved as "new" files,

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9. **XSTABL** files may be copied, deleted, printed, renamed or viewed *without* exiting the program.

10. Screen plots may be saved to disk in one of several different formats for later printing or inclusion within a document prepared with a wordprocessing or charting software.

11. High quality plots may be generated, using **XSTABL**, on several different types of output devices if the screen plots are saved in the default format.

It is expected that the approach offered by **XSTABL** will minimize potential errors and provide a more appropriate data preparation method for the less familiar user. The time expended in learning to use the program is expected to be nominal and users can be expected to generate input data files almost immediately.

1.2 General Information

The **XSTABL** Reference Manual is intended to provide information about the interactive features that allow the user to prepare data files and perform a slope stability analysis. The next six chapters of the Reference Manual provides details concerning the following topics:

1. **XSTABL** program components,
2. **XSTABL** menus and available options,
3. Data tables for establishing the slope geometry, and assigning soil properties and boundary loads,
4. Methods of analysis,
5. Slope stability analysis, including the creation and saving of screen plots,
6. Printing of hardcopy plots.

Further details about the limit equilibrium theory, search procedures and slice development are given in Appendix D.

This manual concentrates on the interactive features and is not intended to provide the necessary engineering background for slope stability analysis. If the user wishes to obtain more information concerning slope stability analysis, the following publications are recommended:

1. *The Stability of Slopes*, by E.N. Bromhead, Surrey University Press, Chapman and Hall, NY, 411 pages, ISBN 0 412 01061 5, 1992.

2. *Landslides: Analysis and Control*, by R.L. Schuster and R.J. Krizek (editors), Special Report 176, Transportation Research Board, National Academy of Sciences, 234 pages, ISBN 0 309 02804 3, 1978. (new edition, edited by R.L. Schuster and K. Turner will be published in 1994)

3. *Rock Slope Engineering*, by E. Hoek and J.W. Bray, Inst. of Mining and Metallurgy, London, England, Third Edition, 358 pages, ISBN 0 900488 573, 1981.

Please note that the above list represents ***a very small*** portion of literature available on the subject of slope stability analysis.

1.3 Hardware Requirements

In order to use **XSTABL**, the user will require:

1. An IBM-PC, or near compatible, with either dual floppy disk drives or a hard disk (preferred) and one floppy disk drive, 640 kb RAM and DOS 2.1 (or later).

   Execution of XSTABL will require at least 450,000 bytes of free RAM. The user may check the amount of RAM available by using the "MEM/C" command, as documented in the DOS manual.

2. An IBM compatible VGA, EGA or CGA graphics adaptor with an appropriate monitor,

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3. One of the following devices for hardcopy output:

   (a) A laser printer, e.g. Hewlett Packard LaserJet with at least 1 Mb of RAM, or

   (b) An IBM Graphics compatible, 9 or 24 pin, dot matrix printer, e.g. EPSON FX-85,

   (c) A HPGL compatible pen plotter, e.g. Hewlett Packard 7475A Plotter.

1.4 XSTABL INSTALLATION

The **XSTABL** programs and example data files are supplied on one 3.5 inch or one 5.25 inch disk in a compressed format. To copy these files to a subdirectory on your hard disk, please follow the instruction listed below:

1. create a directory on your hard disk (e.g. MD XSTABL etc....)
2. change to this newly created directory (e.g. CD XSTABL etc....)
3. from this directory type either :

   (a) A:INSTALL --> if the **XSTABL** disk is in "A" drive, or

   (b) B:INSTALL --> if the **XSTABL** disk is in "B" drive

The installation program will place the XSTABL files in the current directory and copy all example datafiles into a subdirectory named: "EXAMPLES". The complete installation of these files will required about 500 kb of disk space. The PACK.LST file on the original disk includes a list, and description, of **all** files that should have been copied to the current directory on your disk.

NOTE:
The above procedure will work if you are preparing to use **XSTABL** from a hard-disk or at least a 720 kb floppy diskette. However if you would like to use the program on dual 360 kb disk drive system, please contact ***Interactive Software Designs, Inc.***, for special instructions to order a non-compressed version of **XSTABL**.

1.5 XSTABL Components

Before using **XSTABL**, the user should ensure that files listed below, and section 2.2, have been copied :

1. PACK.LST . . . . . summary of file descriptions
2. README . . . . . special "last-minute" notes or revisions to this Manual
3. DEMO.TXT . . . . . dialogue script for demonstration/tutorial

1.6 Files for using XSTABL

1. **XSTABL.EXE** . . . . executable version of program
2. SETUP1.STB . . . . . file used during program startup
3. XSTABL.HLP . . . . . help screen information
4. XSTABL.ERR . . . . . XSTABL error descriptions
5. XSTABL.FN1 . . . . . font file for screen characters
6. XSTABL.FN2 . . . . . font file for hardcopy plots
7. XPLOT.EXE . . . . . executable program for hardcopy plots

The installation process will also copy the example input data files and the output (4 files) corresponding to an analysis using the file EX_1.IPT to the "EXAMPLES" subdirectory. These "extra" files may be deleted to conserve disk space.

The program can then be started by typing, **XSTABL** at the DOS prompt. **The program will NOT operate without the SETUP1.STB file.**

> **Please note that the XSTABL software and documentation is copyrighted and may NOT be copied without permission.** However, the user is permitted to make ONE archival backup copy of these files to guard against possible disk failure.

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1.7 Supporting XSTABL files

File: **SETUP1.STB** -- contains initialization information that sets several parameters at the start of the **XSTABL** program. Also, the first line of this file may be modified to control the amount of information that is written into the output file following a slope analysis. A typical unmodified file will have the following form:

Line 1:	0	10	10	10
Line 2:	1.000	1.000	0.30	9.80
Line 3:	(blank line)			

Let the four values on the *first line* be labeled as **var-1**, **var-2**, **var-3** and **var-4**. Then the user is permitted to modify these according to the following:

var-1 = 0 (zero) for all cases, unless advised otherwise;

var-2 = value between 1 and 10, inclusive, for controlling the number of failure surface coordinates that will be listed in the <u>output file</u> following each slope analysis;

var-3 = value between 1 and 10, inclusive, for controlling the number of critical surfaces that will be *displayed on the screen* at the end of the slope analysis;

var-4 = value between 1 and 10, inclusive, for controlling the number of surfaces *plotted to the hardcopy file.*

Please note that the default for the number of surfaces is set at ten for all cases (i.e. var-2 = var-3 = var-4 = 10). These parameters may be changed directly by editing the SETUP1.STB file. Alternatively these may be changed from within **XSTABL** via the F5 key just before the start of the multiple search analysis.

The four values listed on the second line control the scaling and location of the hardcopy plot on paper. The first two values assign the scaling in the x and y direction of the plot. The last two numbers fix the origin of the plot on the basis of a global origin located in the right-hand corner of the printed 11 x 8.5 inch (landscape) page. The user can manipulate these values to scale the hardcopy plots, but must ensure that the aspect ratio of the vertical to horizontal axes is maintained at unity.

Other Files:

The two files, **XSTABL.HLP** and **XSTABL.ERR**, are used by **XSTABL** to provide help and input data error information, respectively. Although the program can function without these files, on-line help information will not be available and error messages will not be written to the output file created during the slope stability analysis. However, error numbers will be written to the output file and the user can determine the corresponding message from the complete list of possible errors given in Appendix B.

1.8 Connecting HP Plotters

XSTABL screen plots may be successfully plotted using HP plotter models: 7440A, 7470A, 7475A and 7550A connected to a personal computer. The cable should be connected to the PC with a DB 9 or DB 25 connector via the serial or asynchronous port. At the plotter, a DB 25 connector should be used to connect the cable to the computer/modem port. **XSTABL** uses the XON/XOFF protocol and thus only requires ***three*** connecting wires in accordance with Fig 1.1.

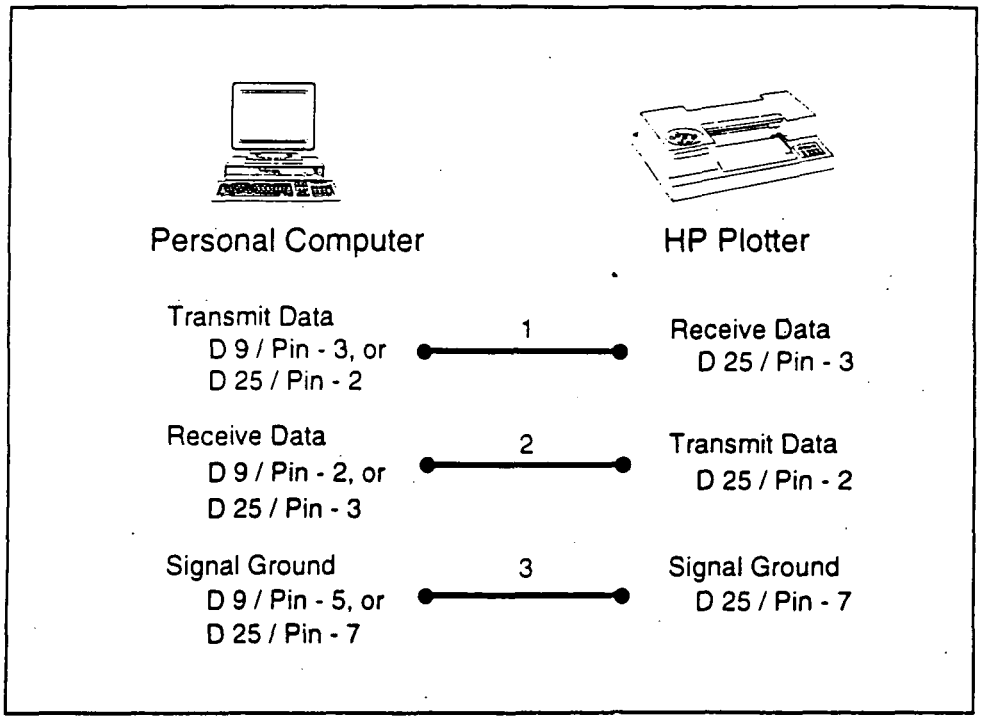

Fig. 1.1. Wire connections for PC - HP plotter cable

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1.9 Starting XSTABL

XSTABL should be executed from the directory occupied by the program's files by typing "XSTABL" at the DOS prompt. Please note that an error will be reported if the user attempts to execute **XSTABL** from a directory which does not have the SETUP1.STB file. Also, the program ***expects*** to access the files: XSTABL.HLP and XSTABL.ERR (i.e. the help and error files) from the current directory only. If these files are not in the current directory, **XSTABL** will be unable to provide a complete report on the errors and the context sensitive help information will not be available.

In executing the program, **XSTABL** offers the user an opportunity to change three default parameters via a command line option. If the user executes the program by only typing "XSTABL", the following default options are invoked:

(a) Imperial units, i.e. pounds, psf, pcf and feet;

(b) Parallel printer port selected as LPT1;

(c) Serial port selected as COM1.

The parallel port is used for printing input and output files and for printing all slope analysis plots, except those sent to a plotter. In this case the plotter is assumed to be connected to the COM1 serial port. If the above default selection is not appropriate, the user may change any of these according to the command-line switches given below.

Alternative SI Units may be selected by executing the program by typing: "XSTABL -m" at the DOS prompt. In this case the program will startup with SI units represented by: kN, kPa (kilo Pascals), kN/m^3 and meters.

The Alternative Parallel Port LPT2 may be selected by starting the program by typing: "XSTABL LPT2". This selection will send all parallel port output to the LPT2 port.

The Alternative Serial Port COM2 may be selected by starting the program by typing: "XSTABL COM2". This selection will send the plotter output to the alternative serial port.

Any combination of the above three options is possible. For example by typing : "XSTABL COM2 LPT2 -m" the user may invoke (1) COM2 as the serial port, (2) LPT2 as the default parallel printer port and (3) SI units.

1.10 Example Input and Output Files

Several data files are provided with the main programs, on the enclosed disk, for evaluating the **XSTABL** software. These files are based on the slope geometry described in Appendix A of this manual. The output files, for example EX_1.IPT, are also included for the convenience of the user and to check for proper operation of **XSTABL** on your computer. A complete description of these example files is summarized in the disk file: PACK.LST.

1.11 XSTABL Tutorial

A dialogue script for a tutorial that demonstrates some of the unique features of **XSTABL** is included with the program disk(s) in the file: DEMO.TXT. The user is encouraged to print this file, and follow the suggested instructions. This tutorial will familiarize users with the editing features, special commands and other data tables that are used to assemble a data file for slope stability analysis.

1.12 ANSI.SYS Device Driver

The **XSTABL** program has been designed to access the video hardware directly, thus minimizing the response time between keyboard entry and subsequent actions. However if the **ANSI.SYS** device driver is loaded, it "filters" the data before it is written to the screen. Thus in order to maximize the speed of **XSTABL**, the use of the ANSI.SYS device driver is not recommended as it tends to slow the response time for data written to screen.

The user may check to see if the ANSI.SYS driver is loaded by examining the CONFIG.SYS file in the root directory. A line of the general form :

DEVICE=ANSI.SYS

will indicate that the device driver is loaded at the start of every session. The user must then choose to either load or omit the ANSI.SYS device driver.

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1.13 Loading and Execution Errors

It is possible that an "unexplainable" error may occur during the loading and execution phase of the program. If such an error occurs, please check you data thoroughly. If your data appears to be correct and the error condition persists, please contact:

Dr. Sunil Sharma,
Interactive Software Designs, Inc.,
953 N. Cleveland,
Moscow, ID 83843.

3.2 Short-Term Liner System Stability on Side Slopes

COMPUTATION COVER SHEET

SUBJECT OF CALCULATION: SHORT-TERM LINER SYSTEM STABILITY ON SIDE SLOPES

Computations By: (Cognizant Engineer)
Signature: [signature] Date: 7 Oct 95
Printed Name and Title: Gary R. Schmertmann, Sr. Project Engineer

Assumptions and Procedures Checked by: (Checker)
Signature: [signature] Date: 7 Oct 95
Printed Name and Title: Robert C. Bachus, Principal

Computations Checked by:
Signature: [signature] Date: 7 Oct 95
Printed Name and Title: Robert C. Bachus, Principal

Computations Backchecked by: (Cognizant Engineer)
Signature: [signature] Date: 7 Oct 95
Printed Name and Title: Gary R. Schmertmann, Sr. Project Engineer

Approved by: (PDP)
Signature: [signature] Date: 7 Oct 95
Printed Name and Title: Gary R. Schmertmann, Sr. Project Engineer

Approved by: (DTL and TETL)
Signature: [signature] Date: 7 Oct 95
Printed Name and Title: Rudolph Bonapaite, Principal

Record of Revision (Number and initial all revisions)

NO.	REASON	DATE	BY	CHECKED	APPROVAL	
Ø	30% Submittal	NA	NA	NA	NA	No changes
B	Exec. Summary	13 Dec 95	GRS	RCB	RB	

Signature: _____
Number: _____
Registration Stamp (if applicable)

Written by: GRS Date (Y/M/D): 95/12/13 Reviewed by: RCB Date: 14 Dec '95

Client.: FERMCO Project: OSDF Project No.: GE3900 Task No.: 9.5

SHORT-TERM LINER SYSTEM STABILITY ON SIDE SLOPES

EXECUTIVE SUMMARY

Purpose of Calculations:

These calculations are performed to evaluate the stability of the liner system on the perimeter side slopes during the period between liner system construction and placement of impacted material in the cell. The evaluation includes assessment of the potential for tensile stresses to develop in the geosynthetic components of the liner system during the indicated time period.

Methodology:

Stability is evaluated by first calculating the minimum slope stability factor of safety (FS) for the liner system on the perimeter side slopes using the 2-dimensional limit equilibrium analysis approach presented by Giroud et al. (1995) (reference no. 1 in Calculation Procedures/Methods package). The calculation considers the following: (i) location of the least stable side slope cross section; (ii) stability during each stage of liner system construction; (iii) the minimum available shear strength, appropriate for short-term conditions, of the materials and interfaces within the liner system; and (iv) the effect of rainfall, specifically, the 25-year, 24-hour storm, on liner system stability. The calculated minimum FS is then compared to the target value of FS given in the Design Criteria Package, i.e., 1.3. Adequate stability is demonstrated if the calculated minimum FS is equal to or greater than the target value.

The potential for tensile stresses to develop in the geosynthetic components of the liner system is evaluated using information presented by Long et al. (1994) (reference no. 4 in Calculation Procedures/Methods package).

Conclusions:

- Calculated minimum slope stability FS is 1.58. This value exceeds the target value of 1.3. Therefore, stability is adequate.
- Predicted tensile stresses in the liner system geosynthetics are negligible.

End of Executive Summary

Written by: GRS Date: 95/10/4 (YY/MM/DD) Reviewed by: Date: / / (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.5

RB 95/10/5
RCB 95/10/7

SHORT-TERM STABILITY OF LINER SYSTEM ON SIDE SLOPES - CALCULATION PROCEDURES / METHODS

PURPOSE: Present procedures and methods for calculations to check short-term, side slope liner system stability

SCOPE: Step-by-step procedures References
Equations used in calculations

STATEMENT OF DESIGN PROBLEM:

The landfill liner system on the sloping cell perimeter is designed to be stable during the period between liner system construction and placement of impacted material in the cell. During this period, the liner system can be viewed as a veneer placed on a sloping foundation. Stability is assessed by considering potential slip surfaces that pass through and/or along materials or interfaces within the system (see conceptual sketch below). Stability is assessed by calculating a slope stability factor of safety (FOS) for the critical (i.e., least stable) potential slip surface within the system. The design is adequate if the FOS ≥ a target value. Two veneer

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Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.5

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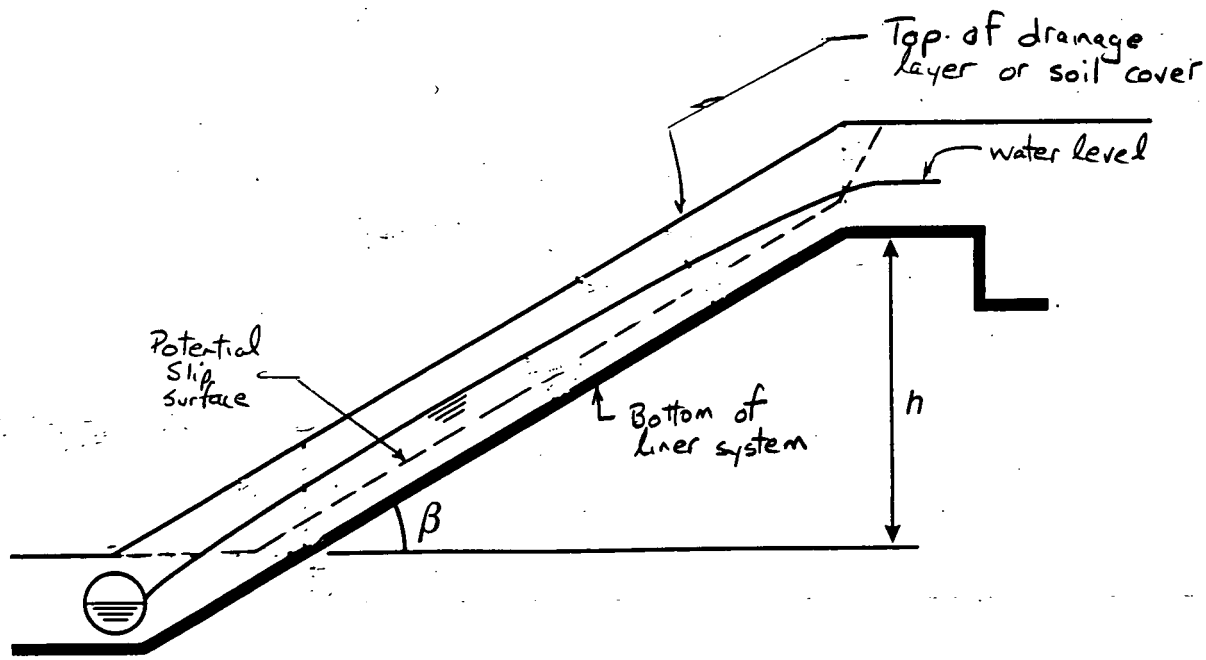
stability conditions will be considered:

[A] compacted clay liner, secondary geosynthetics and LDS drainage layer on cell perimeter slopes (prior to placement of primary geosynthetics)

[B] complete liner system on cell perimeter slopes (prior to placement of protective cover soil and impacted material)

ISSUES TO BE CONSIDERED IN ANALYSIS

- location of critical cross section
- shear strength of materials and interfaces within liner system under veneer stability loading
- effect of rainfall during veneer period on stability
- tension in geosynthetic components of liner system



CONCEPTUAL SKETCH OF POTENTIAL SLIP SURFACE (AFTER REFERENCE 1)

Written by: GES Date: 95/10/5 (YY MM DD) Reviewed by: Date: / / (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.5

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CALCULATION STEPS

① Select location of critical cross section for veneer stablity:

The most critical veneer stability case will be for the highest and steepest cell perimeter slopes. The cross section representing the most critical case will be located based on the cell perimeter slopes shown in the design drawings. The same cross section will be critical for both veneer stability conditions [A] and [B].

Assume that the drainage materials (i.e. the LDS drainage layer for condition [A] or the LCS drainage layer for condition [B]) will be placed over the full height of the slope. This assumption is conservative in that partial-height placement of drainage material results in a higher FOS than full-height placement.

② Evaluate shear strength of all interfaces and materials within liner system. Establish minimum shear strengths for conditions [A] and [B]:

Consider systematically all materials and interfaces within liner system. Shear strengths for soil materials should be assessed using established geotechnical correlations for granular soils. Shear strengths for interfaces and

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Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.5

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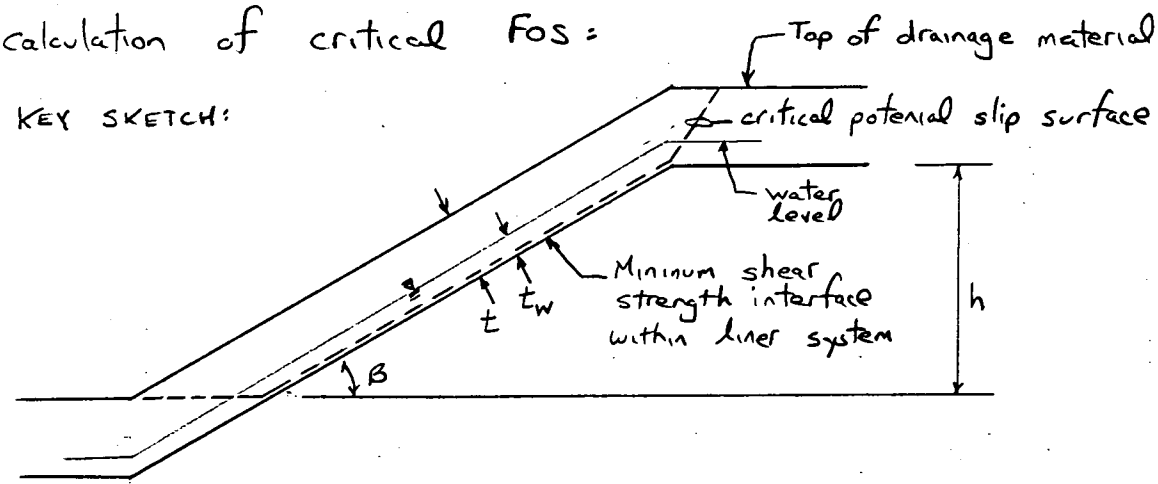
geosynthetic materials should be assessed using published information and project experience. Site-specific shear strength testing will be performed prior to final design to directly measure shear strength parameters. Assessment of shear strengths should consider the relatively low confining stresses and the relatively short duration of the veneer stability scenario.

(3A) Select geometry and shear strength parameters for calculation of critical FOS:

KEY SKETCH:



Geometry parameters: β obtained from critical cross-section geometry

h, t obtained from critical cross-section geometry and location of minimum shear strength interface

Shear strength parameters:

Drainage material ϕ, c obtained from shear strength assessment

Minimum shear strength interface δ, a obtained from shear strength assessment

Written by: CRS Date: 95/10/5 (YY/MM/DD) Reviewed by: Date: / / (YY/MM/DD)

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(3B) Select unit weight parameter for drainage material:

This parameter will be selected based on typical upper-bound moist unit weights of granular drainage materials. Upper-bound will be used because larger unit weights may result in lower computed FOS.

(4) Select water level parameter for calculation of critical FOS:

This parameter represents the maximum water level that might develop due to rainfall on the drainage material during the short-term veneer period.

This parameter will be selected as follows:

- Identify the average 1-hr rainfall intensity for a 24-hr duration storm with 25-year return period using the chart developed in Ref. 2. The ave. for a 24-hr duration was assumed to allow time for steady-state seepage to develop and to represent an appropriate design intensity, recognizing that the drainage layer could be easily repaired. The 25-year return period was selected to be conservative for the short-term duration of the veneer period.
- Obtain the minimum allowable value of hydraulic conductivity for the drainage materials from the liner system design. Use of the minimum value is conservative

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- Use the slope geometry determined in step 3A along with the rainfall intensity and hydraulic conductivity selected above to calculate the maximum water thickness by the following equation:

$$T_{max} = L\left(\frac{\tan\beta}{\cos\beta}\right)\left(\frac{\sqrt{1+4\lambda}-1}{2}\right) \qquad (1)$$

where T_{max} = maximum water thickness

L = horizontal slope length taken as $h/\tan\beta$ where h, $\tan\beta$ shown in key sketch for step 3A

β = slope angle

$\lambda = q_i / k\tan^2\beta$

q_i = infiltration rate, conservatively taken as equal ave. 1-hr, 25-yr rainfall rate

k = hydraulic conductivity of drainage material

Note: Eq. (1) is taken from eq. (30) of reference 3

- Use the maximum water thickness and Figure 11 of reference 3 to obtain the average water thickness, T_{avg}. The water level parameter, t_w, is taken as equal to T_{avg}

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Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.5

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(5) Calculate critical FOS:

Use the following equations (eqs. 57+58 from reference 1):

Potential slip surface above geomembrane:

$$FOS = \frac{\gamma_t (t-t_w) + \gamma_b t_w}{\gamma_t (t-t_w) + \gamma_{sat} t_w} \frac{\tan\delta_A}{\tan\beta} + \frac{a_A/\sin\beta}{\gamma_t (t-t_w) + \gamma_{sat} t_w}$$

$$+ \frac{\gamma_t (t-t_w^*) + \gamma_b t_w^*}{\gamma_t (t-t_w) + \gamma_{sat} t_w} \frac{t}{h} \frac{\sin\phi}{2 \sin\beta \cos\beta \cos(\beta+\phi)} \qquad (2)$$

$$+ \frac{c\, t/h}{\gamma_t (t-t_w) + \gamma_{sat} t_w} \frac{\cos\phi}{\sin\beta \cos(\beta+\phi)}$$

$$+ \frac{T/h}{\gamma_t (t-t_w) + \gamma_{sat} t_w}$$

Potential slip surface below geomembrane:

$$FOS = \frac{\tan\delta_B}{\tan\beta} + \frac{a_B/\sin\beta}{\gamma_t (t-t_w) + \gamma_{sat} t_w} + \frac{\gamma_t (t-t_w^*) + \gamma_b t_w^*}{\gamma_t (t-t_w) + \gamma_{sat} t_w} \frac{t}{h} \frac{\sin\phi}{2 \sin\beta \cos\beta \cos(\beta+\phi)} \qquad (3)$$

$$+ \frac{c\, t/h}{\gamma_t (t-t_w) + \gamma_{sat} t_w} \frac{\cos\phi}{\sin\beta \cos(\beta+\phi)} + \frac{T/h}{\gamma_t (t-t_w) + \gamma_{sat} t_w}$$

where: γ_t = moist unit wt. of drainage material (from step (3B))

γ_{sat} = sat unit wt of drainage material taken as = $\gamma_d + n\gamma_w$ with n = porosity = 0.3, γ_w = 62.4 lb/ft³

γ_b = buoyant unit wt of drainage material = $\gamma_{sat} - \gamma_w$

γ_d = dry unit wt of drainage material

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Client: FERMCO Project: OSDF Project/Proposal No.: GE3906 Task No.: 9.5

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t_w = water level parameter (from step 4) = t_w^*

t = thickness of drainage material (from step 3A)

β = slope angle (from step 3A)

h = slope height (from step 3A)

ϕ, c = shear strength parameters of drainage material (from step 2)

δ, a = shear strength parameters of weakest interface (from step 2)

T = tension in geosynthetic layers above potential slip surface taken as zero

6. Compare calculated critical FOS to target value:

Target value is 1.3 (taken from GeoSyntec Design Criteria document F953004)

Calculated critical FOS must be $\geq$ 1.3 to establish adequate stability

7. Consider tension in geosynthetic components of liner system.

Results presented in reference 4 using strain compatibility analyses indicate that tension in geosynthetic components of the liner system will be negligible if the friction angles of all liner system interfaces and

Written by: GRS Date: 95/10/5 (YY/MM/DD) Reviewed by: Date: / / (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.5

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materials exceed the slope angle, B, assuming that the adhesion is negligible and that the shape of the shear force vs. displacement curves for the considered interfaces are similar to those used in Ref. 4.

The minimum value of friction angle obtained in step (2) will be compared to the value of B from step (3A).

Written by: GRS Date: 95/10/5 (YY MM DD) Reviewed by: Date: / / (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: Task No.:

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REFERENCES

1. Giroud, J.P., Bachus, R.C. and Bonaparte, R., "Influence of Water Flow on the Stability of Geosynthetic-Soil Layered Systems on Slopes," submitted for publication to Geosynthetics International, Sept. 1995.

2. Parsons Company, "2,000-Year Flood and Probable Maximum Flood, Sitewide Flood Plain Determination, CERCLA/RCRA Unit 2, Project Order 148, Revision A," prepared for FERMCO subcontract No. 2-21487, August 1995, Apperdix F.

3. Giroud, J.P. and Houlihan, M.F., "Design of Leachate Collection Layers," Proc. of 5th Int. Landfill Symposium, Sardinia, Italy, October 1995.

4. Long, J.H., Gilbert, R.B. and Daly, J.J., "Geosynthetic Loads in Landfill Slopes: Displacement Compatibility", Journal of Geotechnical Engineering, ASCE, V.120, No. 11, pp. 2009-2025.

Written by: GRS Date: 95/10/5 (YY/MM/DD) Reviewed by: R. Bonaparte Date: 95/10/07 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.5

RCB 95/10/7

SHORT-TERM STABILITY OF LINER SYSTEM ON SIDE SLOPES - DATA VERIFICATION PACKAGE

PURPOSE: Evaluate data and parameters required to perform stability calcs. for short-term stability of liner system on side slopes.

SCOPE: Covers all data and parameter requirements presented in the "calculation procedures/methods" package.

REQUIRED DATA AND PARAMETERS:

This section is organized following the calculation step numbers presented in the "calculation procedures/methods" package

(1) Select location of critical cross section for veneer stability: Critical location is for highest and steepest cell perimeter slopes. Based on subgrade grading plan (see following page) all perimeter slopes are inclined at 4H:1V. Therefore, slope steepness is not a factor in selecting the critical location. Highest cell perimeter slopes occur at the centerline of each cell, with a maximum height of 11 ft. occurring at a number of cells (see example for cell 3 on second page following). Conclude that critical cross-section location is represented by centerline of cell 3.

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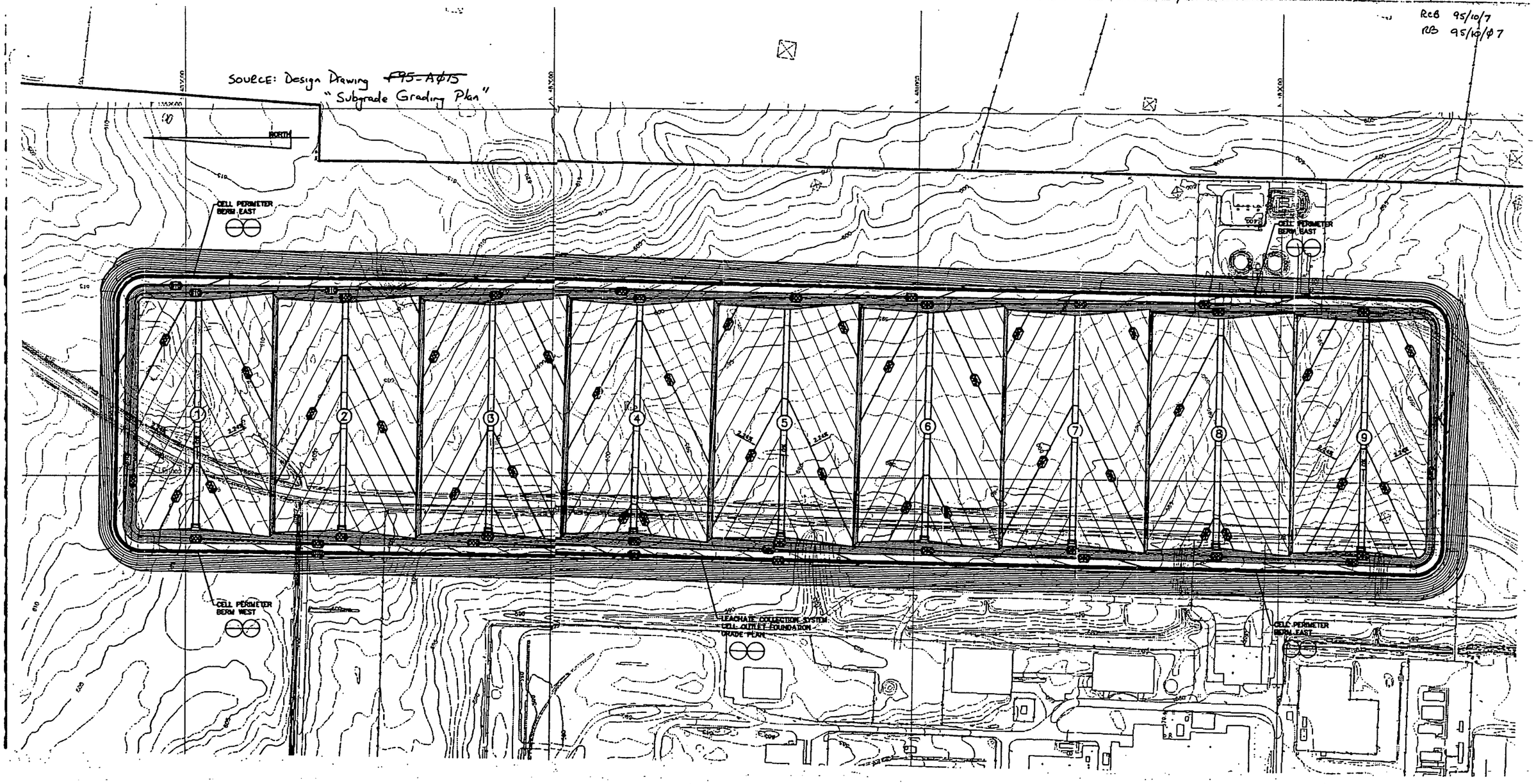

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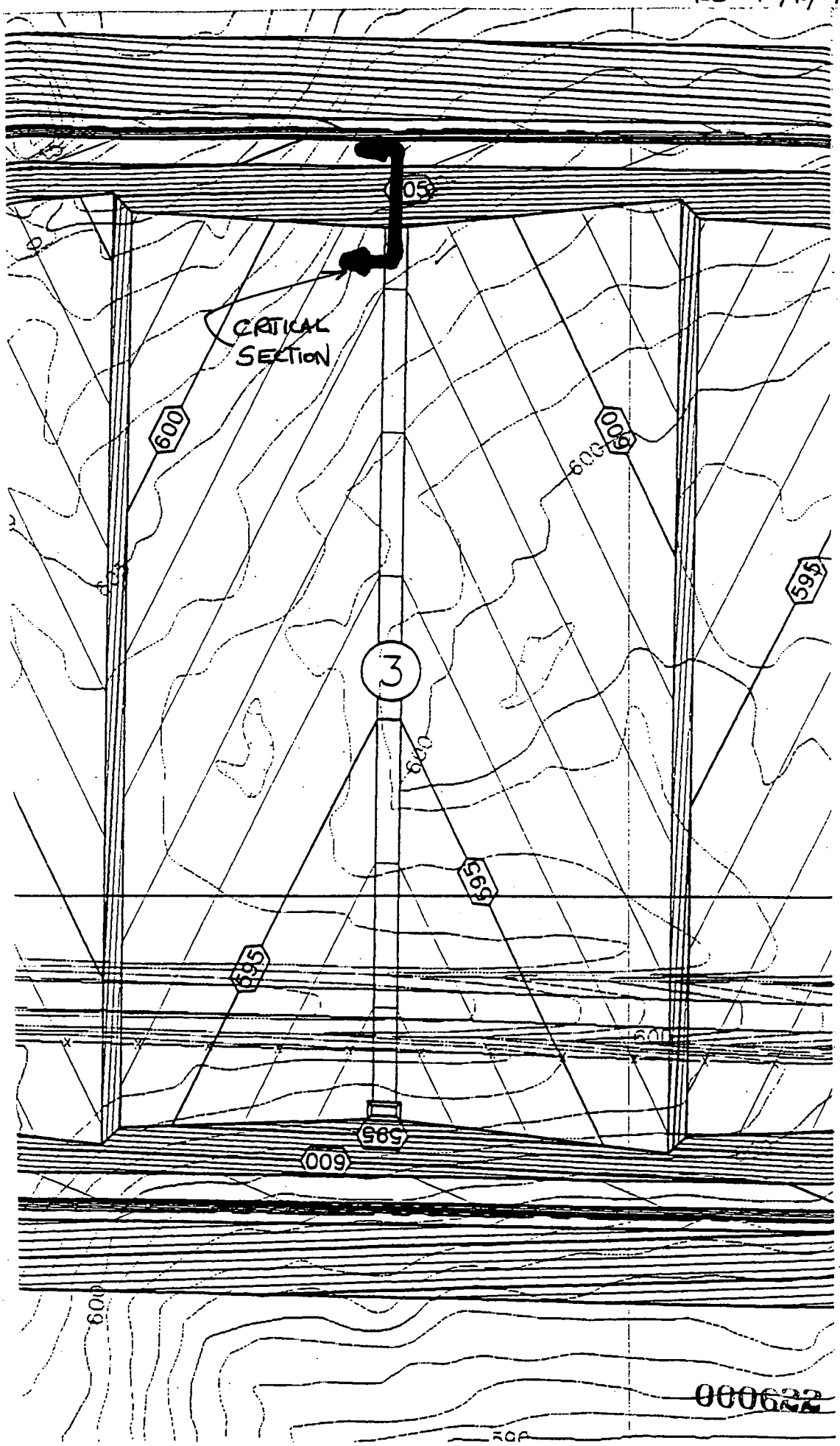
RB 95/10/07



Source: Design Drawing No. ~~F95-A075~~
" Subgrade Grading Plan"

000622

Written by: GRS Date: 95/10/5 (YY/MM/DD) Reviewed by: R. Bonaparte Date: 95/10/07 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.5

ROB 95/10/7

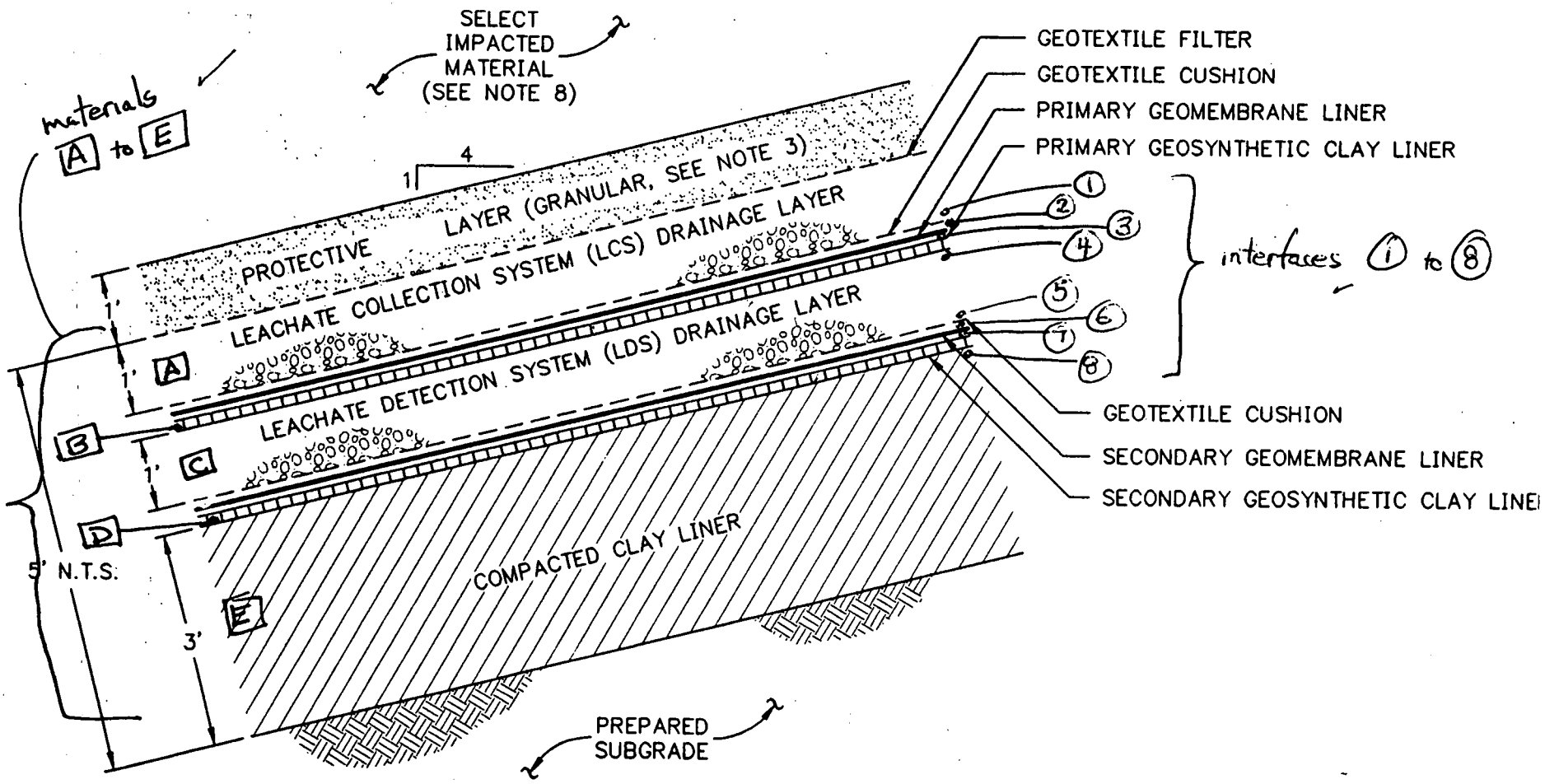
(2) Evaluate shear strength of all interfaces and materials within liner system:

The following page shows the liner system design and identifies 5 materials* (A to E) and 8 interfaces (1 to 8) within the system. The protective layer and the interfaces around the underlying geotextile filter are not identified because they are not placed for the short-term side slope condition.

The ~~second~~ following pages provide a table summarizing the assessment of shear strength parameters for each material and interface for the short-term side slope condition.

Consideration of peak friction angles is appropriate for the short-term side slope condition.

* materials in which internal shear could possibly occur



DET-NO DETAIL

SHT-NO LINER SYSTEM ON PERIMETER AND INTERCELL BERM SLOPES

SCALE: ~~1" = 8'~~

TAKEN FROM: Design Drawing ~~No. F95 A026~~ "Liner ~~Sys~~ and Cover System Details I"

186 p. 5 of 3 RDB 95/01/7 03 95/19/07

000624

Written by: GRS Date: 95 / 10 / 5 (YY MM DD) Reviewed by: _____ Date: / / (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.5

RCB 95/10/7
RB 95/10/07

MATERIALS

No.	Description	Shear Strength Parameters ϕ	c (psf)	Source
A	LCS Drainage Layer (gravel)			
C	LDS Drainage Layer (gravel)	30° ✓	0 ✓	ϕ=30° is a lower bound estimate for granular soil materials. (see page 8)
	For stability purposes, LCS and LDS are treated are taken as the same material			
B	Primary GCL			
	Consists of bentonite bonded to a textured ~~to an~~ HDPE backing membrane. Bentonite will remain unhydrated because it will be between primary geomembrane and backing	25° ✓	0 ✓	See Cover System Stability Calculations (Doc. # F953ØØ22.CDØ)
D	Secondary GCL			See Cover System Stability Calculations (Doc # F953ØØ22.CDØ)
	Consists of internally reinforced bentonite. Assume hydrated.	30° ✓	0 ✓	
E	Compacted Clay Liner	23-29° use 25° ✓	100-400 use 0 ✓	See Cover System Stability Calcs. (Doc. # F953ØØ22.CDØ

10^{-1} cm/sec

Written by: GRS Date: 95/10/6 (YY/MM/DD) Reviewed by: Date: / / (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.5

RCB 95/10/7
RB 95/10/07

INTERFACES

No.	Description	Sheer Strength Parameters δ	a (psf)	Source
1	LCS Drainage layer (gravel) to Geotextile cushion (non-woven)	25°	0	See cover system stability calcs. (Doc # F95300022.CDO)
2	Geotextile cushion (non-woven) to Primary Geomembrane (textured HDPE)	25°	0	"
3	Primary Geomembrane (textured HDPE) to Dry bentonite component of primary GCL	20°	0	"
4	Textured HDPE component of primary GCL to LDS Drainage layer (gravel)	22°	0	Assume tan δ/tan φ = 0.7 for textured HDPE/gravel interface (consistent with reference 4 in cover system stability calculations (Doc. # F95300022.CDO))
5	Geotextile cushion (non-woven) to LDS drainage layer (gravel)	25°	0	same as interface 1
6	Geotextile cushion (non-woven) to Secondary geomembrane (textured HDPE)	25°	0	same as interface 2
7	Secondary geomembrane (textured HDPE) to secondary GCL (internally reinforced, hydrated)	20°	0	See cover system stability calcs. (Doc # F95300022.CDO)
8	secondary GCL (internally reinforced, hydrated) to compacted clay liner	20°	0	Assume tan δ/tan φ = 0.8 for GCL/clay interface (consistent with reference 4 in cover system stability calcs (Doc # F95300022.CDO)

Written by: GRS Date: 95/10/6 (YY MM DD) Reviewed by: Date: / / (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: Task No.:

RCB 95/10/7
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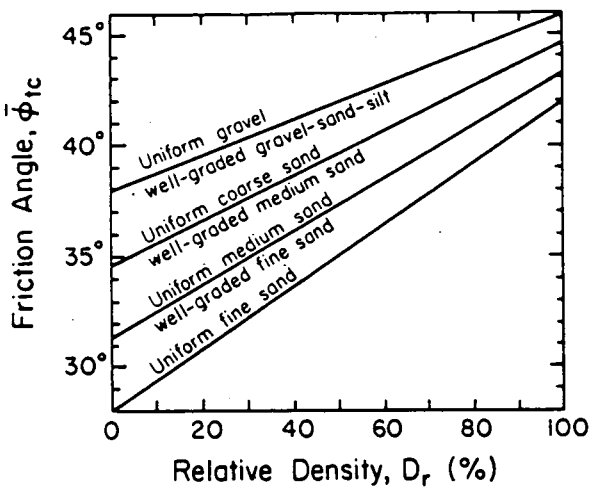

Figure 4-7. $\bar{\phi}_{tc}$ versus Relative Density

SOURCE:

Manual on Estimating Soil Properties for Foundation Design

EL-6800
Research Project 1493-6

Final Report, August 1990

Prepared by

CORNELL UNIVERSITY
Geotechnical Engineering Group
Hollister Hall
Ithaca, New York 14853-3501

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Prepared for

Electric Power Research Institute

Written by: GRS Date: 95/10/6 (YY/MM/DD) Reviewed by: Date: / / (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.5

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Establish minimum shear strengths for conditions [A] and [B], as described in "calculation procedures/methods" package

condition [A] - compacted clay liner, secondary geosynthetics and LDS drainage layer (prior to placement of primary geosynthetics and LCS)

This conditions involves materials [C], [D] and [E] and interfaces (5) through (8). Based on preceding tables minimum shear strength is for interfaces (7) and (8), i.e. $\delta = 20°$, $a = 0$. Shear strength parameters for the LDS are $\phi = 30°$, $c = 0$.

condition [B] - complete liner system (prior to placement of protective layer). This condition involves all materials and interfaces. Based on preceding tables minimum shear strength is for interfaces (3), (7) and (8), i.e., $\delta = 20°$, $a = 0$. Shear strength parameters for the LCS are $\phi = 30°$, $c = 0$.

Note: For both conditions, weakest interfaces below the geomembrane have $\delta = 20°$, $a = 0$. The weakest interfaces above the geomembrane have $\delta = 25°$, $a = 0$.

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Client: FEEMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.5

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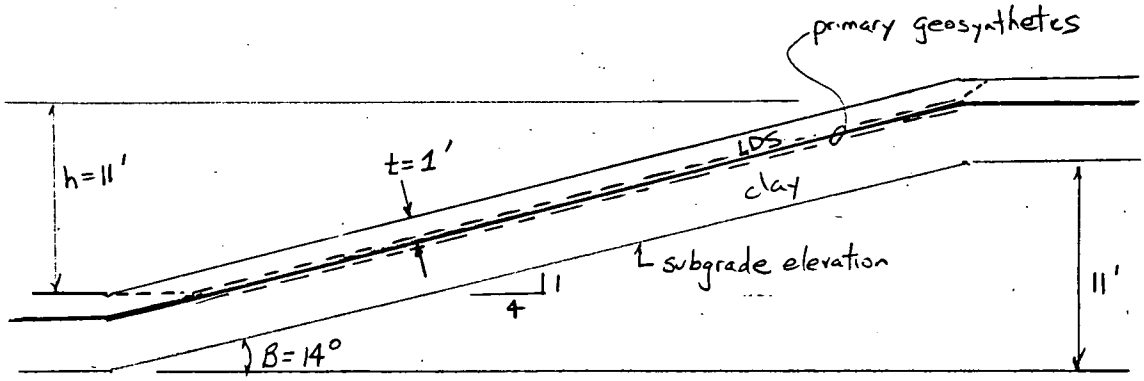
RB 95/10/07

(3A) Select geometry and shear strength parameters for calculation of critical FOS.

Geometry Parameters:

Geometry of critical section will be same for condition [A] and [B]. Geometry is shown below based on subgrade grading (p. 2+3 of this package) and liner system thicknesses (p. 5).



h=11' t=1' B=14°

Shear strength parameters:

For slip surface below geomembrane: $\delta=20°$, $a=0$, $\phi=30°$, $c=0$

For slip surface above geomembrane: $\delta=25°$, $a=0$, $\phi=30°$, $c=0$

(3B) Select unit weight parameter for drainage material:

$\gamma_t = 125$ lb/ft³ This value represents an upper-bound value for typical drainage gravel materials with representative compaction.

Written by: GES Date: 95 / 10 / 7 (YY MM DD) Reviewed by: Date: / / (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.5

RCB 95/10/7
RB 95/10/07

(4) Select water level parameter for calculation of critical FOS:

Ave. 1-hr rainfall intensity for 24-hr storm with 25-year return:

Total 24-hr rainfall = 4.6 in (see p. 12) ✓

x = 1-hr average = 4.6/24 = 0.19 in/hr ✓

Minimum allowable hydraulic conductivity of LDS and LCS:

$k = 10^{-1}$ cm/sec (from project design documents) ✓

Calculate maximum water thickness:

$L = h/\tan\beta = 11'/\tan 14° = 44'$ ✓

$\beta = 14°$ ✓

$q_i = x = 0.19$ in/hr ✓

$k = 10^{-1}\ \text{cm/sec}\left(\frac{1}{2.54}\ \text{in/cm}\right)\left(60^2\ \frac{\text{sec}}{\text{hr}}\right) = 142$ in/hr ✓

$$\lambda = \frac{q_i}{k\tan^2\beta} = \frac{0.19\ \text{in/hr}}{142\ \text{in/hr}\ \tan^2 14°} = 0.022 \quad ✓$$

$$T_{max} = L\left(\frac{\tan\beta}{\cos\beta}\right)\left(\frac{\sqrt{1+4\lambda}-1}{2}\right) \quad ✓ \qquad (1)$$

$$= 44\ \text{ft}\left(\frac{\tan 14°}{\cos 14°}\right)\left(\frac{\sqrt{1+4(0.022)}-1}{2}\right) \quad ✓$$

$$= 44\ \text{ft}\,(0.257)(0.0215) = 0.24\ \text{ft} \quad ✓$$

Calculate ave. water thickness:

$T_{avg}/T_{max} = 0.94$ (using p. 13 with $\lambda = 0.022$) ✓

$\therefore\ T_{avg} = 0.24\ \text{ft}\,(0.94) = 0.23\ \text{ft}$ ✓

$t_w = t_{avg} = \underline{0.23\ \text{ft}}$ ✓

GRS 10/7/95

RCB 95/10/7
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Source: Ref. 2 of calculation procedures/methods package

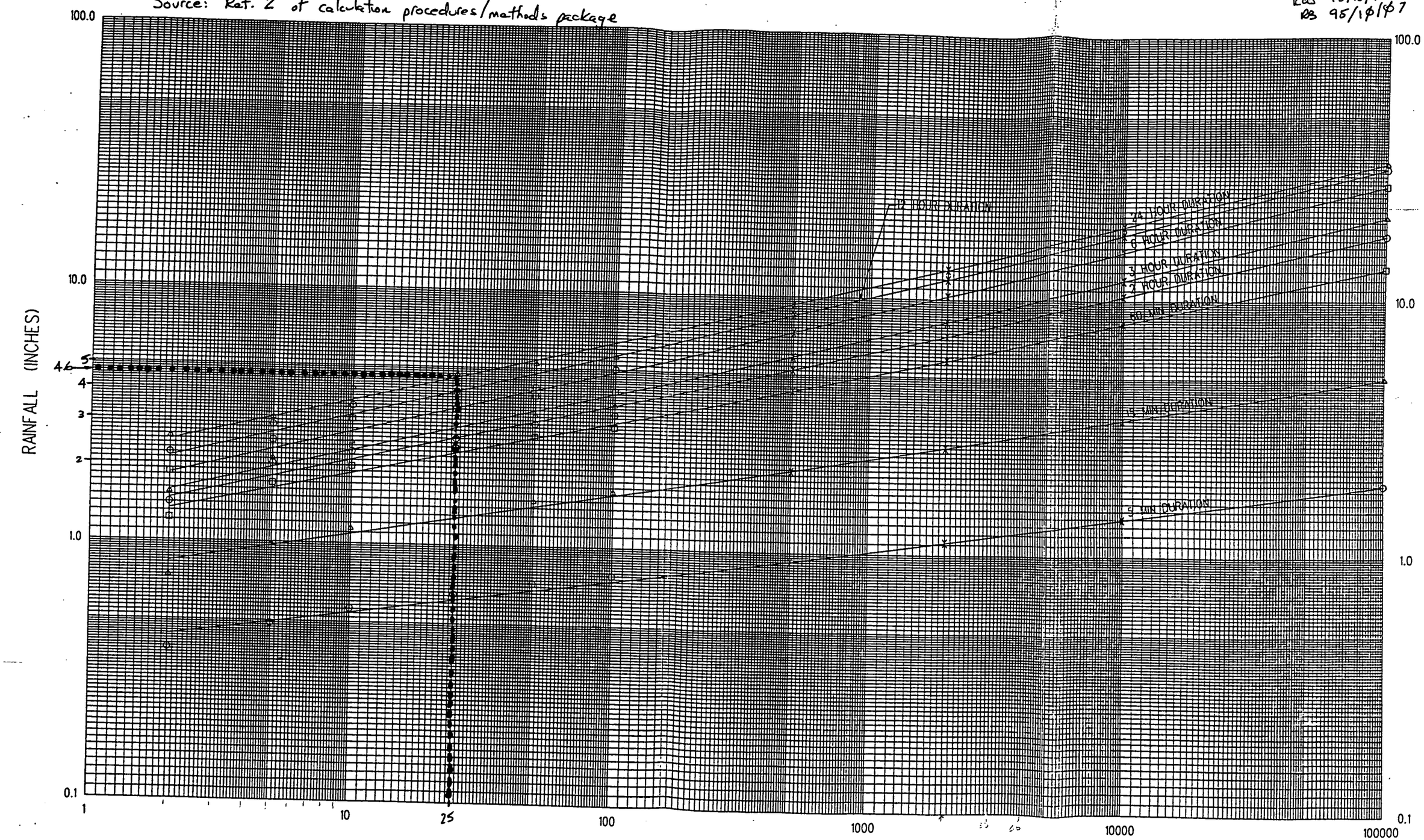

FIGURE 3
RAINFALL - DURATION CHART

Written by: GRS Date: 95/10/7 (YY/MM/DD) Reviewed by: Date: / / (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3700 Task No.: 95

RCB 95/10/7
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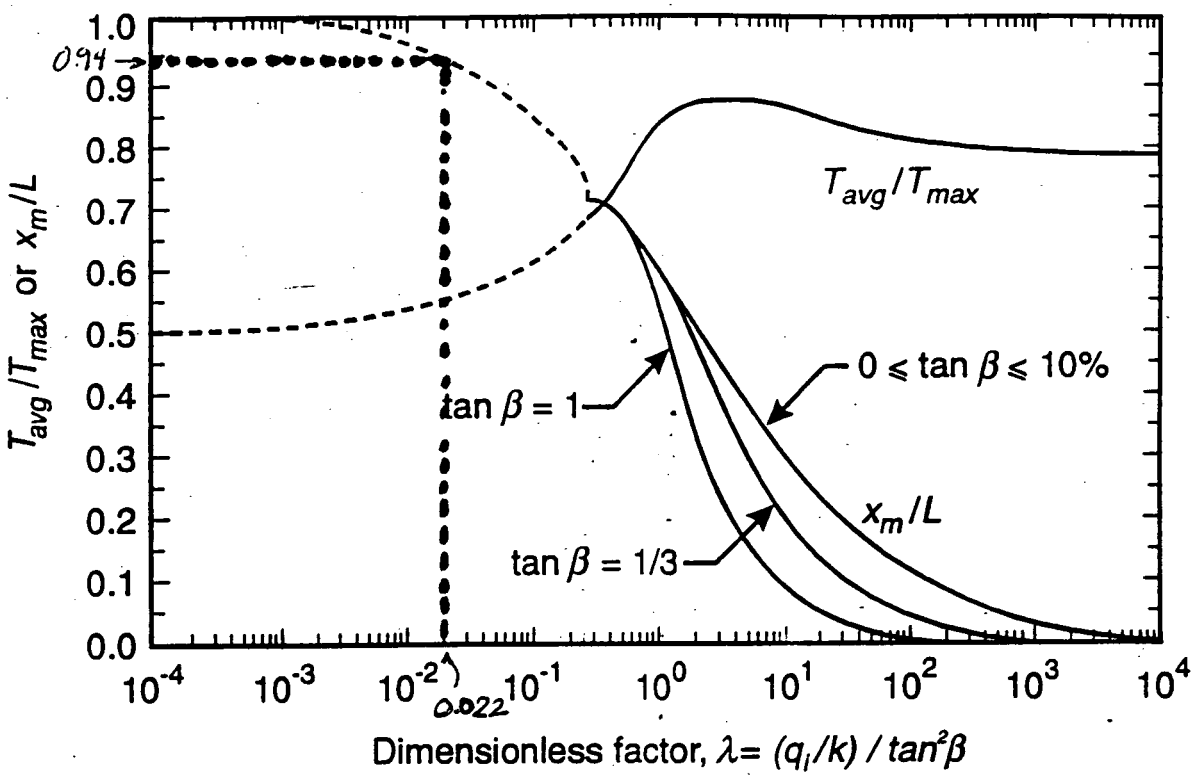

Source: Ref. 3 from Calculation Procedures/Methods Package

Written by: GRS Date: 95 / 10 / 7 (YY MM DD) Reviewed by: Date: / / (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.5

RCB 95/10/7

SHORT-TERM STABILITY OF LINER SYSTEM ON SIDE SLOPES — CALCULATIONS

PURPOSE: Present stability calculations for short-term stability of liner system on side slopes

SCOPE: Presents calculations as described in "Calculation procedures/methods" package beginning at step 5

CALCULATIONS FOR CRITICAL FOS:

5

* Summary of Parameters from "Data Verification" Package:

Geometry: $h = 11$ ft ✓ $\beta = 14°$ ✓ $t = 1$ ft ✓ $t_w = 0.23$ ft $= t_w^*$ ✓

Shear strength: case of potential slip surface above geomembrane

$\delta = 25°$, $a = 0$, $\phi = 30°$, $c = 0$ ✓

case of potential slip surface below geomembrane

$\delta = 20°$, $a = 0$, $\phi = 30°$, $c = 0$ ✓

Other: $T = 0$ $\gamma_t = 125$ pcf $\approx \gamma_d$ ✓

$\gamma_{sat} = 125 + 0.3(62.4) = 144$ pcf ✓

$\gamma_b = 144 - 62.4 = 82$ pcf ✓

Written by: GES Date: 95/10/7 (YY/MM/DD) Reviewed by: _____ Date: __/__/__ (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.5

RCB 95/10/7

* Calculation for potential slip surface above geomembrane

Use eq (2) from "Calculation Procedures / Methods" Package.

Note that 2nd, 4th and 5th terms are zero because $a=0$, $c=0$ and $T=0$

$$FOS = \frac{\tan\delta}{\tan\beta}\left(\frac{\gamma_t(t-t_w)+\gamma_b t_w}{\gamma_t(t-t_w)+\gamma_{sat} t_w}\right) + 0 +$$

$$\frac{\sin\phi}{2\sin\beta\cos\beta\cos(\beta+\phi)}\left(\frac{t}{h}\right)\left[\frac{\gamma_t(t-t_w^*)+\gamma_b t_w^*}{\gamma_t(t-t_w)+\gamma_{sat} t_w}\right] + 0 + 0$$

$$= \frac{\tan 25}{\tan 14}\left[\frac{125(1-0.23)+82(0.23)}{125(1-0.23)+144(0.23)}\right] + \frac{\sin 30}{2\sin 14\cos 14\cos(14+30)}\left(\frac{1}{11}\right)\left[\text{same as in first term since } t_w = t_w^*\right]$$

$$= 1.87\,[0.890] + 1.481(0.091)[0.890] = 1.66 + 0.12$$

$$= \underline{\underline{1.78}}$$

* Calculation for potential slip surface below geomembrane

Use eq (3) from "Calculation Procedures / Methods" package

$$FOS = \frac{\tan\delta}{\tan\beta} + 0 + [\text{same as } 3^{rd} \text{ term from eq (2) above}] + 0 + 0$$

$$= \frac{\tan 20^\circ}{\tan 14^\circ} + [0.12] = 1.46 + 0.12$$

$$= \underline{\underline{1.58}}$$

$\boxed{\text{Critical FOS} = 1.58}$ — smaller of two values calculated above

Written by: GES Date: 95/10/7 (YY/MM/DD) Reviewed by: Date: / / (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.5

RCB 95/10/7

(6) Compare calculated critical FOS to target value.

Calculated critical FOS = 1.58
Target value = 1.3

1.58 > 1.3 OK ✓ ✓

The comparison indicates adequate stability ✓

(7) Consider tension in geosynthetic components of liner system:

The friction angles of all interfaces and materials in the liner system exceed the slope angle (i.e., min friction angle = 20° and slope angle = 14°). Therefore, tension in geosynthetic components should be negligible. ✓

3.3 Interim/Final Waste Slope Stability

COMPUTATION COVER SHEET

SUBJECT OF CALCULATION: INTERIM/FINAL WASTE SLOPE STABILITY

Computations By: (Cognizant Engineer)
Signature [signature] Date 09 Oct 95
Printed Name and Title ROBERT S COBLE II, STAFF ENGINEER

Assumptions and Procedures Checked by: (Checker)
Signature Thomas B. Maier Date 9 Oct 95
Printed Name and Title Thomas B. Maier, Asst. Project Engineer

Computations Checked by:
Signature Thomas B. Maier Date 9 Oct 95
Printed Name and Title Thomas B. Maier, Asst. Project Engineer

Computations Backchecked by: (Cognizant Engineer)
Signature [signature] Date 09 Oct 95
Printed Name and Title ROBERT S COBLE II, STAFF ENGINEER

Approved by: (PDP)
Signature Mark H. Gleason Date 09 Oct 95
Printed Name and Title MARK H GLEASON, ASSISTANT PROJECT ENGINEER

Approved by: (DTL and TETL)
Signature Rudolph Bonaparte Date 10 Oct 95
Printed Name and Title Rudolph Bonaparte

Record of Revision (Number and initial all revisions)

NO.	REASON	DATE	BY	CHECKED	APPROVAL
B	Preliminary Design EPA Submittal	14 Dec 95	[illegible]		

Signature: _____
Number: _____
Registration Stamp (if applicable)

Written by: M. Gleason Date: 95 / 10 12 14 Reviewed by: TM Date: 95 / 12 / 14

Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 9.6

14Dec95

INTERIM/FINAL WASTE MASS STABILITY

EXECUTIVE SUMMARY

Purpose

This calculation package contains analyses for static stability of the OSDF waste mass for final and interim configurations. The stability of the OSDF is calculated for failure surfaces that pass through the waste mass and along the liner system of the OSDF.

Procedure

Calculations were performed for the interim and final OSDF configurations as shown on the figures presented in this package. Minimum acceptable factors of safety (FS) based on UMTRA Technical Approach Document (DOE, 1989) are as follows: (i) Long-Term Stability, FS $\geq$ 1.5; and (ii) End of Construction Stability (Interim/Short-Term), FS $\geq$ 2.3.

The stability analyses are performed using established geotechnical procedures for calculating slope stability.

Results

	Factor of Safety
• Interim Conditions	
· Dry Unreinforced Bentonite Interface	FS = 1.8
· Hydrated Reinforced Bentonite (GCL)	FS = 1.8
• Long-Term Conditions	
· Peak Hydrated GCL Strengths	FS = 2.0
· Large Displacement Hydrated GCL Strengths	FS = 1.7

All factors of safety meet the established criteria.

Written by: R. Coble Date: 95/09/25 (YY MM DD) Reviewed by: JM Date: 95/10/9 (YY MM DD)

Client: Fermco Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.6

RB 95/09/27
JM 95/10/20

INTERIM/FINAL WASTE SLOPE STABILITY

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Written by: M. GLEASON Date: 95/10/9 (YY MM DD) Reviewed by: JM Date: 95/10/9 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.6

INTERIM / FINAL

95/10/10

WASTE MASS STABILITY SUMMARY

JM 95/10/20

INTERIM AND FINAL LANDFILL CONFIGURATION

This calculation package contains analyses for stability of the OSDF waste mass for final and interim configurations. The stability of the OSDF is calculated for failure surfaces that pass through the waste mass and along the liner system of the OSDF.

Calculations were performed for the interim and final OSDF configurations as shown on the Figures presented in this package.

Minimum acceptable factors of Safety (FS) based on UMTRA Technical Approach Document (DOE, 1989) are as follows:

Long-term stability FS ≥ 1.5

End of Construction Stability (Interim / Short Term) FS ≥ 1.3

Results for Waste Mass Stability

Interim conditions

Dry unreinforced Bentonite Interface FS = 1.8

Hydrated reinforced Bentonite (GCL) FS = 1.8

Long-Term Conditions

Peak Hydrated GCL strengths FS = 2.0

Large Displacement Hydrated GCL Strengths FS = 1.7

ALL FACTORS OF SAFETY MEET THE ESTABLISHED CRITERIA

Written by: M. GLEASON Date: 95/9/14 (YY MM DD) Reviewed by: JM Date: 95/10/9 (YY MM DD)

Client: FEMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.6

INTERIM/FINAL WASTE STABILITY - DATA VERIFICATION

RB 95/09/27
JM 95/10/20

PURPOSE: The purpose of this document is to describe the engineering procedures used to collect data for use in the analysis for Foundation Stability of the On-Site Disposal Facility (OSDF). The data thus collected is provided for verification.

SCOPE: Collect Engineering Data for the liner system stability analysis of the OSDF. Data required for this analysis includes engineering properties of the waste, engineering properties of the materials in the cover and liner systems, and shear strength properties of the potential interfaces in the liner system. Also required for the analysis is the geometry of the landfill for interim and final configurations. Data required includes base grades, berm heights, interim and final waste slopes, and waste configuration.

DESIGN: Material properties are required for failure surfaces that pass through the waste and along an interface (found to be a weak layer) in the liner system. The computer program XSTABL (Sharma, 1994) (Ref 1) is used to perform slope stability computations.

PARAMETERS FOR DESIGN

COVER SYSTEM - ASSUME GRANULAR COMPONENTS OF COVER SYSTEM
Granular soils HAVE SIMILAR BASIC PROPERTIES

$\gamma_T = 125$ pcf $\phi = 30$ degrees

Cover system - Recompacted Brown Till 2-ft thick

SEE FOUNDATION STABILITY CALCULATIONS FOR DETAILED DATA ANALYSIS WHICH IS SUMMARIZED HERE:

Assume brown till will be used for the cover clay layer and will be compacted at a minimum dry density of 95 percent of Standard Proctor Optimum (ASTM D698), and at a water content of 2-4 percent wet of optimum.

Written by: M. GILLEASON Date: 95/9/14 (YY MM DD) Reviewed by: JM Date: 95/10/9 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.6

RB 95/09/27
JM 95/10/20

INTERIM / FINAL WASTE STABILITY - DATA VERIFICATION

COVER SYSTEM - RECOMPACTED CLAY.

From information Provided by Parsons, 1995 TABLE 4-8 (Ref 2) the following is assumed to represent average values

$\gamma_{dry\ max} = 118$ pcf W_c optimum $= 13.7\%$

At 95% of $\gamma_{d\,max}$ $\gamma_d = 118(0.95) = 112$ pcf

At 2% wet of optimum $\gamma_d = 112(1.157) = 129.6$ pcf
At 4% wet of optimum $\gamma_d = 112(1.177) = 131.8$ pcf

→ Assume $\gamma_T = 130$ pcf for all recompacted clay

DRAINED SHEAR STRENGTH OF CLAY

Presented Below is a summary of consolidated-undrained triaxial tests on Remolded Brown Till (Parsons, 1995, TABLE 4-9). (Ref 2)

BORING	MATERIAL	DEPTH	$\bar{c}$ psf	$\bar{\phi}$ degrees	
11468	CL	2-6.5	325	29	At optimum W_c
11472	CL	9-12	100	29	"
11474	CL	3-7.5	200	30	"
11478	CL	3-7.5	400	23	"
11478	CL	3-7.5	175	28	3% Dry of Opt.
11478	CL	3-7.5	250	25	4% wet of Opt.

Inconclusive tests

Average $\bar{\phi}$ for Sample at optimum $\bar{\phi} = 27.8°$

Assume ~10% decrease in strength for samples compacted 2-4% wet of optimum and at 95% of γ_d max.

∴ Assume $\bar{\phi} = (27.8) - 0.1(27.8) \approx 25°$

ASSUME GEOSYNTHETICS IN COVER SYSTEM ARE NOT RELEVANT FOR LINER SYSTEM STABILITY

UNDRAINED SHEAR STRENGTH OF COMPACTED CLAY LINER WAS CONSIDERED IN THE ANALYSIS FOR FOUNDATION STABILITY OF THE OSDF AND THEREFORE IS NOT CONSIDERED IN THESE CALCULATIONS

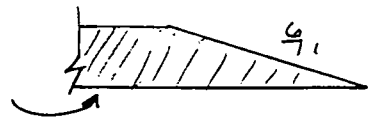
Written by: M. GLEASON Date: 95/9/14 (YY/MM/DD) Reviewed by: JM Date: 95/10/9 (YY/MM/DD)

Client: FERMCO Project: OSDE Project/Proposal No.: GE 3900 Task No.: 9.6

INTERIM/FINAL STABILITY - DATA VERIFICATION

RB 95/09/27
JM 95/10/20

PARAMETERS FOR DESIGN



WASTE MATERIAL - IN OSDE

- BASED ON project scope of work, waste material is expected to include the following:
  - contaminated site soils,
  - demolition debris,
  - municipal solid waste (MSW)
  - lime sludge, and
  - fly ash (properties comparable to bottom ash).

Because of the waste variability, the waste properties will also vary. Assume the waste will be placed under well-controlled conditions

For the analysis, assume a range of properties:

unit weight γ_T = 80 pcf for waste only. (low)
γ_T = 125 pcf for waste only (high)

Shear Strength: Assume lime sludge will be mixed with soils and/or demolition debris so that it is not placed in one location in significant quantities.

For MSW - estimate $\phi = 33$ (Kavazanjian et al 1995) (Ref 3)
- assume demolition debris will have at least this strength.

For ash materials - description of ash is that it is similar to bottom ash.
- Assume $\phi = 34°$ (EPRI, 1989). (Ref 4)

FOR THE ANALYSIS ASSUME THE FOLLOWING:

γ_T = 125 pcf

Short-term shear strength $\phi = 25°$ C = 200 psf

long-term shear strength $\phi = 25°$ C = 0 psf

Written by: M. GLEASON Date: 95/9/14 (YY MM DD) Reviewed by: JM Date: 95/10/9 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.6

WASTE MASS STABILITY - DATA VERIFICATION

RB 95/09/27
JM 95/10/20

PARAMETERS FOR DESIGN

LINER SYSTEM - MATERIALS

- GRANULAR SOILS COMPONENTS

12" Pea Gravel leachate collection layer
12" Pea Gravel leachate detection layer

ASSUME $\gamma_T = 125$ pcf $\phi = 30°$

- RECOMPACTED CLAY

ASSUME A SIMILAR TYPE CLAY WITH SIMILAR COMPACTION REQUIREMENTS WILL BE USED IN THE LINER AS WAS DESCRIBED PREVIOUSLY FOR THE RECOMPACTED CLAY IN THE COVER SYSTEM. USE THE SAME PROPERTIES LISTED ON PAGE 2 OF THIS VERIFICATION PACKAGE

$\gamma_T = 130$ pcf $\bar{\phi} = 25°$

LINER SYSTEM - GEOSYNTHETICS AND INTERFACES

δ = interface shear strength

Geotextile/Pea Gravel Interface	$\tan\delta / \tan\phi \approx 0.7$-$0.9$ for angular soil For $\phi = 30°$ for pea gravel (conservative) $\delta = 22°$ to $27°$ ✓	(Ref 5)
Geotextile/HDPE Interface	For textured HDPE Assume $\delta = 25°$	(Ref 5)
Recompacted Clay/ Geotextile Interface	Assume $\tan\delta / \tan\phi = 0.8$ For $\phi = 25°$ ∴ Assume $\delta = 20°$ ✓	(Ref 5)

Written by: M. GLEASON Date: 95/9/14 (YY MM DD) Reviewed by: JM Date: 95/10/9 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.6

RB 95/09/27
JM 95/10/20

WASTE MASS Stability - Data Verification

LINER SYSTEM - GEOSYNTHETICS

GCL INTERNAL SHEAR STRENGTH AND GCL/HDPE INTERFACE SHEAR STRENGTH.

- FOR SHORT-TERM CONDITIONS.

  Bentonite in primary GCL is protected from hydration by a geomembrane on either side.
  Interface is unhydrated bentonite / textured HDPE.
  Assume ϕ unhydrated bentonite = 25°.
  Bentonite / HDPE $\tan\delta / \tan\phi \approx 0.8$

  Interface strength $\delta = 20°$ ✓

  Bentonite in secondary GCL in a reinforced GCL. GCL will be placed against most soil and is expected to become hydrated in short-term conditions.
  Assume GCL reinforcement in short-term is in-tact.
  → Assume reinforced GCL $\tan\phi_{peak}$ = 2 $\tan\phi_{peak}$ unreinforced GCL.
  Use peak strengths for reinforced GCLs.
  ϕ_{peak} unreinforced GCL is dependent on normal stress in the GCL as described below.

  Based on test data in Geosyntec files JM

- For LONG-TERM CONDITIONS, reinforcement assume Bentonite in GCL is hydrated and GCL (if reinforced) is not effective. Based on Ref 6, the following strengths are used

Normal Stress (psf)	ϕ_{peak}	$\phi_{large\ displacement}$	$\phi_{peak\ reinforced}$
7500	8	5	15
5600	9	6	17
1900	12	10	23
200	16	15	30

The minimum normal stress on the figure on page 10 is 500 psf. The ϕ shown for 500 psf was used for 200 psf and is conservative. JM

Written by: M. GLERSON Date: 95/9/14 Reviewed by: JM Date: 95/10/8

Client: FREMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.5

RB 95/09/27
JM 95/10/20

WASTE STABILITY

SUMMARY.

FOR SHORT-TERM CONDITIONS CRITICAL INTERFACE IS EITHER PRIMARY GCL/HDPE interface ($\delta = 70°$) or Reinforced GCL internal shear strength where ϕ_p varies with σ_n. Both cases will be considered.

FOR LONG-TERM CONDITIONS, THE CRITICAL INTERFACE IS EITHER GCL. (Assuming both are hydrated). Shear strength varies with σ_n as shown on previous page.

Written by: M. GLEASON Date: 95/9/14 (YY MM DD) Reviewed by: JM Date: 95/10/9 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.6

NB 95/09/27
JM 95/10/20

WASTE MASS STABILITY

REFERENCES

1. Sharma, S. "XSTABL: An Integrated Slope Stability Analysis Program for Personal Computers, Version 5.1," Interactive Software Designs, Moscow, ID, 1994

2. PARSONS, "Disposal Facility Pre-Design Geotechnical Investigation, Soil Investigation Data Report," Operable Unit 2, Project Order 132, July 1995 FERMCO, DOE

3. KAVAZANJIAN, E, MAHMOUD, N, Bonaparte, R., and Schmertmann, G. "Evaluation of MSW Properties for Seismic Analysis" Proceedings Geoenvironment 2000, New Orleans, LA 1995

4. Electric Power Research Institute, "Ash Utilization in Highways, Delaware Demonstration Project," prepared by Delmarva Power and Light Company, Wilmington, DE, EPRI Project 2422-3 August 1989.

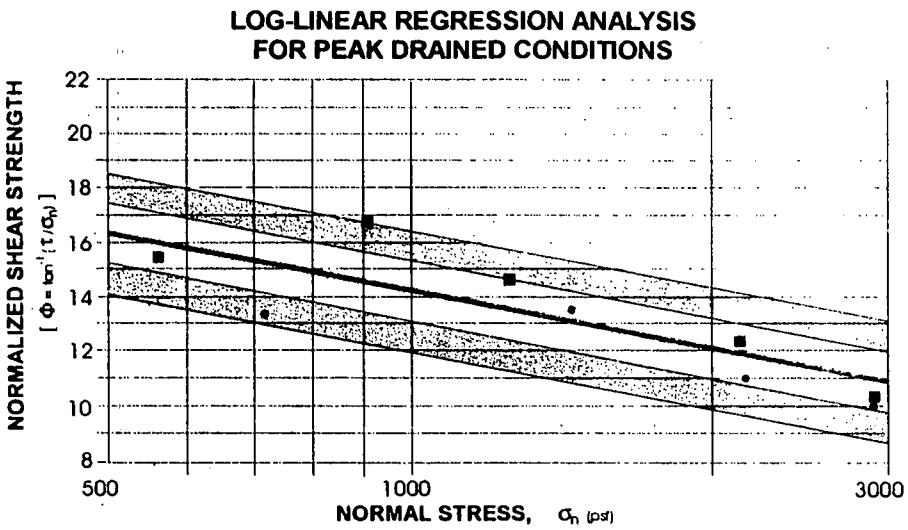
5. Data established from
   - manufacturer's Literature
   - unpublished results from GeoSyntec
   - Martin, J.P., Koerner, R.M., and Whitty "Experimental Friction Evaluation of Slippage Between Geomembranes, Geotextiles, and Soils," Proceedings, International Conference on Geotextiles, IFAI Denver, 1984, pp 191-196
   - Koerner, R.M., Martin, J.P., and Koerner, G.R., "Shear strength Parameters between Geomembranes and Cohesive Soils", Geotextiles and Geomembranes. Vol 4, No. 1 1986, pp 21-30.
   - Williams, N.D., and Houlihan, M.F. "Evaluation of Interface Friction Properties Between Geosynthetics and Soils," Proceedings Geosynthetics '87, New Orleans, LA Feb 1987, pp 616-627.

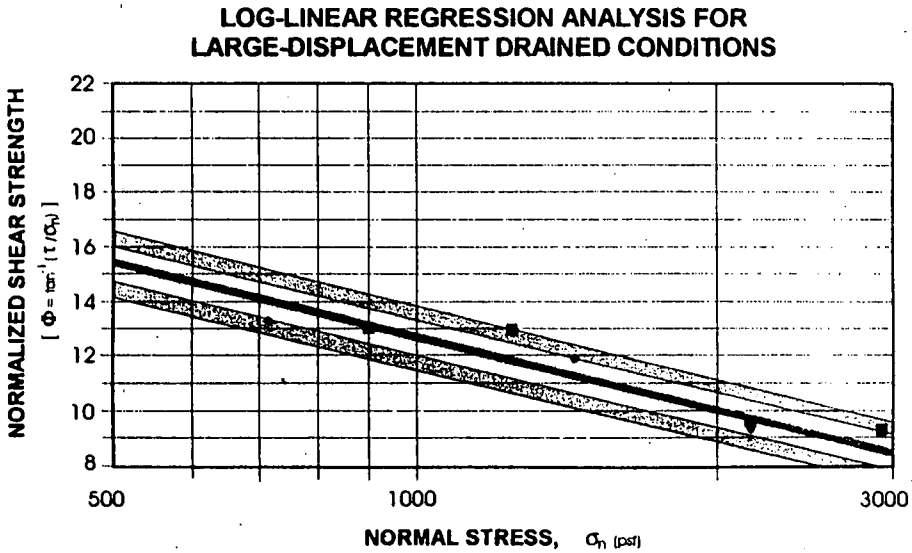
6. Internal memorandum by GeoSyntec Consultants, "Internal Shear Strength of Hydrated GCL's," August 1994.

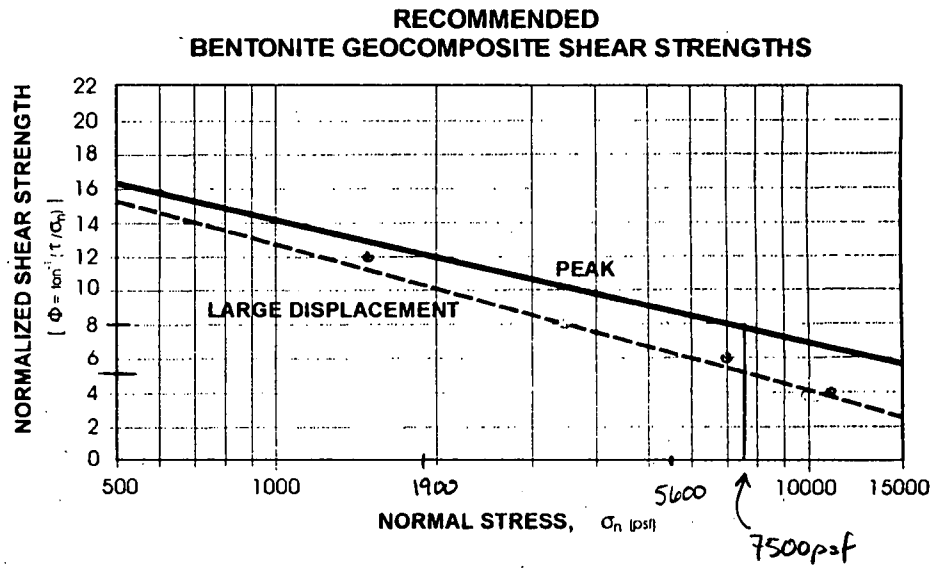
7. Spencer, E "A method of Analysis of the Stability of Embankments Assuming Parallel Interslice Forces," Geotechnique Vol. 17 1967 pp 11-26

8. US Dept. of Energy, "Uranium Mill Tailings Remediation Control Act," Remedial Action Design, Technical Approach Document, Revision 2, December 1989.

10. Use this space to provide any additional information or description of resources (including any computer design capabilities) supporting your firm's qualifications for the proposed project.







- • CLAYMAX
- ■ GUNDSEAL
- ● HSM = HOMION SODIUM MONTMORILLONITE, CONSOLIDATED FROM A SLURRY, AND TESTED IN TRIAXIAL COMPRESSION HSM DATA FROM MESRI,G AND OLSON, R E., "SHEAR STRENGTH OF MONTMORILLONITE", GEOTECHNIQUE, VOL NO 20, 1970, PP 2261-270
- 67% STANDARD ERROR RANGE
- 95% STANDARD ERROR RANGE

FIGURE 10-6
DRAINED SHEAR STRENGTH OF UNREINFORCED BENTONITE GEOCOMPOSITE

186 03 95/09/27 95/10/20 10/48

000650

Written by: R. COBLE Date: 95/09/25 (YY MM DD) Reviewed by: JM Date: 95/10/9 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.6

JM 95/10/20

INTERIM/FINAL WASTE SLOPE STABILITY CALCULATION PACKAGE

PURPOSE: THE PURPOSE OF THIS DOCUMENT IS TO PROVIDE THE ENGINEERING CALCULATIONS USED IN ESTABLISHING THE STABILITY OF THE OSDF LINER SYSTEM. THE CALCULATIONS EXAMINE THE RESISTANCE TO FAILURE DUE TO SLIPPAGE ALONG THE OSDF LINER. ANALYSES WERE PERFORMED FOR BOTH THE INTERIM AND FINAL CONFIGURATIONS OF THE LANDFILL. THE INTERIM CONFIGURATIONS MODEL THE CONDITIONS EXPECTED TO OCCUR WHILE THE LANDFILL IS BEING FILLED. THE INTERIM CONFIGURATIONS WERE ANALYSED FOR BOTH SHORT-TERM (UNDRAINED) AND LONG-TERM (DRAINED) SOIL STRENGTH PARAMETERS.

PROCEDURE: THE CALCULATION PROCEDURE USED FOR THE LINER STABILITY ANALYSIS IS DESCRIBED IN DETAIL IN THE DESIGN CRITERIA PACKAGE AND IS SUMMARIZED HERE. THE DATA USED IN THE LINER ANALYSIS (I.E. UNIT WEIGHTS, UNDRAINED SHEAR STRENGTHS, AND DRAINED SHEAR STRENGTHS) ARE PROVIDED IN THE DATA VERIFICATION PACKAGE.

THE COMPUTER PROGRAM XSTABL (SHARMA, 1994) WAS USED TO PERFORM THE STABILITY ANALYSES. THE WEDGE FAILURE/SLIP SURFACES WERE ANALYSED USING SPENCER'S METHOD (SPENCER, 1967).

ANALYSIS:

I. XSTABL COMPUTER MODEL NOTES

A. THE STABILITY OF THE LINER SYSTEM AND THE ASSOCIATED FACTORS OF SAFETY AGAINST FAILURE WERE GENERATED USING THE PROGRAM XSTABL, VERSION 5.

B. FOR WEDGE FAILURE ANALYSES, THE COMPUTER PROGRAM REQUIRES THE OPERATOR TO DESIGNATE ONE, OR MORE, "BOXES" WITHIN THE MODEL THROUGH WHICH ALL OF THE FAILURE SURFACES MUST PASS.

Written by: R. COBLE Date: 95/09/25 (YY MM DD) Reviewed by: JM Date: 95/10/9 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.6

JM 95/10/20

II. METHODOLOGY FOR CRITICAL FAILURE PLANE SEARCH

A. THE INTERFACE FRICTION STRENGTHS AND INTERNAL STRENGTH OF EACH OF THE LINER SYSTEM COMPONENTS WERE EXAMINED AND THE WEAKEST LINER SYSTEM COMPONENT WAS IDENTIFIED (SEE DATA COLLECTION AND VERIFICATION).

B. A SIMPLIFIED MODEL OF THE LANDFILL WAS CONSTRUCTED SO THAT THE WEAKEST LAYER OF THE LINER AND THE OVERLYING LAYERS OF THE LANDFILL COULD BE STUDIED.

C. TWO BOXES WERE DESIGNATED WITHIN THE MODEL. THE FIRST "BOX" CONSISTED OF A LINE (A BOX WITH NO HEIGHT) LOCATED IN THE WEAKEST LAYER OF THE LINER SYSTEM. THE LINE WAS SIZED TO CONTAIN THE LINER SYSTEM FROM THE TOE OF THE LANDFILL TO A POINT HAVING THE SAME X-COORDINATE AS THE MID-POINT OF THE LANDFILL FACE SLOPE. THE SECOND BOX (LINE) WAS SIZED TO CONTAIN AS MUCH OF THE REMAINING LINER SYSTEM AS THE MODEL WOULD ALLOW.

D. ONE HUNDRED FAILURE SURFACES WERE THEN GENERATED THROUGH THE 2 INITIAL BOXES.

E. THE 10 MOST CRITICAL FAILURE PLANES WERE PLOTTED.

F. BOTH LINES WERE THEN SHORTENED AND REPOSITIONED TO CONTAIN THE INFLECTION POINTS OF THE 10 MOST CRITICAL FAILURE PLANES.

G. STEPS C THROUGH F WERE REPEATED UNTIL A SINGLE, MINIMUM FACTOR OF SAFETY AGAINST FAILURE WAS OBTAINED FOR 2 CONSECUTIVE RUNS, OR THE FACTOR OF SAFETY BEGAN TO INCREASE.

H. THE FINAL FACTOR OF SAFETY AGAINST A WEDGE FAILURE WAS DERIVED BY USING SPENCER'S METHOD ON THE WEDGE FAILURE PLANES GENERATED IN THE ABOVE STEPS.

Written by: R. Cobb Date: 95/09/25 (YY MM DD) Reviewed by: JM Date: 95/10/9 (YY MM DD)

Client: Fermco Project: OSDF Project/Proposal No.: GR 3900 Task No.: 09.6

JM 95/10/20

III. INTERIM LANDFILL CONDITIONS

A. LANDFILL GEOMETRY

THE INTERIM CONDITIONS ARE EXPECTED TO OCCUR PRIOR TO CAPPING, WHILE THE LANDFILL IS BEING FILLED. DURING FILLING OPERATIONS, IT IS ASSUMED THAT:

- THE MAXIMUM HEIGHT OF WASTE WILL BE 60 FT.;
- ANY OPEN FACE WILL HAVE A TEMPORARY MAXIMUM SLOPE OF 3H:1V; AND
- ADJACENT CELLS MAY BE EXCAVATED UP TO 10 FT. IN DEPTH.

SEE FIG. 1 FOR THE INTERIM MODEL GEOMETRY.

B. MATERIAL STRENGTH PARAMETERS

1. THE WEAKEST LAYER IDENTIFIED IN THE LINER SYSTEM WAS THE BENTONITE LAYERS INCLUDED AS PART OF THE GEOSYNTHETIC CLAY LINER (GCL). THE STABILITY OF THE LANDFILL WAS CALCULATED FOR THE FOLLOWING CONDITIONS: (i) short-term conditions with "dry" unreinforced GCL; and (ii) short-term conditions with hydrated reinforced GCL.

2. IN ADDITION TO THE BENTONITE'S STRENGTH VARIATION DUE TO HYDRATION, THE STRENGTH OF THE BENTONITE WILL ALSO VARY WITH THE STRESS INDUCED BY THE OVERBURDEN. DUE TO VARIATION IN OVERBURDEN THICKNESS, THE BENTONITE WAS DIVIDED INTO 4 SECTIONS AND THE AVERAGE OVERBURDEN STRESS FOR EACH SECTION WAS USED.

3. TABLE 1 SHOWS THE STRENGTH PARAMETERS USED IN THE INTERIM ANALYSIS.

Written by: R. Cobb Date: 95/09/25 (YY/MM/DD) Reviewed by: JM Date: 95/10/9 (YY/MM/DD)

Client: Fernco Project: OSDF Project/Proposal No.: GE 3900 Task No.: 08.6

JM 95/10/20

INTERIM LANDFILL CONFIGURATION
(NOT TO SCALE)

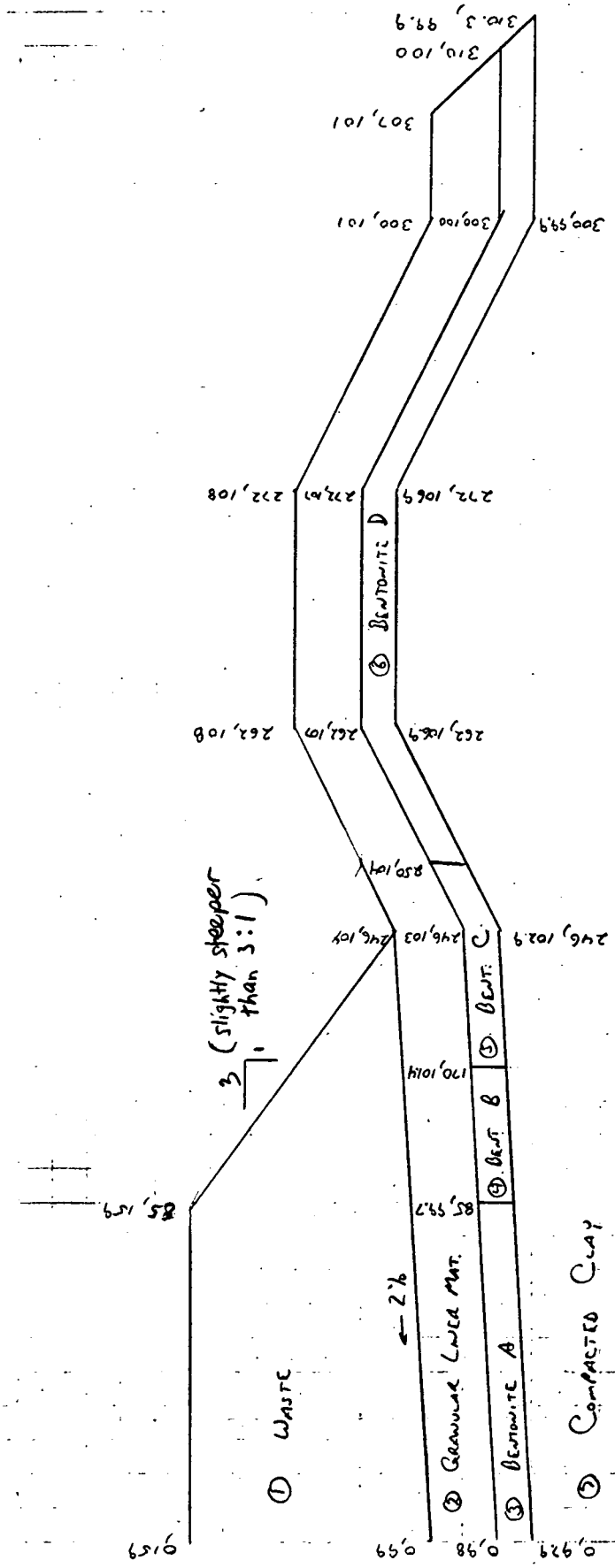


FIGURE 1

JM 95/10/20

TABLE 1: INTERIM MATERIAL STRENGTH PARAMETERS

* USE SHORT-TERM WASTE STRENGTH

Used for interim Condition JM

	MATERIAL	WEIGHT γ (PCF)	OVERBURDEN* STRESS (PSF)	SHEAR STRENGTH PARAMETER - ϕ (DEGREES) DRY	PEAK HYDRATED (unreinforced)	Hydrated Peak Reinforced
1	WASTE	125	N/A	$\phi = 25°$ $C = 200$ psf	—	—
2	GRANULAR LINER MATERIAL	125	N/A	30	—	—
3	BENTONITE A	125	7500	20	8	15
4	BENTONITE B	125	5600	20	9	17
5	BENTONITE C	125	1900	20	12	23
6	BENTONITE D	125	200	20	16	30
7	COMPACTED CLAY	130	N/A	25	—	—

* ASSUMES AN AVERAGE OVERBURDEN DENSITY OF 125 PCF.

Written by: R. COOLE Date: 95/09/25 (YY/MM/DD) Reviewed by: JM Date: 95/10/9 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.6

JM 95/10/20

IV FINAL LANDFILL CONDITIONS

A. LANDFILL GEOMETRY

THE FINAL CONDITIONS EXAMINED WILL OCCUR AFTER THE LANDFILL HAS BEEN CLOSED AND CAPPED. SEE FIGURES 2 AND 3 FOR THE FINAL MODEL GEOMETRY.

B. MATERIAL STRENGTH PARAMETERS

FOR THE FINAL CONFIGURATION OF THE LANDFILL, ONLY THE HYDRATED STRENGTHS OF THE BENTONITE WERE INPUT. THIS IS DUE TO THE ASSUMPTION THAT THE BENTONITE IN ALL GCLS will become hydrated and the reinforcement will be lost.

AS IN THE INTERIM MODEL, THE STRENGTH OF THE BENTONITE WILL VARY WITH THE OVERBURDEN PRESSURE.

TABLE 2 SHOWS THE STRENGTH PARAMETERS USED IN THE FINAL CONFIGURATION MODEL

THE FACTOR OF SAFETY IS CALCULATED FOR PEAK STRENGTHS AND FOR LARGE DISPLACEMENT STRENGTHS

Written by: R. Cooke Date: 95/09/25 (YY MM DD) Reviewed by: JM Date: 95/10/9 (YY MM DD)

Client: Fermco Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.6

JM 95/10/20

FINAL CONFIGURATION GEOMETRY
(NOT TO SCALE)

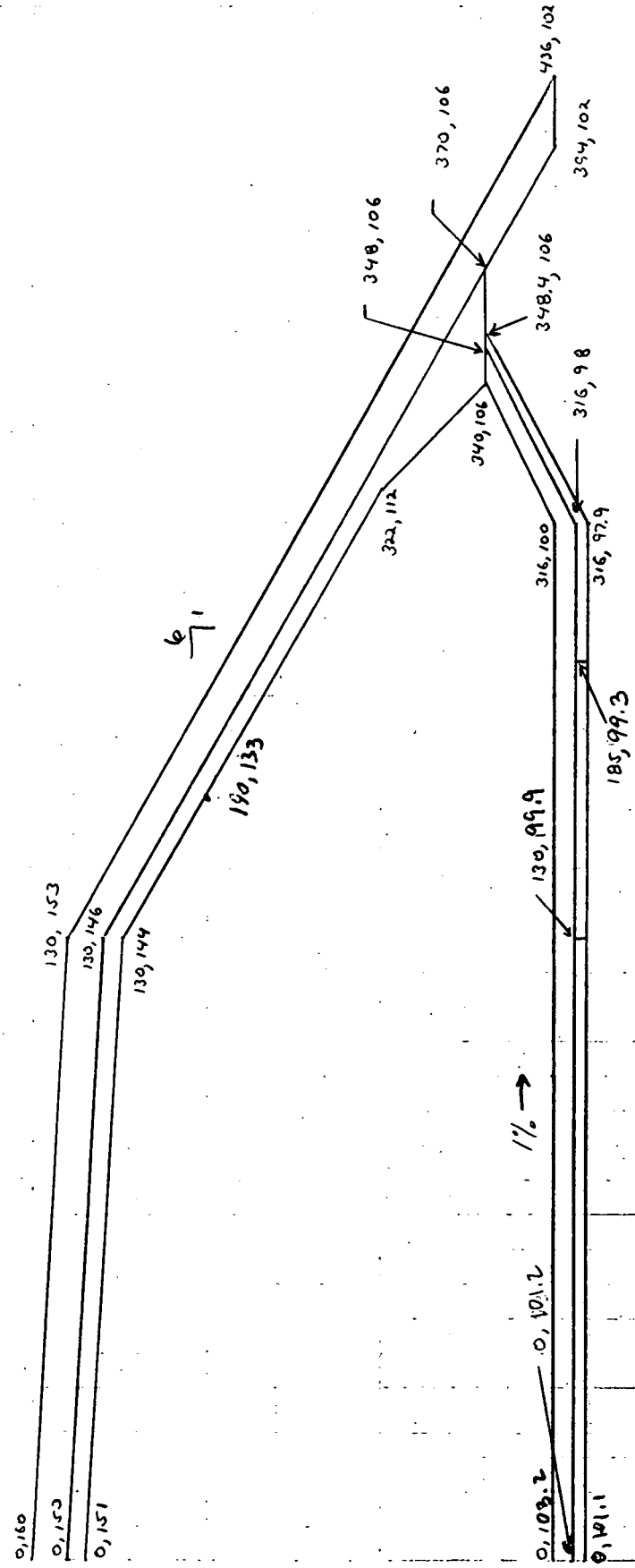


FIGURE 2

GEOSYNTEC CONSULTANTS

Written by: R. Cobce Date: 95/09/25 (YY/MM/DD) Reviewed by: JM Date: 95/10/9 (YY/MM/DD)

Client: Fermco Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.6

JM 95/10/20

FINAL CONFIGURATION COMPONENTS MATERIAL

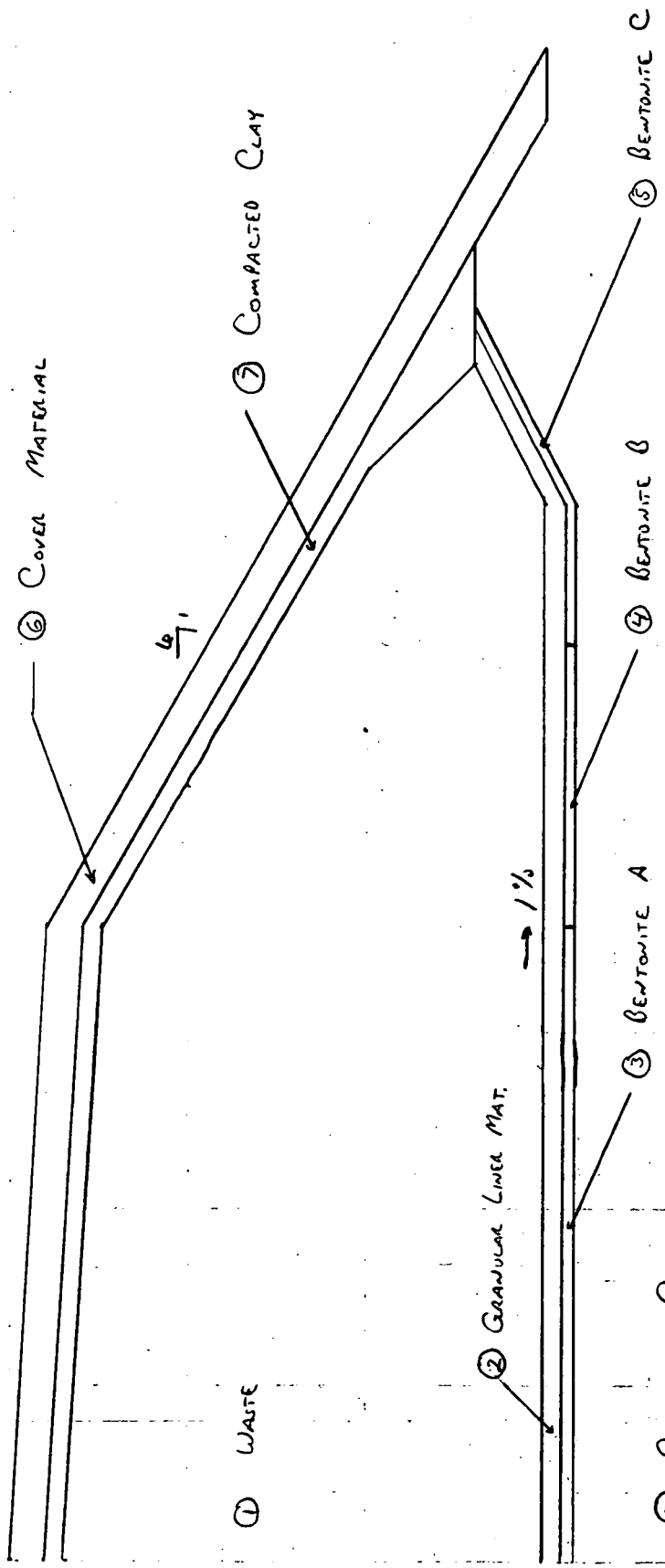


FIGURE 3

Written by: R. Cobble Date: 95/09/25 (YY MM DD) Reviewed by: JM Date: 95/10/8 (YY MM DD)

Client: Fermco Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.6

JM 95/10/20

TABLE 2: FINAL MATERIAL STRENGTH PARAMETERS

MATERIAL	WEIGHT - γ (PCF)	OVERBURDEN* STRESS (PSF)	SHEAR STRENGTH PARAMETER - ϕ (DEGREES) DRY	PEAK HYDRATED	LARGE DISP. HYD.
① WASTE	125	N/A	25	—	—
② GRANULAR LINER MATERIAL	125	N/A	30	—	—
③ BENTONITE A	125	7500	—	8	5
④ BENTONITE B	125	6300	—	8	6
⑤ BENTONITE C	125	3900	—	10	7
⑥ COVER MATERIAL	125	N/A	30	—	—
⑦ COMPACTED CLAY	130	N/A	25	—	—

* ASSUMES AN AVERAGE OVERBURDEN DENSITY OF 125 PCF.

Written by: M. GLEASON Date: 95/10/19 (YY MM DD) Reviewed by: JM Date: 95/10/9 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.6

JM 95/10/20

WASTE MASS STABILITY

The minimum acceptable Factors of Safety for slope stability as stated in USNRC, 1989 (Ref 8) are:

1.5 for long-term conditions; and

1.3 for interim - end of construction conditions.

THE CALCULATED FACTORS OF SAFETY FOR THE CASES CONSIDERED IN THIS ANALYSIS ARE:

INTERIM CONDITIONS

1.8 FOR DRY GCL (UNREINFORCED)

1.8 FOR HYDRATED GCL (REINFORCED)

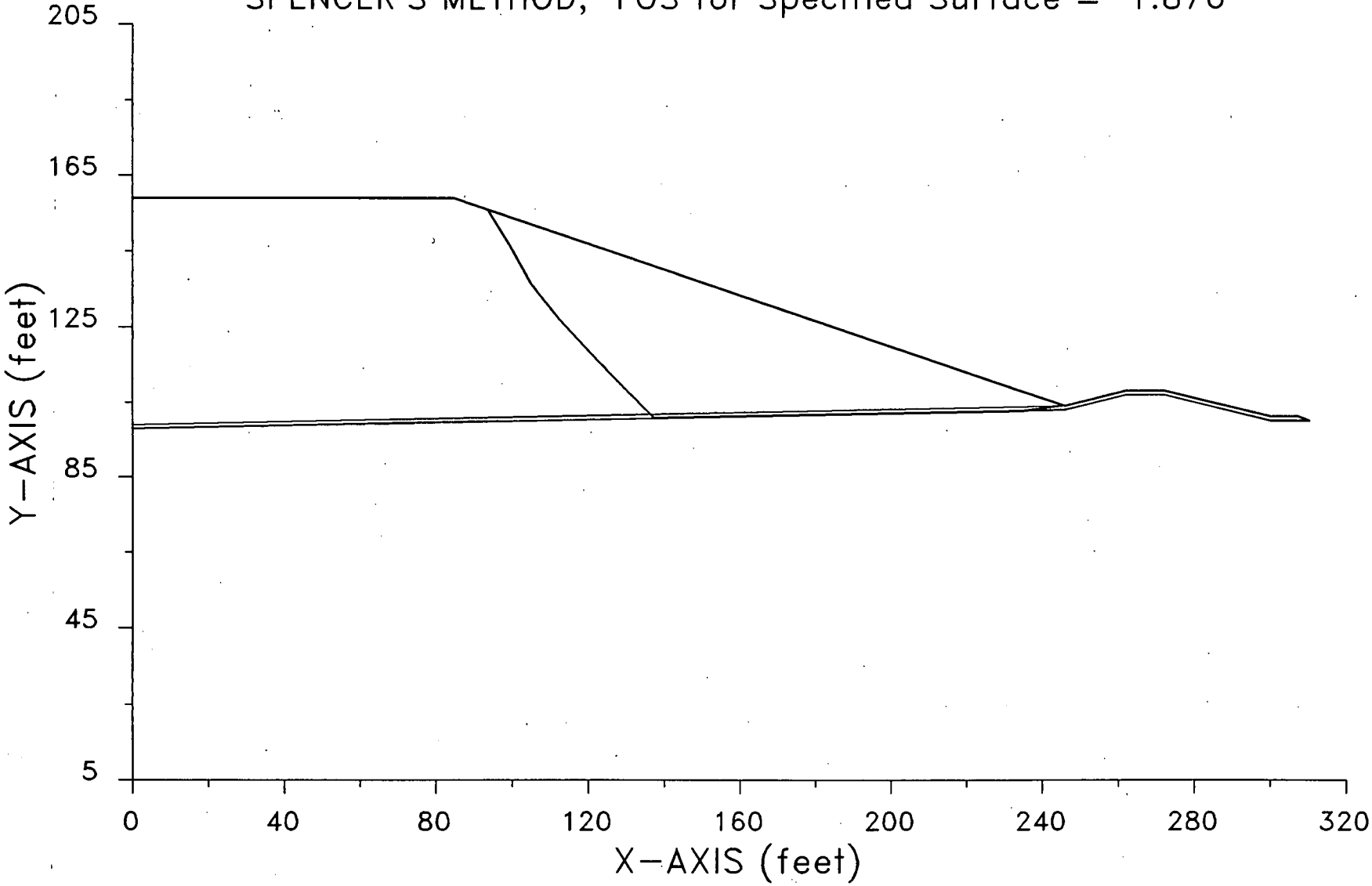
LONG-TERM CONDITIONS

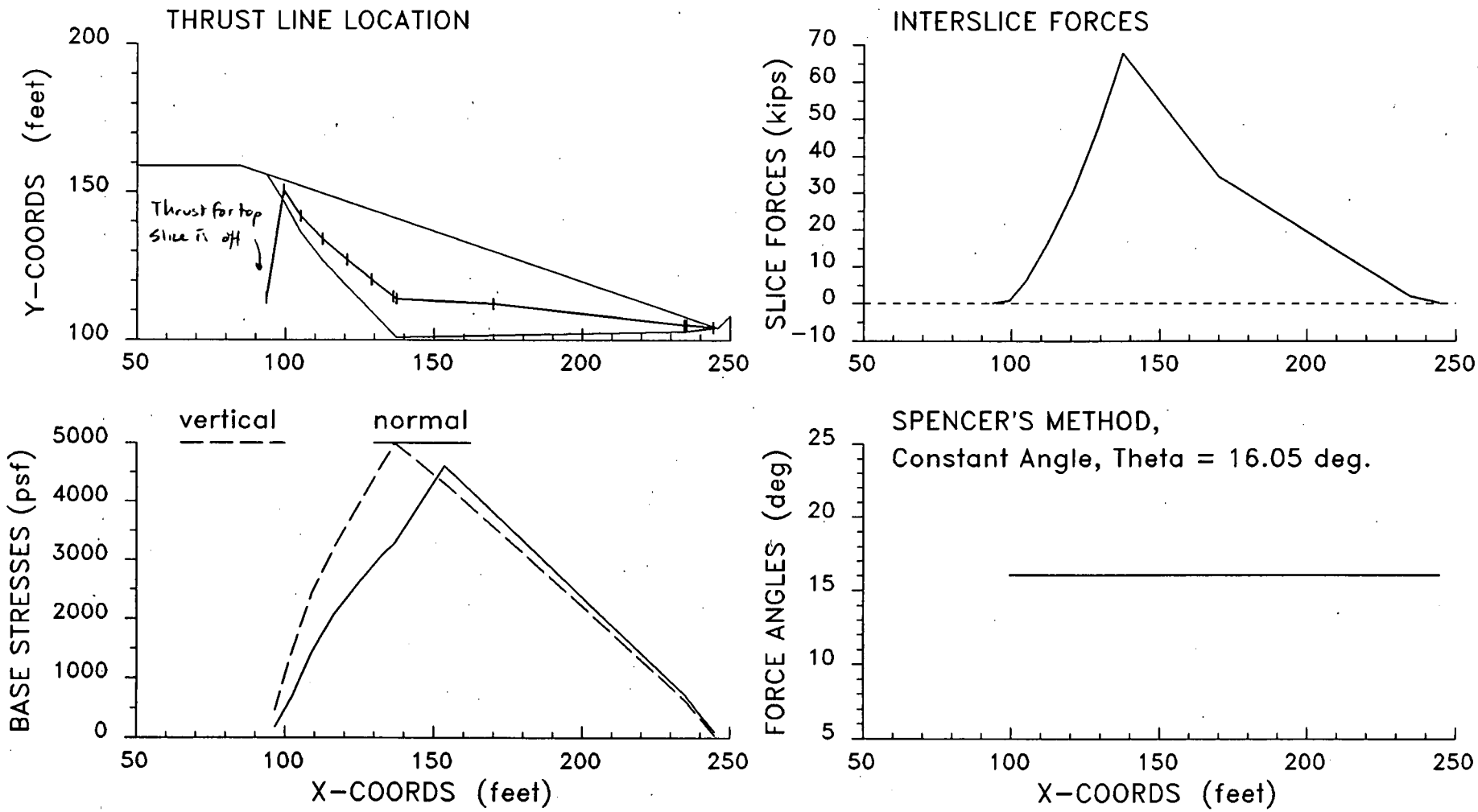
2.0 FOR PEAK HYDRATED GCL STRENGTHS

1.7 FOR LARGE DISPLACEMENT HYDRATED GCL STRENGTHS

ALL FACTORS OF SAFETY MEET THE ESTABLISHED CRITERIA

SHORT TERM DRY STRENGTHS
SPENCER'S METHOD, FOS for Specified Surface = 1.876





SHORT TERM DRY STRENGTHS
SPENCER'S METHOD, FOS for Specified Surface = 1.876

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Acc 95/10/20 F-186

Asc 09 Oct 95 JM 95/10/20

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*              X S T A B L              *
*                                       *
*       Slope Stability Analysis        *
*              using the                *
*           Method of Slices            *
*                                       *
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Problem Description : SHORT TERM DRY STRENGTHS

SEGMENT BOUNDARY COORDINATES
---

8 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	159.0	85.0	159.0	1
2	85.0	159.0	246.0	104.0	1
3	246.0	104.0	262.0	108.0	2
4	262.0	108.0	272.0	108.0	2
5	272.0	108.0	300.0	101.0	2
6	300.0	101.0	307.0	101.0	2
7	307.0	101.0	310.0	100.0	2
8	310.0	100.0	310.3	99.9	6

14 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	99.0	246.0	104.0	2
2	.0	98.0	85.0	99.7	3
3	85.0	99.7	170.0	101.4	4
4	170.0	101.4	246.0	103.0	5
5	246.0	103.0	250.0	104.0	5
6	250.0	104.0	262.0	107.0	6
7	262.0	107.0	272.0	107.0	6
8	272.0	107.0	300.0	100.0	6
9	300.0	100.0	310.0	100.0	6
10	.0	97.9	246.0	102.9	7
11	246.0	102.9	262.0	106.9	7

12	262.0	106.9	272.0	106.9	7
13	272.0	106.9	300.0	99.9	7
14	300.0	99.9	310.3	99.9	7

ISOTROPIC Soil Parameters
---

7 Soil unit(s) specified

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	125.0	125.0	200.0	25.00	.000	.0	0
2	125.0	125.0	.0	30.00	.000	.0	0
3	125.0	125.0	.0	20.00	.000	.0	0
4	125.0	125.0	.0	20.00	.000	.0	0
5	125.0	125.0	.0	20.00	.000	.0	0
6	125.0	125.0	.0	20.00	.000	.0	0
7	130.0	130.0	.0	25.00	.000	.0	0

A SINGLE FAILURE SURFACE HAS BEEN SPECIFIED FOR ANALYSIS

Trial failure surface specified by
the following 9 coordinate points :

Point No.	x-surf (ft)	y-surf (ft)
1	245.63	104.13
2	234.78	102.68
3	137.56	100.75
4	129.19	109.35
5	120.86	117.98
6	112.70	126.78
7	105.33	136.26
8	99.50	146.74
9	93.74	156.01

****
SELECTED METHOD OF ANALYSIS: Spencer (1973)
****

****
SUMMARY OF INDIVIDUAL SLICE INFORMATION
****

Slice	x-base (ft)	y-base (ft)	height (ft)	width (ft)	alpha	beta	weight (lb)

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1	245.04	104.05	.28	1.19	-7.59	18.86	42.
2	239.99	103.37	2.68	8.92	-7.59	18.86	2988.
3	235.15	102.73	4.98	.75	-7.59	18.86	464.
4	202.39	102.04	16.86	64.78	-1.14	18.86	136531.
5	153.78	101.07	34.43	32.44	-1.14	18.86	139626.
6	137.06	101.26	39.95	1.00	45.78	18.86	4979.
7	132.88	105.56	37.08	7.37	45.78	18.86	34170.
8	125.02	113.67	31.66	8.33	46.01	18.86	32968.
9	116.78	122.38	25.76	8.16	47.16	18.86	26279.
10	109.01	131.52	19.28	7.37	52.14	18.86	17758.
11	102.42	141.50	11.55	5.83	60.91	18.86	8418.
12	96.62	151.38	3.65	5.76	58.16	18.86	2630.

ITERATIONS FOR SPENCER'S METHOD

Iter #	Theta	FOS_force	FOS_moment
2	16.0254	1.8760	1.9306
3	16.0505	1.8765	1.8760

SLICE INFORMATION ... continued :

Slice	Sigma (psf)	c-value (psf)	phi	U-base (lb)	U-top (lb)	P-top (lb)	Delta
1	93.4	200.0	25.00	0.	0.	0.	.00
2	402.7	.0	30.00	0.	0.	0.	.00
3	706.8	.0	20.00	0.	0.	0.	.00
4	2255.0	.0	20.00	0.	0.	0.	.00
5	4605.0	.0	20.00	0.	0.	0.	.00
6	3278.6	.0	30.00	0.	0.	0.	.00
7	3079.8	200.0	25.00	0.	0.	0.	.00
8	2613.2	200.0	25.00	0.	0.	0.	.00
9	2081.4	200.0	25.00	0.	0.	0.	.00
10	1423.2	200.0	25.00	0.	0.	0.	.00
11	677.9	200.0	25.00	0.	0.	0.	.00
12	176.2	200.0	25.00	0.	0.	0.	.00

SPENCER'S (1973) - TOTAL Stresses at center of slice base

Slice #	Base x-coord (ft)	Normal Stress (psf)	Vertical Stress (psf)	Pore Water Pressure (psf)	Shear Stress (psf)
1	245.04	93.4	35.2	.0	129.8
2	239.99	402.7	335.1	.0	123.9
3	235.15	706.8	622.0	.0	137.1
4	202.39	2255.0	2107.6	.0	437.4
5	153.78	4605.0	4304.0	.0	893.2
6	137.06	3278.6	4994.0	.0	1008.7
7	132.88	3079.8	4635.3	.0	871.9
8	125.02	2613.2	3957.7	.0	756.0
9	116.78	2081.4	3220.4	.0	623.8
10	109.01	1423.2	2409.5	.0	460.3
11	102.42	677.9	1443.8	.0	275.1

12	96.62	176.2	456.7	.0	150.4

SPENCER'S (1973) - Magnitude & Location of Interslice Forces

Slice #	Right x-coord (ft)	Force Angle (degrees)	Interslice Force (lb)	Force Height (ft)	Boundary Height (ft)	Height Ratio
1	244.44	16.05	175.	.25	.56	.443
2	235.53	16.05	1823.	2.08	4.80	.434
3	234.78	16.05	2003.	2.20	5.15	.426
4	170.00	16.05	34504.	10.67	28.57	.373
5	137.56	16.05	67742.	12.96	40.30	.322
6	136.56	16.05	65294.	12.70	39.61	.321
7	129.19	16.05	47708.	10.92	34.55	.316
8	120.86	16.05	30794.	8.97	28.77	.312
9	112.70	16.05	17032.	7.16	22.76	.315
10	105.33	16.05	6522.	5.41	15.79	.342
11	99.50	16.05	798.	3.81	7.31	.521
12	93.74	.00	-2.	-42.06	.00	.000

AVERAGE VALUES ALONG FAILURE SURFACE

Total Normal Stress = 2347.88 (psf)
Pore Water Pressure = .00 (psf)
Shear Stress = 538.10 (psf)

Total Length of failure surface = 179.10 feet

For the single specified surface and the assumed angle of the interslice forces, the SPENCER'S (1973) procedure gives a

FACTOR OF SAFETY = 1.876

Total shear strength available along specified failure surface = 180.84E+03 lb

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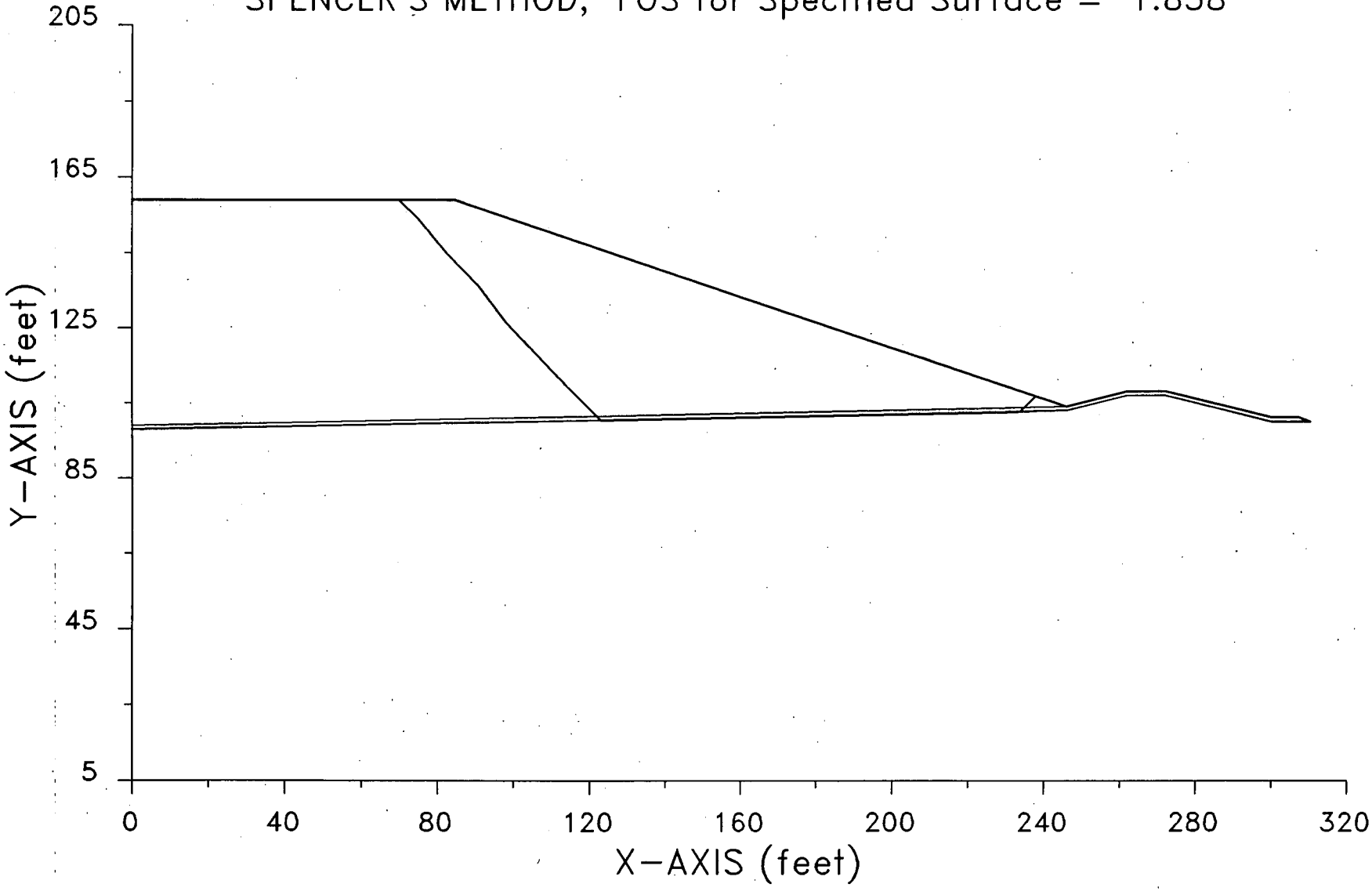
SHORT-TERM HYDRATED GCL STRENGTHS

SPENCER'S METHOD, FOS for Specified Surface = 1.858



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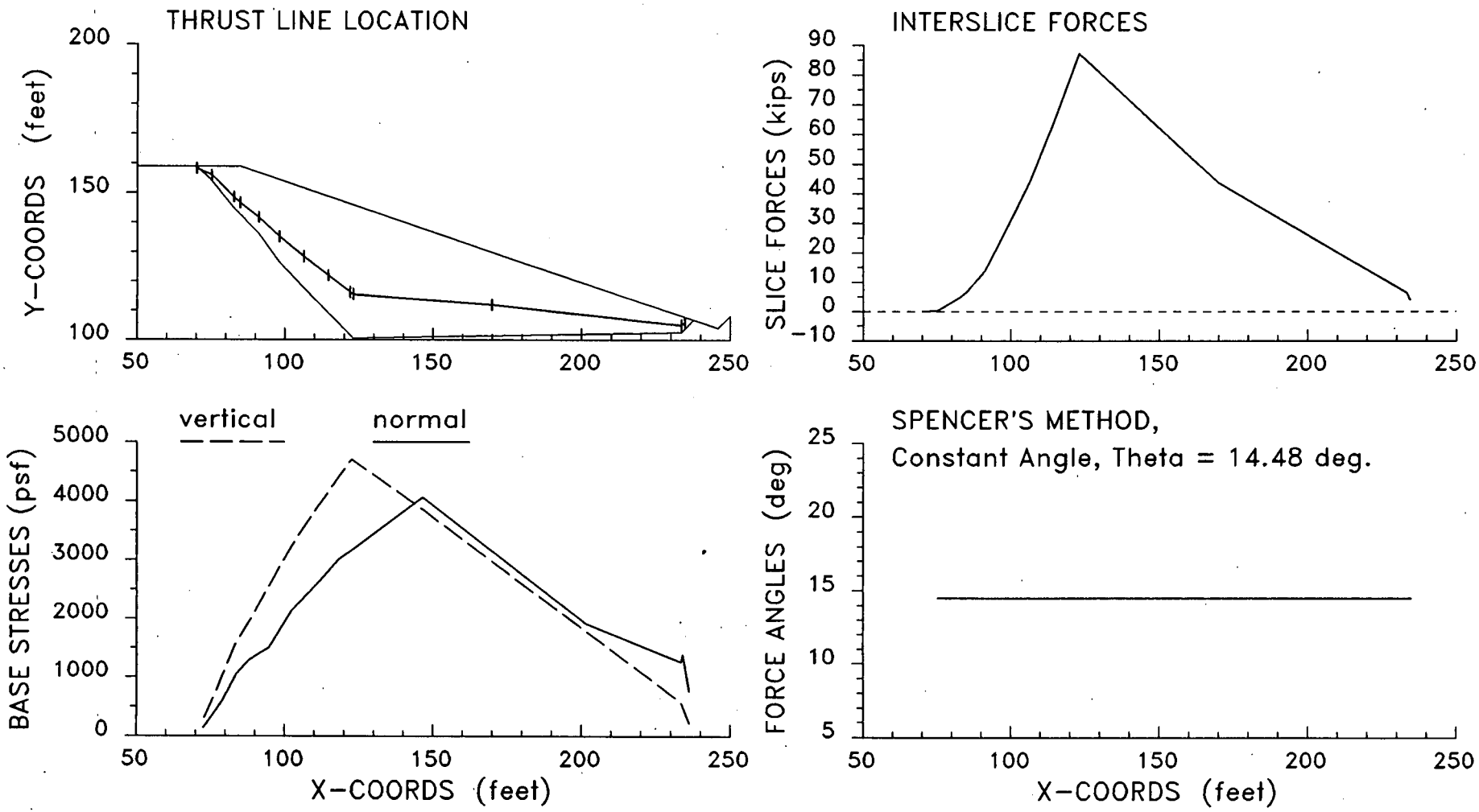

SHORT-TERM HYDRATED GCL STRENGTHS
SPENCER'S METHOD, FOS for Specified Surface = 1.858

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*****************************************
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*                                       *
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*               using the               *
*            Method of Slices           *
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Problem Description : SHORT-TERM HYDRATED GCL STRENGTHS

SEGMENT BOUNDARY COORDINATES
---

8 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	159.0	85.0	159.0	1
2	85.0	159.0	246.0	104.0	1
3	246.0	104.0	262.0	108.0	2
4	262.0	108.0	272.0	108.0	2
5	272.0	108.0	300.0	101.0	2
6	300.0	101.0	307.0	101.0	2
7	307.0	101.0	310.0	100.0	2
8	310.0	100.0	310.3	99.9	6

14 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	99.0	246.0	104.0	2
2	.0	98.0	85.0	99.7	3
3	85.0	99.7	170.0	101.4	4
4	170.0	101.4	246.0	103.0	5
5	246.0	103.0	250.0	104.0	5
6	250.0	104.0	262.0	107.0	6
7	262.0	107.0	272.0	107.0	6
8	272.0	107.0	300.0	100.0	6
9	300.0	100.0	310.0	100.0	6
10	.0	97.9	246.0	102.9	7
11	246.0	102.9	262.0	106.9	7

12	262.0	106.9	272.0	106.9	7
13	272.0	106.9	300.0	99.9	7
14	300.0	99.9	310.3	99.9	7

ISOTROPIC Soil Parameters
---

7 Soil unit(s) specified

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	125.0	125.0	200.0	25.00	.000	.0	0
2	125.0	125.0	.0	30.00	.000	.0	0
3	125.0	125.0	.0	15.00	.000	.0	0
4	125.0	125.0	.0	17.00	.000	.0	0
5	125.0	125.0	.0	23.00	.000	.0	0
6	125.0	125.0	.0	30.00	.000	.0	0
7	130.0	130.0	.0	25.00	.000	.0	0

A SINGLE FAILURE SURFACE HAS BEEN SPECIFIED FOR ANALYSIS

Trial failure surface specified by
the following 10 coordinate points :

Point No.	x-surf (ft)	y-surf (ft)
1	237.85	106.78
2	233.68	102.65
3	123.21	100.46
4	114.72	108.95
5	106.50	117.69
6	98.30	126.45
7	91.19	136.11
8	82.82	144.71
9	75.21	154.00
10	70.21	159.00

****
SELECTED METHOD OF ANALYSIS: Spencer (1973)
****

****
SUMMARY OF INDIVIDUAL SLICE INFORMATION
****

Slice	x-base (ft)	y-base (ft)	height (ft)	width (ft)	alpha	beta	weight (lb)

1	236.33	105.28	2.02	3.04	-44.75	18.86	769.
2	234.29	103.26	4.74	1.04	-44.75	18.86	616.
3	233.73	102.70	5.50	.09	-44.75	18.86	64.
4	201.84	102.02	17.07	63.68	-1.14	18.86	135853.
5	146.60	100.92	37.03	46.79	-1.14	18.86	216609.
6	122.70	100.97	45.15	1.02	45.00	18.86	5753.
7	118.45	105.22	42.36	7.47	45.00	18.86	39531.
8	110.61	113.32	36.93	8.22	46.76	18.86	37947.
9	102.40	122.07	30.99	8.20	46.89	18.86	31761.
10	94.74	131.28	24.39	7.11	53.65	18.86	21677.
11	88.10	139.29	18.65	6.19	45.78	18.86	14432.
12	83.91	143.59	15.41	2.18	45.78	.00	4199.
13	79.01	149.36	9.64	7.61	50.68	.00	9175.
14	72.71	156.50	2.50	5.00	45.00	.00	1563.

ITERATIONS FOR SPENCER'S METHOD

Iter #	Theta	FOS_force	FOS_moment
2	14.3129	1.8541	1.9249
3	14.4803	1.8578	1.8541
4	14.4762	1.8577	1.8578

SLICE INFORMATION ... continued :

Slice	Sigma (psf)	c-value (psf)	phi	U-base (lb)	U-top (lb)	P-top (lb)	Delta
1	900.6	200.0	25.00	0.	0.	0.	.00
2	1666.4	.0	30.00	0.	0.	0.	.00
3	1498.4	.0	23.00	0.	0.	0.	.00
4	2290.6	.0	23.00	0.	0.	0.	.00
5	4877.1	.0	17.00	0.	0.	0.	.00
6	3790.9	.0	30.00	0.	0.	0.	.00
7	3610.2	200.0	25.00	0.	0.	0.	.00
8	3067.7	200.0	25.00	0.	0.	0.	.00
9	2559.6	200.0	25.00	0.	0.	0.	.00
10	1801.1	200.0	25.00	0.	0.	0.	.00
11	1542.0	200.0	25.00	0.	0.	0.	.00
12	1264.0	200.0	25.00	0.	0.	0.	.00
13	707.9	200.0	25.00	0.	0.	0.	.00
14	161.1	200.0	25.00	0.	0.	0.	.00

SPENCER'S (1973) - TOTAL Stresses at center of slice base

Slice #	Base x-coord (ft)	Normal Stress (psf)	Vertical Stress (psf)	Pore Water Pressure (psf)	Shear Stress (psf)
1	236.33	900.6	253.1	.0	333.7
2	234.29	1666.4	592.7	.0	517.9
3	233.73	1498.4	687.1	.0	342.4
4	201.84	2290.6	2133.4	.0	523.4
5	146.60	4877.1	4629.0	.0	802.6

6	122.70	3790.9	5643.6	.0	1178.1
7	118.45	3610.2	5294.4	.0	1013.9
8	110.61	3067.7	4616.4	.0	877.7
9	102.40	2559.6	3873.2	.0	750.1
10	94.74	1801.1	3048.9	.0	559.8
11	88.10	1542.0	2331.6	.0	494.7
12	83.91	1264.0	1926.2	.0	424.9
13	79.01	707.9	1205.6	.0	285.3
14	72.71	161.1	312.5	.0	148.1

SPENCER'S (1973) - Magnitude & Location of Interslice Forces

Slice #	Right x-coord (ft)	Force Angle (degrees)	Interslice Force (lb)	Force Height (ft)	Boundary Height (ft)	Height Ratio
1	234.81	14.48	3848.	1.90	4.05	.469
2	233.77	14.48	6176.	2.24	5.43	.411
3	233.68	14.48	6353.	2.29	5.56	.412
4	170.00	14.48	43761.	10.47	28.58	.366
5	123.21	14.48	87224.	15.02	45.49	.330
6	122.19	14.48	84473.	14.74	44.81	.329
7	114.72	14.48	64452.	12.91	39.90	.324
8	106.50	14.48	44212.	10.69	33.97	.315
9	98.30	14.48	27408.	8.57	28.01	.306
10	91.19	14.48	13549.	5.51	20.78	.265
11	85.00	14.48	6583.	4.05	16.53	.245
12	82.82	14.48	4616.	3.74	14.29	.262
13	75.21	14.48	67.	1.85	5.00	.371
14	70.21	.00	0.	-.86	.00	.000

AVERAGE VALUES ALONG FAILURE SURFACE

Total Normal Stress = 2766.19 (psf)
Pore Water Pressure = .00 (psf)
Shear Stress = 624.09 (psf)

Total Length of failure surface = 195.44 feet

For the single specified surface and the assumed angle of the interslice forces, the SPENCER'S (1973) procedure gives a

FACTOR OF SAFETY = 1.858

Total shear strength available along specified failure surface = 226.59E+03 lb

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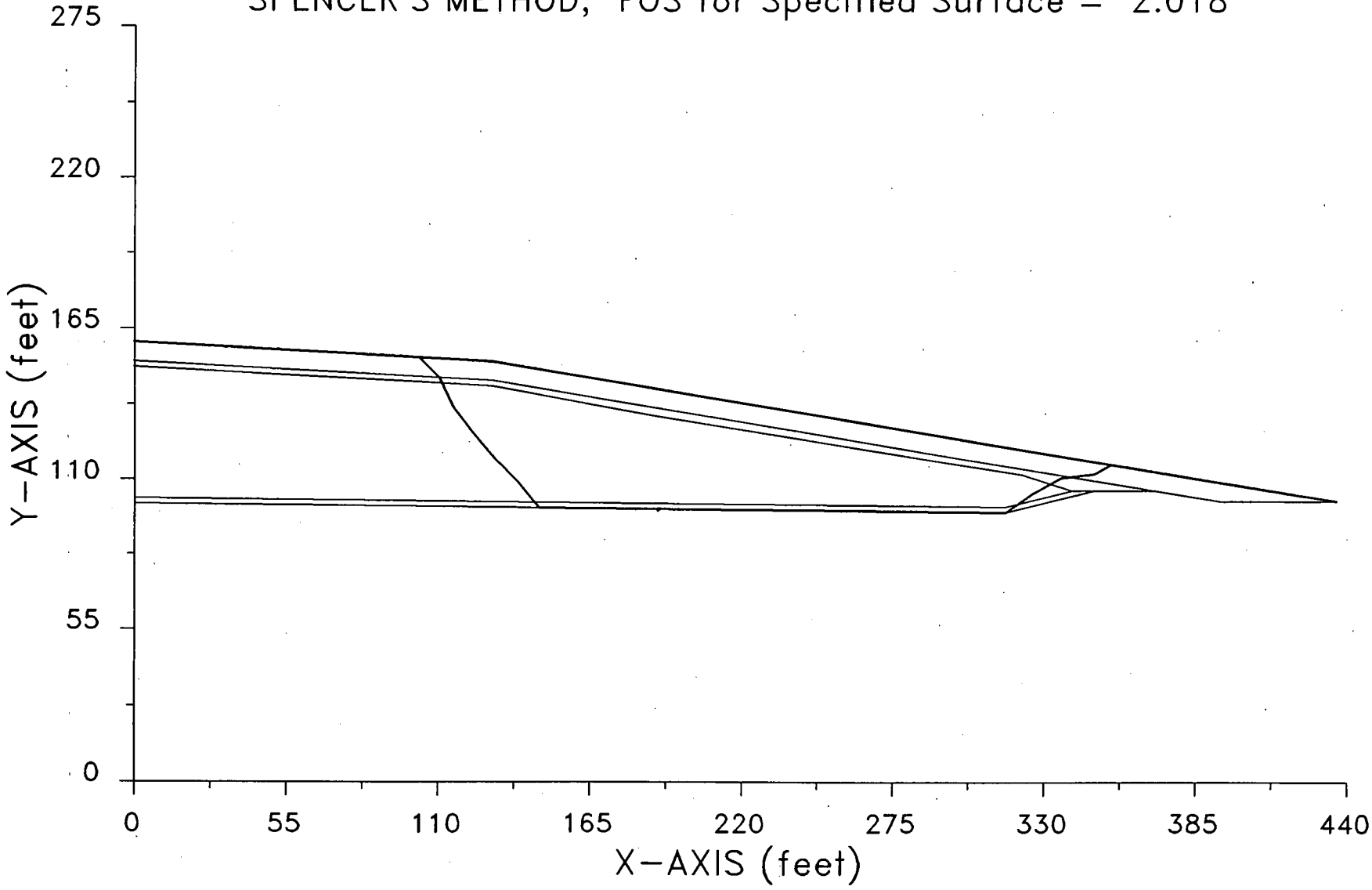
FINAL CONFIGURATION – PEAK STRENGTHS
SPENCER'S METHOD, FOS for Specified Surface = 2.018



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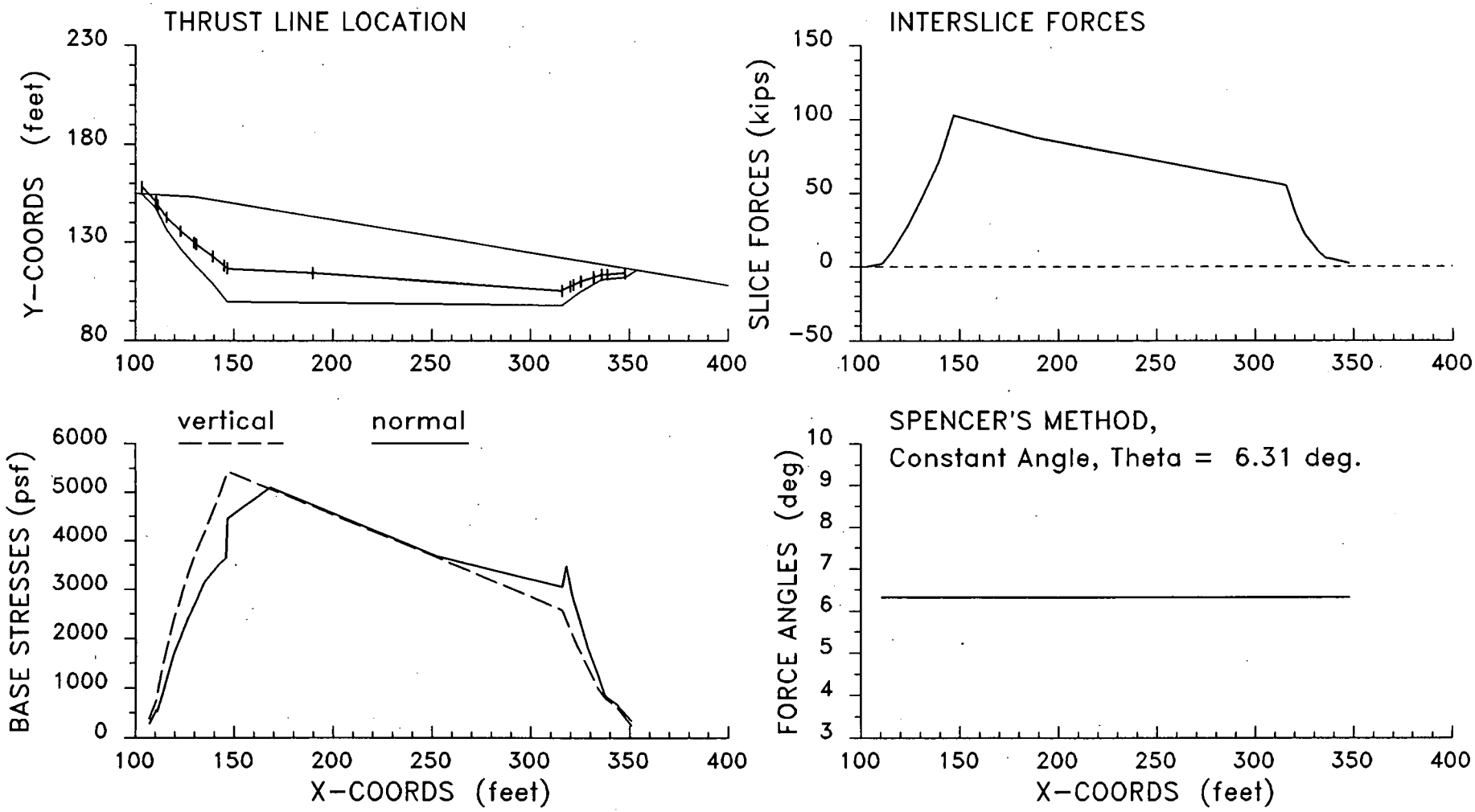

FINAL CONFIGURATION – PEAK STRENGTHS
SPENCER'S METHOD, FOS for Specified Surface = 2.018

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*****************************************
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*                                       *
*        Slope Stability Analysis       *
*               using the               *
*            Method of Slices           *
*                                       *
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Problem Description : FINAL CONFIGURATION - PEAK STRENGTHS

SEGMENT BOUNDARY COORDINATES
---

2 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	160.0	130.0	153.0	6
2	130.0	153.0	436.0	102.0	6

18 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	153.0	130.0	146.0	7
2	130.0	146.0	370.0	106.0	7
3	370.0	106.0	394.0	102.0	7
4	394.0	102.0	436.0	102.0	7
5	.0	151.0	130.0	144.0	1
6	130.0	144.0	190.0	133.0	1
7	190.0	133.0	322.0	112.0	1
8	322.0	112.0	340.0	106.0	1
9	340.0	106.0	348.0	106.0	2
10	348.0	106.0	348.4	106.0	5
11	348.4	106.0	370.0	106.0	7
12	.0	103.2	316.0	100.0	2
13	316.0	100.0	340.0	106.0	2
14	.0	101.2	130.0	99.9	3
15	130.0	99.9	316.0	98.0	4
16	316.0	98.0	348.0	106.0	5
17	.0	101.1	316.0	97.9	7

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18	316.0	97.9	348.4	106.0

ISOTROPIC Soil Parameters
---

7 Soil unit(s) specified

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	125.0	125.0	.0	25.00	.000	.0	0
2	125.0	125.0	.0	30.00	.000	.0	0
3	125.0	125.0	.0	8.00	.000	.0	0
4	125.0	125.0	.0	8.00	.000	.0	0
5	125.0	125.0	.0	10.00	.000	.0	0
6	125.0	125.0	.0	30.00	.000	.0	0
7	130.0	130.0	.0	25.00	.000	.0	0

A SINGLE FAILURE SURFACE HAS BEEN SPECIFIED FOR ANALYSIS

Trial failure surface specified by
the following 12 coordinate points :

Point No.	x-surf (ft)	y-surf (ft)
1	354.10	115.65
2	348.09	112.07
3	336.15	110.86
4	325.71	104.94
5	316.00	97.90
6	146.95	99.62
7	139.43	108.96
8	131.00	117.51
9	123.20	126.62
10	115.96	136.19
11	110.71	146.98
12	103.33	154.44

****
SELECTED METHOD OF ANALYSIS: Spencer (1973)
****

****
SUMMARY OF INDIVIDUAL SLICE INFORMATION
****

Slice	x-base (ft)	y-base (ft)	height (ft)	width (ft)	alpha	beta	weight (lb)

1	351.10	113.86	2.29	6.01	-30.78	9.46	1721.
2	343.58	111.61	5.79	9.02	-5.79	9.46	6532.
3	337.61	111.01	7.39	2.92	-5.79	9.46	2700.
4	334.16	109.73	9.24	3.97	-29.56	9.46	4632.
5	328.94	106.77	13.07	6.47	-29.56	9.46	10668.
6	323.85	103.60	17.10	3.71	-35.94	9.46	7971.
7	321.21	101.68	19.45	1.58	-35.94	9.46	3856.
8	318.32	99.58	22.04	4.21	-35.94	9.46	11640.
9	316.11	97.98	24.01	.21	-35.94	9.46	634.
10	253.00	98.54	33.96	126.00	.58	9.46	536444.
11	168.48	99.40	47.19	43.05	.58	9.46	254491.
12	146.91	99.67	50.51	.09	51.16	9.46	549.
13	146.06	100.73	49.60	1.61	51.16	9.46	10008.
14	142.34	105.34	45.60	5.82	51.16	9.46	33248.
15	135.21	113.24	38.90	8.43	45.40	9.46	41074.
16	130.50	118.09	34.82	1.00	49.43	9.46	4363.
17	126.60	122.65	30.53	6.80	49.43	3.08	26022.
18	119.58	131.40	22.16	7.24	52.89	3.08	20124.
19	113.82	140.59	13.28	4.28	64.05	3.08	7149.
20	111.19	145.98	8.03	.97	64.05	3.08	979.
21	110.68	147.01	7.03	.06	45.29	3.08	54.
22	106.99	150.74	3.50	7.32	45.29	3.08	3202.

ITERATIONS FOR SPENCER'S METHOD

Iter #	Theta	FOS_force	FOS_moment
2	6.1782	2.0132	2.1208
3	6.3149	-----	2.0132
3	6.2465	2.0158	-----
4	6.3113	2.0184	2.0158
5	6.3096	2.0183	2.0184

SLICE INFORMATION ... continued :

Slice	Sigma (psf)	c-value (psf)	phi	U-base (lb)	U-top (lb)	P-top (lb)	Delta
1	391.1	.0	30.00	0.	0.	0.	.00
2	779.9	.0	30.00	0.	0.	0.	.00
3	985.1	.0	25.00	0.	0.	0.	.00
4	1493.5	.0	25.00	0.	0.	0.	.00
5	2112.6	.0	25.00	0.	0.	0.	.00
6	2956.2	.0	25.00	0.	0.	0.	.00
7	3359.7	.0	25.00	0.	0.	0.	.00
8	4060.7	.0	30.00	0.	0.	0.	.00
9	3555.6	.0	10.00	0.	0.	0.	.00
10	4282.6	.0	8.00	0.	0.	0.	.00
11	5946.4	.0	8.00	0.	0.	0.	.00
12	5200.9	.0	8.00	0.	0.	0.	.00
13	4251.1	.0	30.00	0.	0.	0.	.00
14	4082.9	.0	25.00	0.	0.	0.	.00
15	3688.6	.0	25.00	0.	0.	0.	.00
16	3176.6	.0	25.00	0.	0.	0.	.00
17	2786.3	.0	25.00	0.	0.	0.	.00
18	1949.2	.0	25.00	0.	0.	0.	.00
19	996.3	.0	25.00	0.	0.	0.	.00

20	601.7	.0	25.00	0.	0.	0.	.00
21	666.0	.0	25.00	0.	0.	0.	.00
22	319.6	.0	30.00	0.	0.	0.	.00

SPENCER'S (1973) - TOTAL Stresses at center of slice base

Slice #	Base x-coord (ft)	Normal Stress (psf)	Vertical Stress (psf)	Pore Water Pressure (psf)	Shear Stress (psf)
1	351.10	391.1	286.4	.0	111.9
2	343.58	779.9	723.9	.0	223.1
3	337.61	985.1	925.8	.0	227.6
4	334.16	1493.5	1166.1	.0	345.1
5	328.94	2112.6	1649.4	.0	488.1
6	323.85	2956.2	2148.5	.0	683.0
7	321.21	3359.7	2441.8	.0	776.2
8	318.32	4060.7	2764.5	.0	1161.6
9	316.11	3555.6	3011.0	.0	310.6
10	253.00	4282.6	4257.5	.0	298.2
11	168.48	5946.4	5911.5	.0	414.1
12	146.91	5200.9	6325.0	.0	362.2
13	146.06	4251.1	6210.8	.0	1216.0
14	142.34	4082.9	5710.9	.0	943.3
15	135.21	3688.6	4872.4	.0	852.2
16	130.50	3176.6	4362.9	.0	733.9
17	126.60	2786.3	3826.8	.0	643.7
18	119.58	1949.2	2779.5	.0	450.3
19	113.82	996.3	1670.4	.0	230.2
20	111.19	601.7	1008.8	.0	139.0
21	110.68	666.0	878.8	.0	153.9
22	106.99	319.6	437.5	.0	91.4

SPENCER'S (1973) - Magnitude & Location of Interslice Forces

Slice #	Right x-coord (ft)	Force Angle (degrees)	Interslice Force (lb)	Force Height (ft)	Boundary Height (ft)	Height Ratio
1	348.09	6.31	2085.	2.12	4.58	.463
2	339.07	6.31	4828.	2.29	7.00	.326
3	336.15	6.31	5789.	2.47	7.78	.318
4	332.18	6.31	10553.	3.44	10.70	.322
5	325.71	6.31	21524.	4.95	15.44	.321
6	322.00	6.31	32073.	5.91	18.75	.315
7	320.42	6.31	37177.	6.33	20.16	.314
8	316.21	6.31	54568.	7.27	23.91	.304
9	316.00	6.31	55180.	7.36	24.10	.306
10	190.00	6.31	87460.	14.96	43.82	.341
11	146.95	6.31	102774.	16.73	50.55	.331
12	146.86	6.31	102242.	16.72	50.46	.331
13	145.25	6.31	95654.	15.98	48.73	.328
14	139.43	6.31	71476.	13.69	42.47	.322
15	131.00	6.31	46974.	11.22	35.32	.318

16	130.00	6.31	43980.	10.89	34.32	.317
17	123.20	6.31	26120.	8.69	26.75	.325
18	115.96	6.31	10633.	6.20	17.57	.353
19	111.68	6.31	2807.	3.56	9.00	.395
20	110.71	6.31	1736.	3.29	7.06	.466
21	110.65	6.31	1704.	3.29	7.00	.470
22	103.33	.00	0.	3.72	.00	.000

AVERAGE VALUES ALONG FAILURE SURFACE

Total Normal Stress = 3676.44 (psf)
Pore Water Pressure = .00 (psf)
Shear Stress = 402.78 (psf)

Total Length of failure surface = 282.53 feet

For the single specified surface and the assumed angle of the interslice forces, the SPENCER'S (1973) procedure gives a

FACTOR OF SAFETY = 2.018

Total shear strength available along specified failure surface = 229.68E+03 lb

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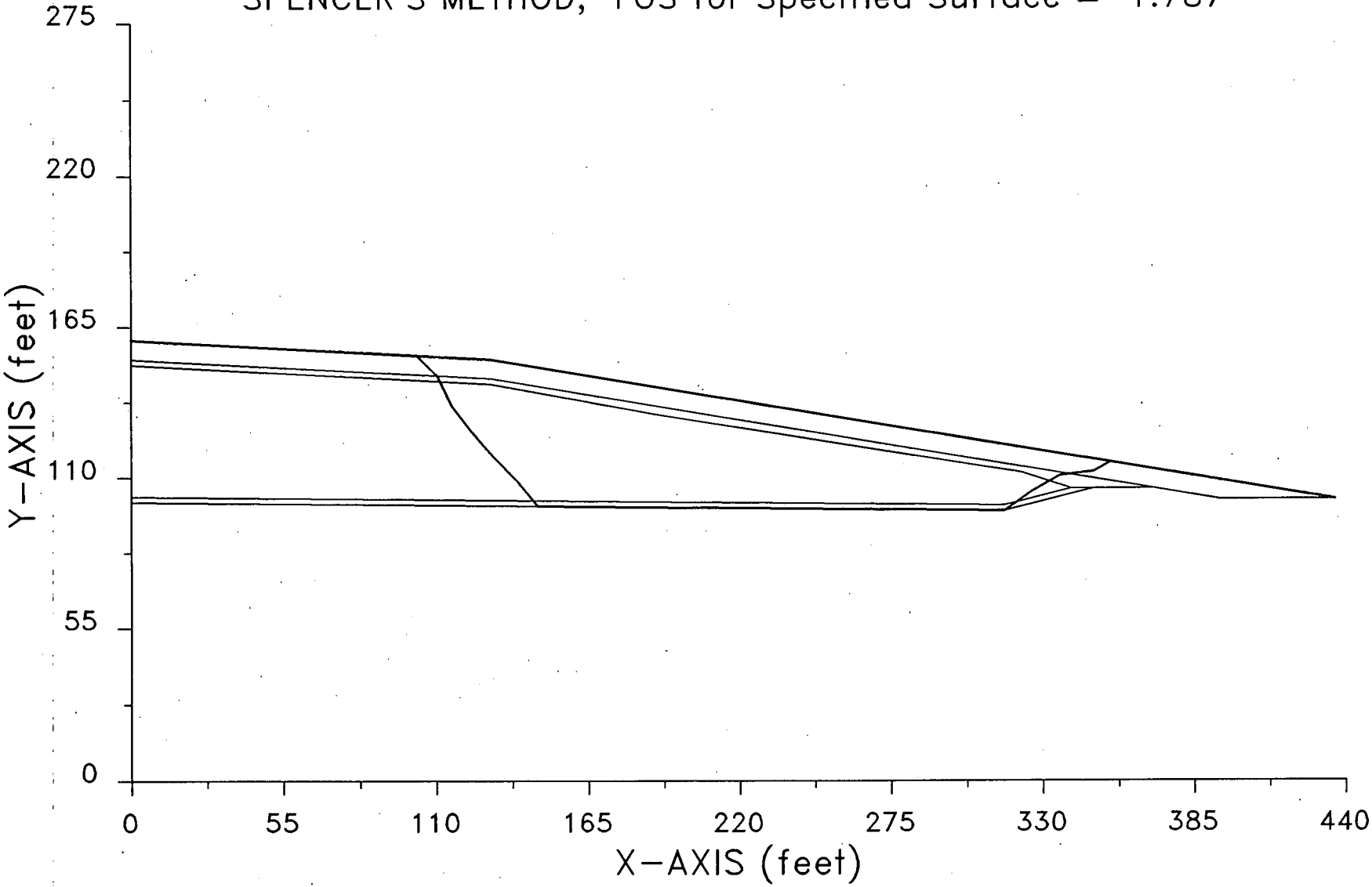
FINAL CONFIG. – LARGE DISPLACEMENT
SPENCER'S METHOD, FOS for Specified Surface = 1.787



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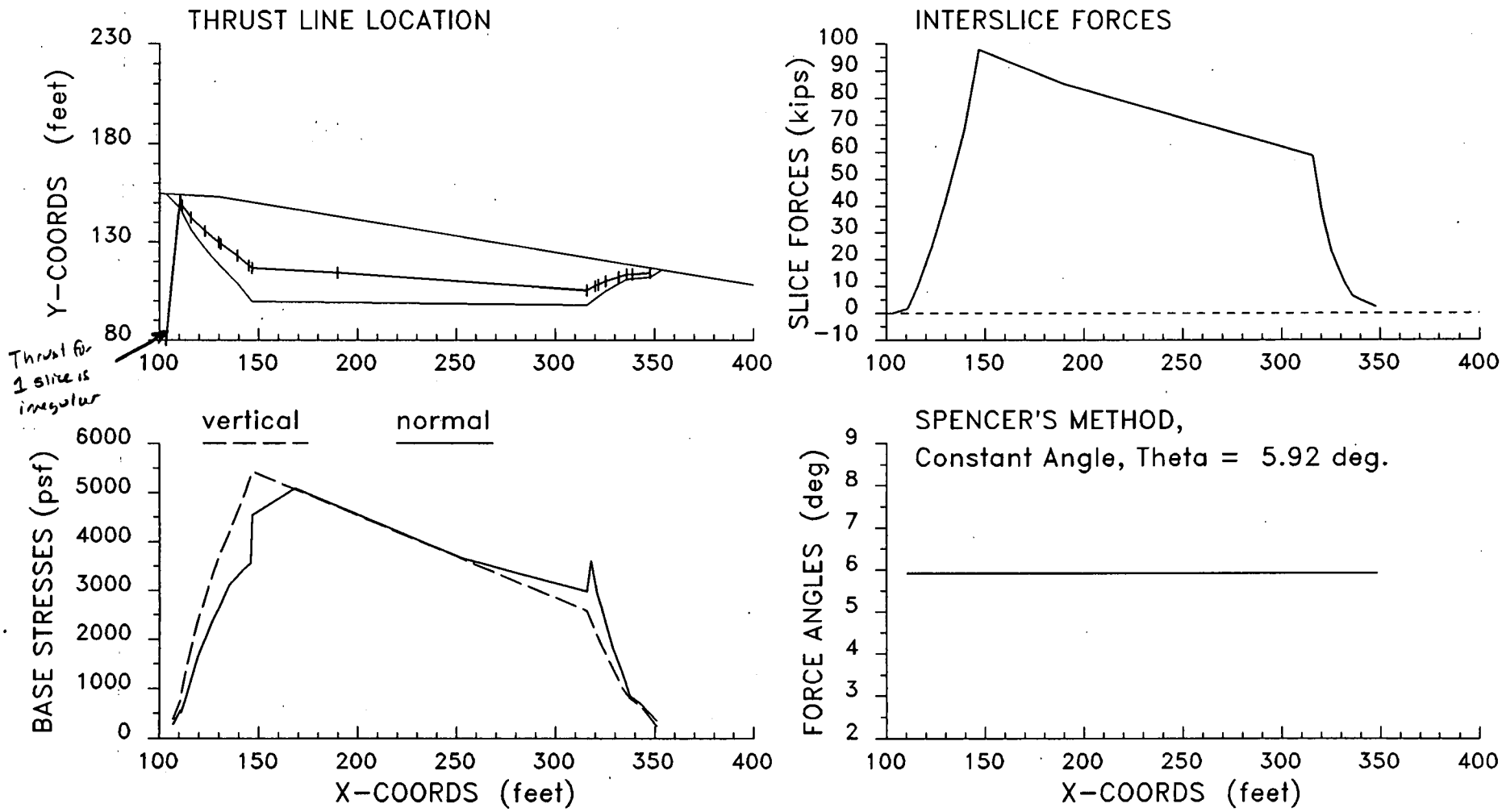

FINAL CONFIG. – LARGE DISPLACEMENT
SPENCER'S METHOD, FOS for Specified Surface = 1.787

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09 Oct 95
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XSTABL File: FHYDLD1S 10-09-95 13:40

```
*****************************************
*              X S T A B L              *
*                                       *
*        Slope Stability Analysis       *
*               using the               *
*            Method of Slices           *
*                                       *
*         Copyright (C) 1992 á 94       *
*   Interactive Software Designs, Inc.  *
*        Moscow, ID 83843, U.S.A.       *
*                                       *
*          All Rights Reserved          *
*                                       *
*  Ver. 5.100                95 á 1305  *
*****************************************
```

Problem Description : FINAL CONFIG. - LARGE DISPLACEMENT

SEGMENT BOUNDARY COORDINATES
---

2 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	160.0	130.0	153.0	6
2	130.0	153.0	436.0	102.0	6

18 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	153.0	130.0	146.0	7
2	130.0	146.0	370.0	106.0	7
3	370.0	106.0	394.0	102.0	7
4	394.0	102.0	436.0	102.0	7
5	.0	151.0	130.0	144.0	1
6	130.0	144.0	190.0	133.0	1
7	190.0	133.0	322.0	112.0	1
8	322.0	112.0	340.0	106.0	1
9	340.0	106.0	348.0	106.0	2
10	348.0	106.0	348.4	106.0	5
11	348.4	106.0	370.0	106.0	7
12	.0	103.2	316.0	100.0	2
13	316.0	100.0	340.0	106.0	2
14	.0	101.2	130.0	99.9	3
15	130.0	99.9	316.0	98.0	4
16	316.0	98.0	348.0	106.0	5
17	.0	101.1	316.0	97.9	7

18	316.0	97.9	348.4	106.0

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ISOTROPIC Soil Parameters
---

7 Soil unit(s) specified

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	125.0	125.0	.0	25.00	.000	.0	0
2	125.0	125.0	.0	30.00	.000	.0	0
3	125.0	125.0	.0	5.00	.000	.0	0
4	125.0	125.0	.0	6.00	.000	.0	0
5	125.0	125.0	.0	7.00	.000	.0	0
6	125.0	125.0	.0	30.00	.000	.0	0
7	130.0	130.0	.0	25.00	.000	.0	0

A SINGLE FAILURE SURFACE HAS BEEN SPECIFIED FOR ANALYSIS

Trial failure surface specified by
the following 12 coordinate points :

Point No.	x-surf (ft)	y-surf (ft)
1	354.10	115.65
2	348.09	112.07
3	336.15	110.86
4	325.71	104.94
5	316.00	97.90
6	146.95	99.62
7	139.43	108.96
8	131.00	117.51
9	123.20	126.62
10	115.96	136.19
11	110.71	146.98
12	103.33	154.44

****
SELECTED METHOD OF ANALYSIS: Spencer (1973)
****

****
SUMMARY OF INDIVIDUAL SLICE INFORMATION
****

Slice	x-base (ft)	y-base (ft)	height (ft)	width (ft)	alpha	beta	weight (lb)

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1	351.10	113.86	2.29	6.01	-30.78	9.46	1721.
2	343.58	111.61	5.79	9.02	-5.79	9.46	6532.
3	337.61	111.01	7.39	2.92	-5.79	9.46	2700.
4	334.16	109.73	9.24	3.97	-29.56	9.46	4632.
5	328.94	106.77	13.07	6.47	-29.56	9.46	10668.
6	323.85	103.60	17.10	3.71	-35.94	9.46	7971.
7	321.21	101.68	19.45	1.58	-35.94	9.46	3856.
8	318.32	99.58	22.04	4.21	-35.94	9.46	11640.
9	316.11	97.98	24.01	.21	-35.94	9.46	634.
10	253.00	98.54	33.96	126.00	.58	9.46	536444.
11	168.48	99.40	47.19	43.05	.58	9.46	254491.
12	146.91	99.67	50.51	.09	51.16	9.46	549.
13	146.06	100.73	49.60	1.61	51.16	9.46	10008.
14	142.34	105.34	45.60	5.82	51.16	9.46	33248.
15	135.21	113.24	38.90	8.43	45.40	9.46	41074.
16	130.50	118.09	34.82	1.00	49.43	9.46	4363.
17	126.60	122.65	30.53	6.80	49.43	3.08	26022.
18	119.58	131.40	22.16	7.24	52.89	3.08	20124.
19	113.82	140.59	13.28	4.28	64.05	3.08	7149.
20	111.19	145.98	8.03	.97	64.05	3.08	979.
21	110.68	147.01	7.03	.06	45.29	3.08	54.
22	106.99	150.74	3.50	7.32	45.29	3.08	3202.

ITERATIONS FOR SPENCER'S METHOD

Iter #	Theta	FOS_force	FOS_moment
2	5.7857	1.7823	1.8931
3	5.9272	-----	1.7823
3	5.8564	1.7847	-----
4	5.9239	1.7871	1.7847
5	5.9223	1.7870	1.7871

SLICE INFORMATION ... continued :

Slice	Sigma (psf)	c-value (psf)	phi	U-base (lb)	U-top (lb)	P-top (lb)	Delta
1	402.0	.0	30.00	0.	0.	0.	.00
2	784.0	.0	30.00	0.	0.	0.	.00
3	989.1	.0	25.00	0.	0.	0.	.00
4	1522.0	.0	25.00	0.	0.	0.	.00
5	2152.9	.0	25.00	0.	0.	0.	.00
6	3032.3	.0	25.00	0.	0.	0.	.00
7	3446.2	.0	25.00	0.	0.	0.	.00
8	4207.6	.0	30.00	0.	0.	0.	.00
9	3469.5	.0	7.00	0.	0.	0.	.00
10	4276.5	.0	6.00	0.	0.	0.	.00
11	5937.9	.0	6.00	0.	0.	0.	.00
12	5289.3	.0	6.00	0.	0.	0.	.00
13	4149.9	.0	30.00	0.	0.	0.	.00
14	4005.2	.0	25.00	0.	0.	0.	.00
15	3628.5	.0	25.00	0.	0.	0.	.00
16	3118.9	.0	25.00	0.	0.	0.	.00
17	2735.6	.0	25.00	0.	0.	0.	.00
18	1910.4	.0	25.00	0.	0.	0.	.00
19	969.8	.0	25.00	0.	0.	0.	.00

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20	585.7	.0	25.00	0.	0.	0.	.00
21	655.2	.0	25.00	0.	0.	0.	.00
22	313.0	.0	30.00	0.	0.	0.	.00

SPENCER'S (1973) - TOTAL Stresses at center of slice base

Slice #	Base x-coord (ft)	Normal Stress (psf)	Vertical Stress (psf)	Pore Water Pressure (psf)	Shear Stress (psf)
1	351.10	402.0	286.4	.0	129.9
2	343.58	784.0	723.9	.0	253.3
3	337.61	989.1	925.8	.0	258.1
4	334.16	1522.0	1166.1	.0	397.2
5	328.94	2152.9	1649.4	.0	561.8
6	323.85	3032.3	2148.5	.0	791.3
7	321.21	3446.2	2441.8	.0	899.3
8	318.32	4207.6	2764.5	.0	1359.4
9	316.11	3469.5	3011.0	.0	238.4
10	253.00	4276.5	4257.5	.0	251.5
11	168.48	5937.9	5911.5	.0	349.2
12	146.91	5289.3	6325.0	.0	311.1
13	146.06	4149.9	6210.8	.0	1340.8
14	142.34	4005.2	5710.9	.0	1045.1
15	135.21	3628.5	4872.4	.0	946.8
16	130.50	3118.9	4362.9	.0	813.9
17	126.60	2735.6	3826.8	.0	713.8
18	119.58	1910.4	2779.5	.0	498.5
19	113.82	969.8	1670.4	.0	253.1
20	111.19	585.7	1008.8	.0	152.8
21	110.68	655.2	878.8	.0	171.0
22	106.99	313.0	437.5	.0	101.1

SPENCER'S (1973) - Magnitude & Location of Interslice Forces

Slice #	Right x-coord (ft)	Force Angle (degrees)	Interslice Force (lb)	Force Height (ft)	Boundary Height (ft)	Height Ratio
1	348.09	5.92	2232.	2.10	4.58	.459
2	339.07	5.92	5251.	2.21	7.00	.316
3	336.15	5.92	6301.	2.39	7.78	.307
4	332.18	5.92	11334.	3.40	10.70	.318
5	325.71	5.92	22925.	4.92	15.44	.319
6	322.00	5.92	34077.	5.88	18.75	.314
7	320.42	5.92	39471.	6.30	20.16	.312
8	316.21	5.92	58139.	7.21	23.91	.301
9	316.00	5.92	58721.	7.31	24.10	.303
10	190.00	5.92	85072.	15.00	43.82	.342
11	146.95	5.92	97573.	16.85	50.55	.333
12	146.86	5.92	97027.	16.85	50.46	.334
13	145.25	5.92	90849.	16.10	48.73	.330
14	139.43	5.92	67850.	13.80	42.47	.325
15	131.00	5.92	44684.	11.29	35.32	.320

16	130.00	5.92	41840.	10.96	34.32	.319
17	123.20	5.92	24877.	8.72	26.75	.326
18	115.96	5.92	10125.	6.19	17.57	.352
19	111.68	5.92	2638.	3.55	9.00	.394
20	110.71	5.92	1613.	3.31	7.06	.469
21	110.65	5.92	1583.	3.32	7.00	.474
22	103.33	.00	0.	-88.41	.00	.000

AVERAGE VALUES ALONG FAILURE SURFACE

Total Normal Stress = 3667.75 (psf)
Pore Water Pressure = .00 (psf)
Shear Stress = 397.59 (psf)

Total Length of failure surface = 282.53 feet

For the single specified surface and the assumed angle of the interslice forces, the SPENCER'S (1973) procedure gives a

FACTOR OF SAFETY = 1.787

Total shear strength available along specified failure surface = 200.74E+03 lb

APPENDIX A

COMPUTER SOFTWARE USED TO PREPARE CALCULATION PACKAGE

XSTABL - Version 5

Sharma, S., "*XSTABL: An Integrated Slope Stability Analysis Program for Personal Computers, Version 5*," Interactive Software Designs, Moscow, ID, 1994.

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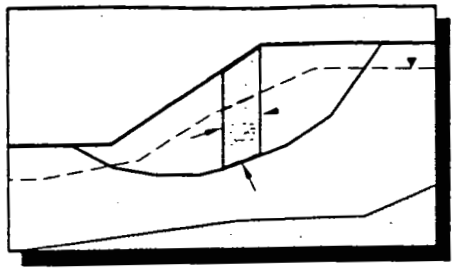

XSTABL©

An Integrated Slope Stability Analysis Program for Personal Computers

Reference Manual

Version 5

prepared by

Sunil Sharma

for

Interactive Software Designs, Inc
953 N. Cleveland Street
Moscow, ID 83843, U.S.A.

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XSTABL

VERSION 5.00

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4. Attempt to disassemble the **XSTABL** machine-code for any purpose whatsoever.

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CHAPTER 1

1.0 INTRODUCTION

XSTABL is a fully integrated slope stability analysis program designed to operate on an IBM personal computer, or close compatible. It permits the engineer to develop the slope geometry interactively and perform the slope analysis from within a single program. The slope analysis portion of **XSTABL** uses a modified version of the popular STABL program, originally developed at Purdue University.

XSTABL performs a two dimensional limit equilibrium analysis to compute the factor of safety for a layered slope according to:

(a) General Limit Equilibrium (GLE) Method,

(b) Janbu's Generalized Procedure of Slices (GPS),

(c) Simplified Bishop,

(d) Simplified Janbu.

If the program is used to search for the most critical surface, only the simplified Bishop and Janbu methods are available for calculating the factor of safety. The program can be used to search for the most critical surface or the factor of safety may be determined for specific surfaces. **XSTABL**, version 5.0, is programmed to handle:

1. heterogenous soil systems with up to 20 soil units,
2. The strength of a soil unit may be defined using:
   (a) conventional, c-ϕ parameters,
   (b) undrained strengths as a function of vertical effective stress,
   (c) a nonlinear Mohr-Coulomb envelop.
3. Anisotropic soil strength properties,

4. Reinforced slopes,
5. Pore water pressures for effective stress analysis using:
   (a) phreatic and piezometric surfaces
   (b) pore pressure grid
   (c) R_u factor
   (d) constant pore water pressure
6. Pseudo-static earthquake loading,
7. Surcharge boundary loads,
8. Automatic generation and analysis of an unlimited number of circular, noncircular and block-shaped failure surfaces,
9. Analysis of right-facing slopes,
10. Both SI and Imperial units.

1.1 Summary of Interactive Features of XSTABL

XSTABL is intended for use on an IBM-PC, or near compatible, suitably equipped for screen graphics. The program uses menus and data-tables to "guide" the potential user through the many options available for performing a slope stability analysis. The interactive features of **XSTABL** include:

1. Selection of options via intuitive, easy to understand menus,
2. Context sensitive help information,
3. All numeric data is entered through prompts into a table,
4. Error checking during data entry phase,
5. Slope geometry may be readily reviewed on-screen,
6. Previously entered data can be edited,
7. Single failure surfaces may be analyzed using several rigorous procedures that satisfy force and moment equilibrium,
8. Previously saved files can be edited and saved as "new" files,

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9. **XSTABL** files may be copied, deleted, printed, renamed or viewed *without* exiting the program,

10. Screen plots may be saved to disk in one of several different formats for later printing or inclusion within a document prepared with a wordprocessing or charting software.

11. High quality plots may be generated, using **XSTABL**, on several different types of output devices if the screen plots are saved in the default format.

It is expected that the approach offered by **XSTABL** will minimize potential errors and provide a more appropriate data preparation method for the less familiar user. The time expended in learning to use the program is expected to be nominal and users can be expected to generate input data files almost immediately.

1.2 General Information

The **XSTABL** Reference Manual is intended to provide information about the interactive features that allow the user to prepare data files and perform a slope stability analysis. The next six chapters of the Reference Manual provides details concerning the following topics:

1. **XSTABL** program components,
2. **XSTABL** menus and available options,
3. Data tables for establishing the slope geometry, and assigning soil properties and boundary loads,
4. Methods of analysis,
5. Slope stability analysis, including the creation and saving of screen plots,
6. Printing of hardcopy plots.

Further details about the limit equilibrium theory, search procedures and slice development are given in Appendix D.

This manual concentrates on the interactive features and is not intended to provide the necessary engineering background for slope stability analysis. If the user wishes to obtain more information concerning slope stability analysis, the following publications are recommended:

1. *The Stability of Slopes*, by E.N. Bromhead, Surrey University Press, Chapman and Hall, NY, 411 pages, ISBN 0 412 01061 5, 1992.

2. *Landslides: Analysis and Control*, by R.L. Schuster and R.J. Krizek (editors), Special Report 176, Transportation Research Board, National Academy of Sciences, 234 pages, ISBN 0 309 02804 3, 1978. (new edition, edited by R.L. Schuster and K. Turner will be published in 1994)

3. *Rock Slope Engineering*, by E. Hoek and J.W. Bray, Inst. of Mining and Metallurgy, London, England, Third Edition, 358 pages, ISBN 0 900488 573, 1981.

Please note that the above list represents ***a very small*** portion of literature available on the subject of slope stability analysis.

1.3 Hardware Requirements

In order to use **XSTABL**, the user will require:

1. An IBM-PC, or near compatible, with either dual floppy disk drives or a hard disk (preferred) and one floppy disk drive, 640 kb RAM and DOS 2.1 (or later).

   Execution of XSTABL will require at least 450,000 bytes of free RAM. The user may check the amount of RAM available by using the "MEM/C" command, as documented in the DOS manual.

2. An IBM compatible VGA, EGA or CGA graphics adaptor with an appropriate monitor,

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3. One of the following devices for hardcopy output:

   (a) A laser printer, e.g. Hewlett Packard LaserJet with at least 1 Mb of RAM, or

   (b) An IBM Graphics compatible, 9 or 24 pin, dot matrix printer, e.g. EPSON FX-85,

   (c) A HPGL compatible pen plotter, e.g. Hewlett Packard 7475A Plotter.

1.4 XSTABL INSTALLATION

The **XSTABL** programs and example data files are supplied on one 3.5 inch or one 5.25 inch disk in a compressed format. To copy these files to a subdirectory on your hard disk, please follow the instruction listed below:

1. create a directory on your hard disk (e.g. MD XSTABL etc....)
2. change to this newly created directory (e.g. CD XSTABL etc....)
3. from this directory type either :

   (a) A:INSTALL --> if the **XSTABL** disk is in "A" drive, or

   (b) B:INSTALL --> if the **XSTABL** disk is in "B" drive

The installation program will place the XSTABL files in the current directory and copy all example datafiles into a subdirectory named: "EXAMPLES". The complete installation of these files will required about 500 kb of disk space. The PACK.LST file on the original disk includes a list, and description, of **all** files that should have been copied to the current directory on your disk.

NOTE:
The above procedure will work if you are preparing to use **XSTABL** from a hard-disk or at least a 720 kb floppy diskette. However if you would like to use the program on dual 360 kb disk drive system, please contact ***Interactive Software Designs, Inc.***, for special instructions to order a non-compressed version of **XSTABL**.

1.5 XSTABL Components

Before using **XSTABL**, the user should ensure that files listed below, and section 2.2, have been copied :

1. PACK.LST . . . . . summary of file descriptions
2. README . . . . . special "last-minute" notes or revisions to this Manual
3. DEMO.TXT . . . . . dialogue script for demonstration/tutorial

1.6 Files for using XSTABL

1. **XSTABL.EXE** . . . . executable version of program
2. SETUP1.STB . . . . . file used during program startup
3. XSTABL.HLP . . . . . help screen information
4. XSTABL.ERR . . . . . XSTABL error descriptions
5. XSTABL.FN1 . . . . . font file for screen characters
6. XSTABL.FN2 . . . . . font file for hardcopy plots
7. XPLOT.EXE . . . . . executable program for hardcopy plots

The installation process will also copy the example input data files and the output (4 files) corresponding to an analysis using the file EX_1.IPT to the "EXAMPLES" subdirectory. These "extra" files may be deleted to conserve disk space.

The program can then be started by typing, **XSTABL** at the DOS prompt. **The program will NOT operate without the SETUP1.STB file.**

> **Please note that the XSTABL software and documentation is copyrighted and may NOT be copied without permission.** However, the user is permitted to make ONE archival backup copy of these files to guard against possible disk failure.

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1.7 Supporting XSTABL files

File: **SETUP1.STB** -- contains initialization information that sets several parameters at the start of the **XSTABL** program. Also, the first line of this file may be modified to control the amount of information that is written into the output file following a slope analysis. A typical unmodified file will have the following form:

Line 1:	0	10	10	10
Line 2:	1.000	1.000	0.30	9.80
Line 3:	(blank line)			

Let the four values on the *first line* be labeled as **var-1**, **var-2**, **var-3** and **var-4**. Then the user is permitted to modify these according to the following:

var-1 = 0 (zero) for all cases, unless advised otherwise;

var-2 = value between 1 and 10, inclusive, for controlling the number of failure surface coordinates that will be listed in the output file following each slope analysis;

var-3 = value between 1 and 10, inclusive, for controlling the number of critical surfaces that will be *displayed on the screen* at the end of the slope analysis;

var-4 = value between 1 and 10, inclusive, for controlling the number of surfaces *plotted to the hardcopy file.*

Please note that the default for the number of surfaces is set at ten for all cases (i.e. var-2 = var-3 = var-4 = 10). These parameters may be changed directly by editing the SETUP1.STB file. Alternatively these may be changed from within **XSTABL** via the F5 key just before the start of the multiple search analysis.

The four values listed on the second line control the scaling and location of the hardcopy plot on paper. The first two values assign the scaling in the x and y direction of the plot. The last two numbers fix the origin of the plot on the basis of a global origin located in the right-hand corner of the printed 11 x 8.5 inch (landscape) page. The user can manipulate these values to scale the hardcopy plots, but must ensure that the aspect ratio of the vertical to horizontal axes is maintained at unity.

Other Files:

The two files, **XSTABL.HLP** and **XSTABL.ERR**, are used by **XSTABL** to provide help and input data error information, respectively. Although the program can function without these files, on-line help information will not be available and error messages will not be written to the output file created during the slope stability analysis. However, error numbers will be written to the output file and the user can determine the corresponding message from the complete list of possible errors given in Appendix B.

1.8 Connecting HP Plotters

XSTABL screen plots may be successfully plotted using HP plotter models: 7440A, 7470A, 7475A and 7550A connected to a personal computer. The cable should be connected to the PC with a DB 9 or DB 25 connector via the serial or asynchronous port. At the plotter, a DB 25 connector should be used to connect the cable to the computer/modem port. **XSTABL** uses the XON/XOFF protocol and thus only requires ***three*** connecting wires in accordance with Fig 1.1.

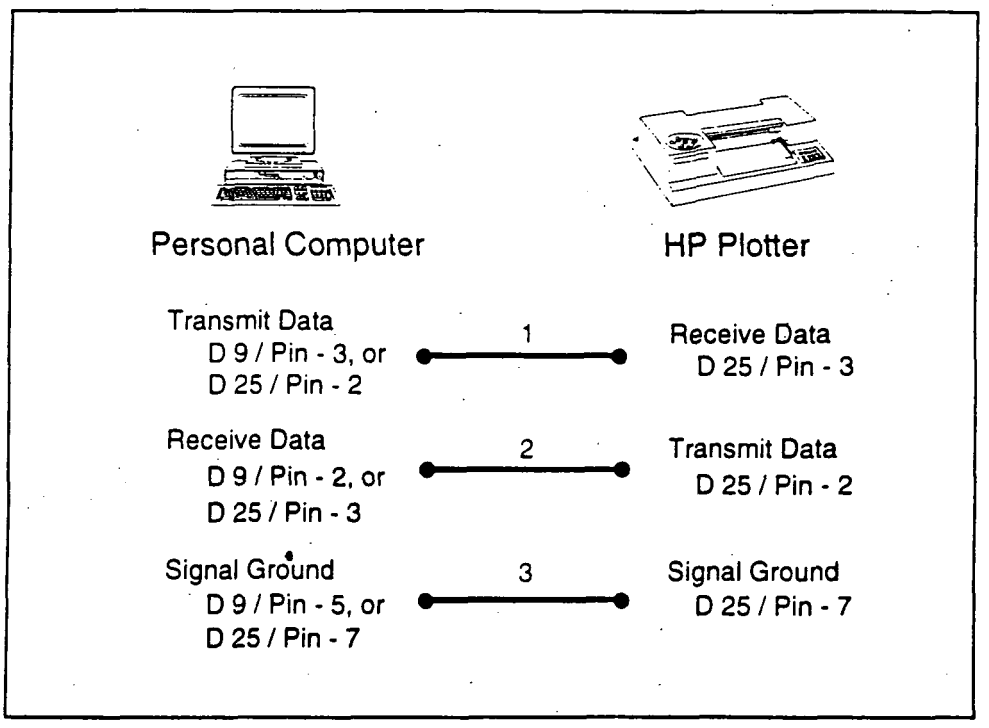

Fig. 1.1. Wire connections for PC - HP plotter cable

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1.9 Starting XSTABL

XSTABL should be executed from the directory occupied by the program's files by typing "XSTABL" at the DOS prompt. Please note that an error will be reported if the user attempts to execute **XSTABL** from a directory which does not have the SETUP1.STB file. Also, the program ***expects*** to access the files: XSTABL.HLP and XSTABL.ERR (i.e. the help and error files) from the current directory only. If these files are not in the current directory, **XSTABL** will be unable to provide a complete report on the errors and the context sensitive help information will not be available.

In executing the program, **XSTABL** offers the user an opportunity to change three default parameters via a command line option. If the user executes the program by only typing "XSTABL", the following default options are invoked:

(a) Imperial units, i.e. pounds, psf, pcf and feet;

(b) Parallel printer port selected as LPT1;

(c) Serial port selected as COM1.

The parallel port is used for printing input and output files and for printing all slope analysis plots, except those sent to a plotter. In this case the plotter is assumed to be connected to the COM1 serial port. If the above default selection is not appropriate, the user may change any of these according to the command-line switches given below.

Alternative SI Units may be selected by executing the program by typing: "XSTABL -m" at the DOS prompt. In this case the program will startup with SI units represented by: kN, kPa (kilo Pascals), kN/m^3 and meters.

The Alternative Parallel Port LPT2 may be selected by starting the program by typing: "XSTABL LPT2". This selection will send all parallel port output to the LPT2 port.

The Alternative Serial Port COM2 may be selected by starting the program by typing: "XSTABL COM2". This selection will send the plotter output to the alternative serial port.

Any combination of the above three options is possible. For example by typing : "XSTABL COM2 LPT2 -m" the user may invoke (1) COM2 as the serial port, (2) LPT2 as the default parallel printer port and (3) SI units.

1.10 Example Input and Output Files

Several data files are provided with the main programs, on the enclosed disk, for evaluating the **XSTABL** software. These files are based on the slope geometry described in Appendix A of this manual. The output files, for example EX_1.IPT, are also included for the convenience of the user and to check for proper operation of **XSTABL** on your computer. A complete description of these example files is summarized in the disk file: PACK.LST.

1.11 XSTABL Tutorial

A dialogue script for a tutorial that demonstrates some of the unique features of **XSTABL** is included with the program disk(s) in the file: DEMO.TXT. The user is encouraged to print this file, and follow the suggested instructions. This tutorial will familiarize users with the editing features, special commands and other data tables that are used to assemble a data file for slope stability analysis.

1.12 ANSI.SYS Device Driver

The **XSTABL** program has been designed to access the video hardware directly, thus minimizing the response time between keyboard entry and subsequent actions. However if the **ANSI.SYS** device driver is loaded, it "filters" the data before it is written to the screen. Thus in order to maximize the speed of **XSTABL**, the use of the ANSI.SYS device driver is not recommended as it tends to slow the response time for data written to screen.

The user may check to see if the ANSI.SYS driver is loaded by examining the CONFIG.SYS file in the root directory. A line of the general form :

DEVICE=ANSI.SYS

will indicate that the device driver is loaded at the start of every session. The user must then choose to either load or omit the ANSI.SYS device driver.

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1.13 Loading and Execution Errors

It is possible that an "unexplainable" error may occur during the loading and execution phase of the program. If such an error occurs, please check you data thoroughly. If your data appears to be correct and the error condition persists, please contact:

Dr. Sunil Sharma,
Interactive Software Designs, Inc.,
953 N. Cleveland,
Moscow, ID 83843.

000707

3.4 Cover System Stability

COMPUTATION COVER SHEET

SUBJECT OF CALCULATION: COVER SYSTEM STABILITY

Computations By: (Cognizant Engineer)
Signature: Mark H. Gleason — Date: 05 OCT. '95
Printed Name and Title: MARK H. GLEASON, ASSISTANT PROJECT ENGINEER

Assumptions and Procedures Checked by: (Checker)
Signature: Saad Qureshi — Date: 06 OCT '95
Printed Name and Title: SAAD QURESHI, PROJECT ENGINEER

Computations Checked by:
Signature: Saad Qureshi — Date: 06 OCT '95
Printed Name and Title: SAAD QURESHI, PROJECT ENGINEER

Computations Backchecked by: (Cognizant Engineer)
Signature: Mark H. Gleason — Date: 06 OCT '95
Printed Name and Title: MARK H. GLEASON, ASSISTANT PROJECT ENGINEER

Approved by: (PDP)
Signature: Mark H. Gleason — Date: 06 OCT '95
Printed Name and Title: MARK H. GLEASON, ASSISTANT PROJECT ENGINEER

Approved by: (DTL and TETL)
Signature: Rudolph Bonaparte — Date: 6 Oct 95
Printed Name and Title: Rudolph Bonaparte

Record of Revision (Number and initial all revisions)

NO.	REASON	DATE	BY	CHECKED	APPROVAL
B	Preliminary Design EPA Submittal	14 Dec. 95	[illegible]		

Signature: _____
Number: _____
Registration Stamp (if applicable)

Written by: M. Gleason Date: 95 / 12 / 14 Reviewed by: SQ Date: 95 / 12 / 14

Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 9.7

14Dec95

COVER SYSTEM STABILITY

EXECUTIVE SUMMARY

Purpose

The purpose of this calculation package is to calculate the static stability of the cover system for the On-Site Disposal Facility (OSDF).

Procedure

Provided in this package are the analyses of Final Cover System and Partial Closure Cover System stability for failure surfaces that pass along interfaces within each cover system (i.e., veneer stability). The conditions considered are: (i) final cover system for short-term and long-term stability at 6H:1V and 5H:1V (long-term case only) inclinations; (ii) partial closure cover system for short-term and long-term stability at 3H:1V slope inclination.

The minimum acceptable Factors of Safety based on the UMTRA Technical Approach Document (DOE, 1989) are: (i) long-term stability of Final Cover, FS $\geq$ 1.5; and (ii) short-term stability of Final Cover and stability of Partial Closure Cover, FS $\geq$ 1.3. The stability analyses are performed using established geotechnical procedures for calculating veneer stability.

Results

	Factor of Safety	
• Final Cover System		
· 6H:1V Short-Term Stability	FS = 2.4	acceptable
· 6H:1V Long-Term Stability	FS = 1.6	acceptable
· 5H:1V Long-Term Stability	FS = 1.4	not acceptable
	∴ 6H:1V slopes must be used	
• Partial Closure Cover System		
· 3H:1V Short-Term Stability	FS = 1.4	acceptable
· 3H:1V Long-Term Stability	FS = 1.3	acceptable

Written by: M. GLEASON Date: 95/10/5 (YY MM DD) Reviewed by: SQ Date: 95/10/6 (YY MM DD)

Client: FERMICO Project: OSDF Project/Proposal No.: 6E 3900 Task No.: 9.7

COVER SYSTEM STABILITY

SUMMARY OF CALCULATION RESULTS

Provided in this package are the analyses of Final Cover System and Partial Closure Cover System stability for failure surfaces that pass along interfaces within each cover system (i.e. veneer stability).

The conditions considered are as follows:

Final Cover system for short-term and long-term stability at 6H:1V and 5H:1V (long-term case only) inclination.

Partial Closure Cover system for short-term and long-term stability at 3H:1V slope inclination

The minimum acceptable Factors of Safety Based on the UMTRA Technical Approach Document (DOE, 1989) are:

Long-Term Stability of Final Cover FS ≥ 1.5
Short-term Stability of Final Cover and Stability of Partial Closure Cover FS ≥ 1.3

RESULTS

FINAL COVER SYSTEM

6H:1V	Short-Term Stability	FS = 2.4	ACCEPTABLE ✓
6H:1V	Long-Term Stability	FS = 1.6	ACCEPTABLE ✓
5H:1V	Long-Term Stability	FS = 1.4	NOT ACCEPTABLE ✓

∴ 6H:1V slopes must be used. ✓

PARTIAL CLOSURE COVER SYSTEM

3H:1V	Short-Term Stability	FS = 1.4	ACCEPTABLE ✓
3H:1V	Long-Term Stability	FS = 1.3	ACCEPTABLE ✓

Written by: M. GLEASON Date: 95/10/5 (YY MM DD) Reviewed by: SQ Date: 95/10/06 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.7

RB 95/10/5

COVER SYSTEM STABILITY CALCULATION PACKAGE

PURPOSE: The purpose of this document is to provide the engineering calculations for veneer stability of the OSDF cover system. The cover system considered for the analyses is the final cover system (Figure 1) and the Partial Closure Cover system (Figure 2). The calculations provide an analysis of the stability of the cover system for failure surfaces that pass along the critical interfaces that exist within the cover systems considered.

PROCEDURE The calculation procedure for the cover system stability analysis is described the 'Design Criteria Package and is summarized below. The data used for the analyses are provided in the Data Verification Package that is included with these calculations.

The veneer stability of the cover system is calculated using the methods described in Giroud, et. al (submitted for publication, 1995).

Final Cover System

The final cover system will be constructed over the entire OSDF. The maximum slope inclination is 6H:1V. The maximum slope (landfill) height of approximately 60 ft. Consider for the analysis the following cases: (i) short term stability; (ii) long term stability; and (iii) long term stability of a 5H:1V slope (to demonstrate that 5H:1V does not satisfy minimum stability requirements).

PARTIAL CLOSURE COVER SYSTEM.

A partial closure cover system may be constructed on interim OSDF slopes during temporary slow down of construction and filling. The partial closure cover system, if constructed will be on slopes with a maximum inclination of 3H:1V and with a maximum slope (landfill) height of approximately 60 ft. Consider for the analysis the following cases: (i) short term stability; and (ii) long-term stability (i.e. 5-10 years)

Written by: M. Gleason Date: 95/10/5 (YY MM DD) Reviewed by: SC Date: 95/10/06 (YY MM DD)

Client: FERMIO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.7

RB 95/10/5

COVER SYSTEM STABILITY.

ANALYSIS

USE THE FOLLOWING EQUATION

$$FS = \frac{\gamma_t (t-t_w) + \gamma_b t_w}{\gamma_t (t-t_w) + \gamma_{sat} t_w} \frac{\tan\delta}{\tan\beta} + \frac{a/\sin\beta}{\gamma_t (t-t_w) + \gamma_{sat} t_w}$$

$$+ \frac{\gamma_t (t-t_w^*) + \gamma_b t_w^*}{\gamma_t (t-t_w) + \gamma_{sat} t_w} \frac{t}{h} \frac{\sin\phi}{2\sin\beta\cos\beta\cos(\beta+\phi)}$$

$$+ \frac{c\, t/h}{\gamma_t (t-t_w) + \gamma_{sat} t_w} \frac{\cos\phi}{\sin\beta\cos(\beta+\phi)} + \frac{T/h}{\gamma_t (t-t_w) + \gamma_{sat} t_w}$$

where:

- FS = Factor of Safety
- γ_t = total unit weight of soil (pcf)
- γ_{sat} = saturated unit weight of soil (pcf)
- γ_b = bouyant unit weight of soil (pcf)
- t = thickness of soil layer (ft)
- t_w = thickness of water flow along slope (ft)
- t_w^* = Thickness of water flow in toe of slope (ft)
- β = slope angle (degrees)
- δ = interface friction along slip surface (degrees)
- a = interface adhesion (assumed to be zero)
- ϕ = internal friction of soil above critical surface (degrees)
- h = height of slope (ft)
- T = Tension in geosynthetics (assumed to be zero)
- c = cohesion of soil above critical surface (assumed to be zero)

For c, T, and $a = 0$ The equation becomes:

$$FS = \frac{\gamma_t (t-t_w) + \gamma_b t_w}{\gamma_t (t-t_w) + \gamma_{sat} t_w} \frac{\tan\delta}{\tan\beta}$$

$$+ \frac{\gamma_t (t-t_w^*) + \gamma_b t_w^*}{\gamma_t (t-t_w) + \gamma_{sat} t_w} \frac{t}{h} \frac{\sin\phi}{2\sin\beta\cos\beta\cos(\beta+\phi)}$$

GEOSYNTEC CONSULTANTS

Written by: M. Gleason Date: 95/10/5 (YY MM DD) Reviewed by: SR Date: 95/10/06 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.7

RB 95/10/5

COVER SYSTEM STABILITY - DATA FOR ANALYSIS

FINAL COVER SYSTEM

REFER TO FIGURE 1 FOR INTERFACES

FROM BOTTOM TO TOP:

CONTOURING LAYER (Compacted Fill)	Assume ML/SM Material γ_t = 130 pcf ϕ_{min} = 30°	Reference 2 ✓
COMPACTED CLAY CAP	γ_T = 130 pcf placed $\bar{\phi}$ = 23-29° $\bar{c}$ = 100-400 psf use $\bar{\phi}$ = 25° c = 0 for design	Reference 3 Table 4-9 ✓
GCL internal shear strength and/or GCL/HDPE interface shear strength long term: Hydrated bentonite, no effect of GCL reinforcement short term: Hydrated reinforced GCL or non hydrated geomembrane protected GCL (ie. Gundseal)	<u>long term</u> $\bar{\phi}$ dependent on overburden stress for 6.75 ft of cover material at γ_T = 125 pcf σ_n = 800 psf $\bar{\phi}_{peak}$ = 15° $\bar{\phi}$ large displacement = 13° (Figure 3) <u>Short term</u> if Reinforced, Assume ϕ_p = 2 ϕ_p unreinforced = 30° at low normal stress if Protected by Geomembrane assume ϕ_p = 25° dry $\tan\delta/\tan\phi$ = 0.8 δ = 20°	Reference 5 ✓ Ref 4
Geotextile, textured HDPE	Assume lowest δ_p = 25° under low normal stress.	Reference 4 ✓
Granular Soil - Pea Gravel cobbles, granular filter, vegetative soil layer, topsoil	Assume γ_T = 125 pcf Assume ϕ_{min} = 30°	✓
Geotextile/Granular Soil	$\tan\delta/\tan\phi$ = 0.8 δ_{min} = 25° for ϕ = 30°	Reference 4 ✓

Written by: M. GLEASON Date: 95/10/5 Reviewed by: SG Date: 95/10/06

Client: FERMCO Project: OSDF Project/Proposal No.: 6E 3900 Task No.: 9.7

COVER SYSTEM STABILITY RB 95/10/05

FINAL COVER SYSTEM CONT.

ASSUME MAXIMUM HEAD IN THE COVER SYSTEM = 0.5 ft

CRITICAL INTERFACES:

- Critical interface shear strength for final cover veneer stability for long-term conditions is for the internal and/or the interface strength of the hydrated bentonite component of the GCL.
  - For long-term condition, assume HDPE is not entirely intact; therefore, hydraulic head of 0.5 ft exists on GCL.
- Critical interface for short term final cover veneer stability is either:
  - a) interface strength of dry GCL/HDPE interface (assuming Gundseal type product used) without hydraulic head (head acts on geomembrane, not GCL)
  - b) interface strength of geotextile/HDPE interface with 0.5 ft of hydraulic head.

Assumption of maximum hydraulic head in the cover system is a conservative assumption based on analyses performed by GeoSyntec in the Cover System Performance Calculation Package. ✓

Written by: M. GLEASON Date: 95 / 10 / 5 (YY MM DD) Reviewed by: SR Date: 95 / 10 / 06 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: 6E 3900 Task No.: 9.7

RB 95/10/5

COVER SYSTEM STABILITY - DATA FOR ANALYSIS

PARTIAL CLOSURE COVER SYSTEM

FROM BOTTOM TO TOP

CONTOURING LAYER (compacted Fill)	Assume ML/SM material γ_t = 130 pcf ϕ_{min} = 30°	Reference 2 ✓
CONTOURING LAYER/HDPE Geomembrane Interface	$\tan\delta / \tan\phi$ = 0.8 - 0.9 for ϕ = 30° δ = 24°	Reference 4 ✓
HDPE/Geocomposite drainage layer (HDPE/NW geotextile)	Assume lowest δ_p = 25° UNDER LOW NORMAL STRESS	Reference 4 ✓
Geotextile/Granular Soil	$\tan\delta / \tan\phi$ = 0.8 δ_{min} = 25° for ϕ = 30°	Reference 4 ✓
Granular Soil	Assume γ_t = 125 pcf ϕ = 30°	

CRITICAL INTERFACES

short term stability: assume geocomposite drainage layer removes all water from cover without allowing hydraulic head to develop. Critical interface is contouring layer / HDPE interface with zero pore pressures.

long-term stability: assume hydraulic head builds to 0.5 ft on surface of HDPE geomembrane. Critical interface is Geotextile/HDPE interface. ✓

Written by: M. GLEASON Date: 95/10/5 (YY MM DD) Reviewed by: [illegible] Date: 95/10/06 (YY MM DD)

Client: FERNALD Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.7

RB 95/10/6

COVER SYSTEM STABILITY

MINIMUM ACCEPTABLE FACTORS OF SAFETY BASED ON UMTRA Technical Approach Document (DOE, 1989) Ref 6

FOR FINAL COVER SYSTEM

LONG TERM STABILITY FS ≥ 1.5 ✓

short term stability FS ≥ 1.3

FOR PARTIAL CLOSURE COVER SYSTEM

BECAUSE THIS IS A TEMPORARY COVER, CONSIDER FACTORS OF SAFETY ACCEPTABLE IF FS ≥ 1.3 FOR BOTH LONG-TERM (5-10 yrs) AND SHORT-TERM CONDITIONS.

PARAMETERS FOR DESIGN

FINAL COVER SYSTEM

$\gamma_T = \gamma_{sat} = 125$ pcf

$\gamma_b = 62.6$ pcf

$\phi = 30°$

$t = 6.8$ ft

$t_w = 0.5$ ft (ASSUMED)

$t_w^* = 3.4$ ft (Assumed)

$\beta = 9.5°$ (6H:1V) or [11.3 (5H:1V)]

$h = 60$ ft maximum

δ = VARIABLE w/ CASE ✓

PARTIAL CLOSURE COVER SYSTEM

$\gamma_t = \gamma_{sat} = 125$ pcf

$\gamma_b = 62.6$ pcf

$\phi = 30°$

$t = 3.15$ ft

$t_w = 0.5$ ft (if applicable)

$t_w^* = 1.6$ ft (assumed if applicable).

$\beta = 18.4°$ (3H:1V)

$h = 60$ ft MAX ✓

δ = variable w/ case

Written by: M. GLEASON Date: 95/10/5 (YY MM DD) Reviewed by: SR Date: 95/10/06 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.7

COVER SYSTEM STABILITY

RB 95/10/6

FINAL COVER SYSTEM STABILITY

SHORT TERM STABILITY

CASE A Dry Bentonite GCL/HDPE interface. $\delta = 20°$
For this case, $t_w = 0$, $t_w^* = 0$

$$FS = \frac{125(6.8-0) + 62.6(0)}{125(6.8-0) + 125(0)} \frac{\tan 20}{\tan 9.5} + \frac{125(6.8-0) + 62.6(0)}{125(6.8-0) + 125(0)} \frac{6.8}{60} \frac{\sin 30}{2 \sin 9.5 \cos 9.5 \cos(39.5)}$$

$$FS = 2.18 + 0.22 = 2.4$$ ACCEPTABLE ✓

CASE B GEOTEXTILE/HDPE INTERFACE WITH $\delta = 25°$
$t_w = 0.5$ ft $t_w^* = 3.4$ ft

$$FS = \frac{125(6.8-0.5) + 62.6(0.5)}{125(6.8-0.5) + 125(0.5)} \frac{\tan 25}{\tan 9.5} + \frac{125(6.8-3.4) + 62.6(3.4)}{125(6.8-0.5) + 125(0.5)} \frac{6.8}{60} \frac{\sin 30}{2 \sin 9.5 \cos 9.5 \cos(39.5)}$$

$$FS = 2.68 + 0.07 = 2.7$$ ACCEPTABLE. ✓

FINAL COVER SYSTEM IS STABLE IN SHORT TERM.

Written by: M. GLEASON Date: 95/10/5 Reviewed by: SR Date: 95/10/06

Client: FRMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.7

RB 95/10/16

COVER SYSTEM STABILITY

FINAL COVER SYSTEM

LONG-TERM STABILITY

6H:1V Slope $t_w = 0.5$ $t_w^* = 3.4$ $\delta = 15°$ peak

$$FS = \frac{125(6.8-0.5)+62.6(0.5)}{125(6.8-0.5)+125(0.5)} \frac{\tan 15}{\tan 9.5}$$

$$+ \frac{125(6.8-3.4)+62.6(3.4)}{125(6.8-0.5)+125(0.5)} \frac{6.8}{60} \frac{\sin 30}{2\sin 9.5 \cos 9.5 \cos 39.5}$$

$FS = 1.54 + 0.07 = 1.6$ ACCEPTABLE

CHECK LARGE DISPLACEMENT $FS > 1.3$ $\delta = 13°$

$FS = 1.33 + 0.07 = 1.4$ ACCEPTABLE ✓

5H:1V Slope $t_w = 0.5$ $t_w^* = 3.4$ $\delta = 15°$ peak $\beta = 11.3°$

$$FS = \frac{125(6.8-0.5)+62.6(0.5)}{125(6.8-0.5)+125(0.5)} \frac{\tan 15}{\tan 9.5}$$

$$+ \frac{125(6.8-3.4)+62.6(3.4)}{125(6.8-0.5)+125(0.5)} \frac{6.8}{60} \frac{\sin 30}{2\sin 9.5 \cos 9.5 \cos 39.5}$$

$FS = 1.34 + 0.7 = 1.4$ NOT ACCEPTABLE. MINIMUM FS OF 1.5 NOT ACHIEVED ✓

∴ SLOPE MUST BE 6H:1V ✓

Written by: M. GLEASON Date: 95/10/5 (YY/MM/DD) Reviewed by: SR Date: 95/10/06 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.7

RB 95/10/6

COVER SYSTEM STABILITY

PARTIAL CLOSURE COVER SYSTEM

SHORT TERM — CRITICAL INTERFACE CONTOURING LAYER / HDPE
zero pore pressure
$t_w = 0$ $t_w^* = 0$ $\delta = 24°$ $\beta = 18.4°$

$$FS = \frac{125(3.15-0)+62.6(0)}{125(3.15-0)+125(0)} \frac{\tan 24°}{\tan 18.4°}$$

$$+ \frac{125(3.15-0)+62.6(0)}{125(3.15-0)+125(0)} \frac{3.15}{60} \frac{\sin 30}{2 \sin 18.4 \cos 18.4 \cos 48.4}$$

$\cos(30+18.4)$

$FS = 1.34 + 0.07 = 1.4$ ACCEPTABLE ✓

LONG TERM — CRITICAL INTERFACE IS GEOTEXTILE / HDPE GEOMEMBRANE WITH HYDRAULIC HEAD IN GEOCOMPOSITE DRAINAGE LAYER OF 0.5 ft MAXIMUM OVER TIME PERIOD OF 5-10 YEARS

$t_w = 0.5$ $t_w^* = 1.6$ $\beta = 18.4$ $\delta_p = 25°$

$$FS = \frac{125(3.15-0.5)+62.6(0.5)}{125(3.15-0.5)+125(0.5)} \frac{\tan 25}{\tan 18.4}$$

$$+ \frac{125(3.15-1.6)+62.6(1.6)}{125(3.15-0.5)+125(0.5)} \frac{3.15}{60} \frac{\sin 30}{2 \sin 18.4 \cos 18.4 \cos 48.4}$$

$FS = 1.29 + 0.05 = 1.3$ ACCEPTABLE ✓

PARTIAL CLOSURE SYSTEM IS STABLE IN SHORT-TERM AND LONG-TERM ✓

Written by: M. GLEASON Date: 95/9/6 (YY MM DD) Reviewed by: [illegible] Date: 95/10/06 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.7

RB 95/10/6

COVER SLOPE STABILITY DATA VERIFICATION

REFERENCES

1. FERMCO, ON-SITE DISPOSAL FACILITY STATEMENT OF WORK JUNE 1995

2. Holtz, R.D., and Kovacs, W.D. "An Introduction to Geotechnical Engineering" Prentice-Hall, Inc., Englewood Cliffs, NJ, 1981 p. 518

3. "Disposal Facility Pre-Design Geotechnical Investigation, Soil Investigation Data Report," Operable Unit-2 Project Order 132, July 1995 by PARSONS - Fairfield Executive Center, 6120 South Gilmore Rd, Fairfield Ohio 45014

4. Data established from:
   - Manufacturer's literature
   - unpublished results from GeoSyntec Consultants
   - Martin, J.P., Koerner, R.M., and Whitty, J.E. "Experimental Friction Evaluation of Slippage Between Geomembranes, Geotextiles, and Soils," Proceedings, International Conference on Geotextiles, IFAI Denver, 1984, pp 191-196
   - Koerner, R.M., Martin, J.P., and Koerner, G.R., "Shear Strength Parameters Between Geomembranes and Cohesive Soils," Geotextiles and Geomembranes, Vol 4. No. 1 1986 pp 21-30.
   - Williams N.D., and Houlihan, M.F., "Evaluation of Interface Friction Properties Between Geosynthetics and Soils," Proceedings, Geosynthetics '87, New Orleans, LA Feb. 1987, pp 616-627

5. Internal memorandum by GeoSyntec Consultants "Internal Shear Strength of Hydrated GCL's" August, 1994. SEE ATTACHED FIGURE 3.

6. U.S. Department of Energy, "Uranium Mill Tailings Remediation Control Act, Remedial Action Design," Technical Approach Document, Revision II, December, 1989

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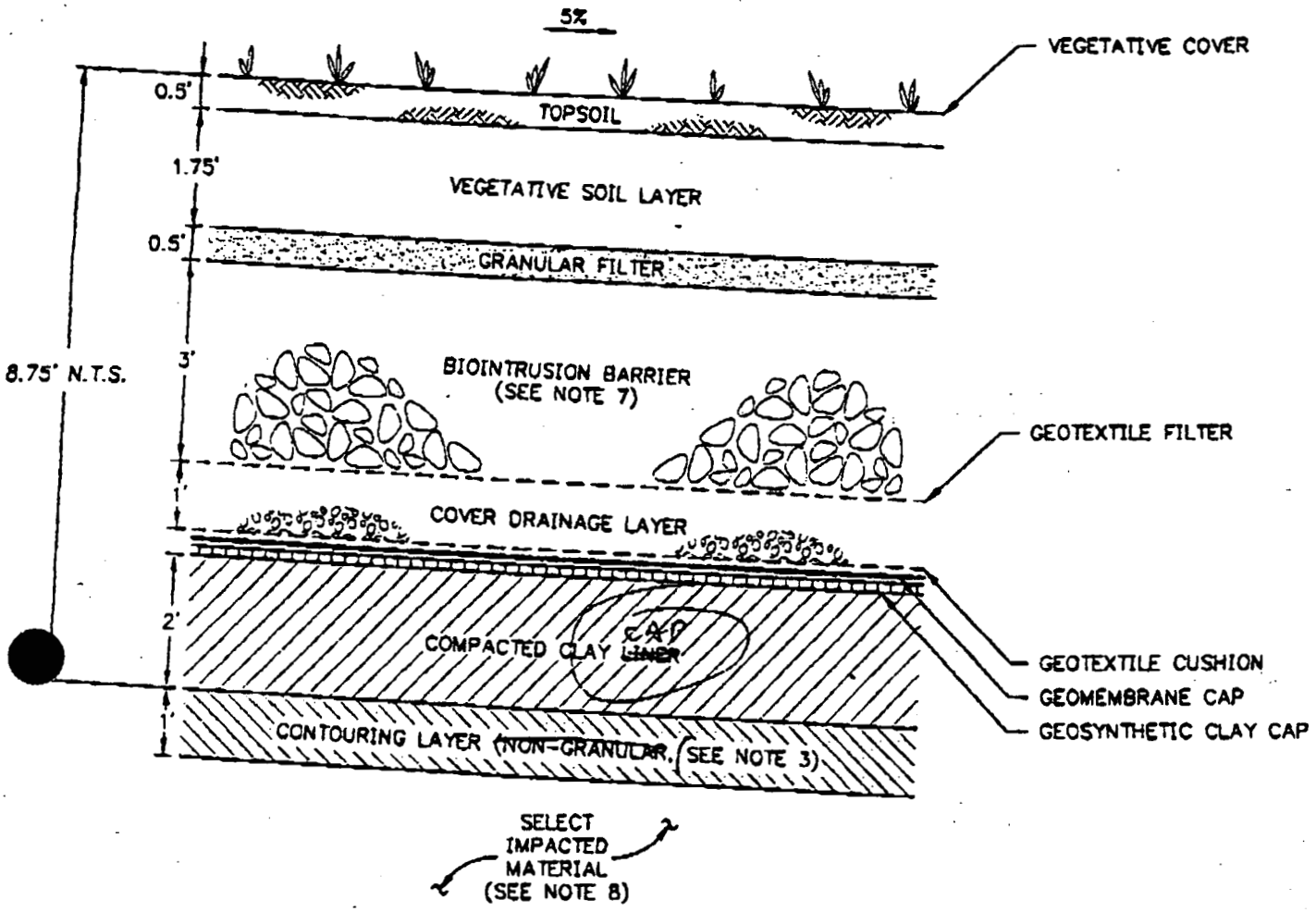
12/14

RB 95/10/5



DET-NO DETAIL
SHT-NO FINAL COVER SYSTEM
SCALE: 1" = 2'

FIGURE 1

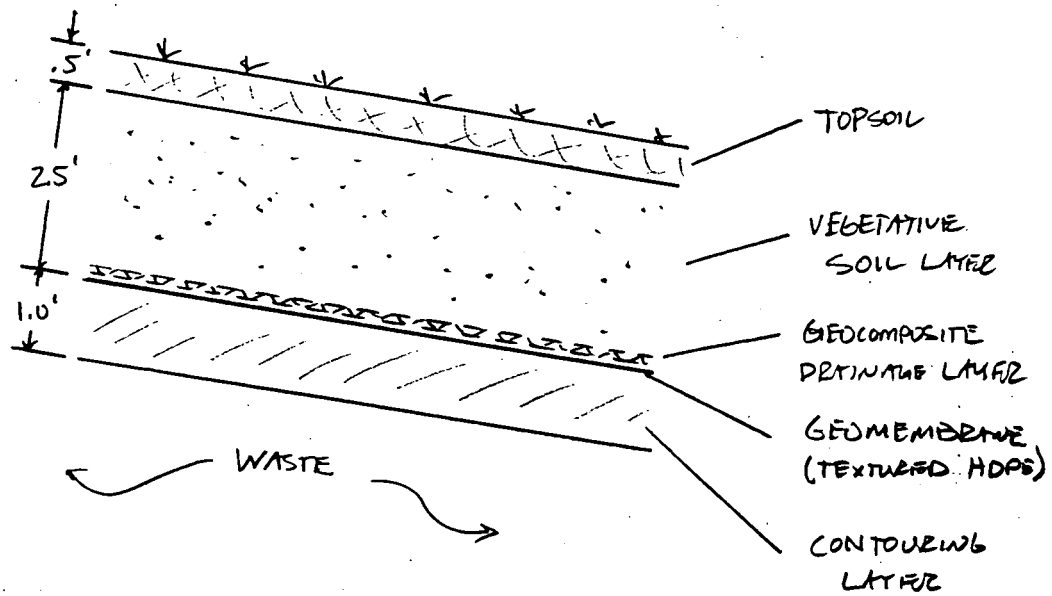
TOTAL P.02

Written by: M. GLEESON Date: 95/10/5 (YY/MM/DD) Reviewed by: [illegible] Date: 95/10/06 (YY/MM/DD)

Client: FECMLO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.7

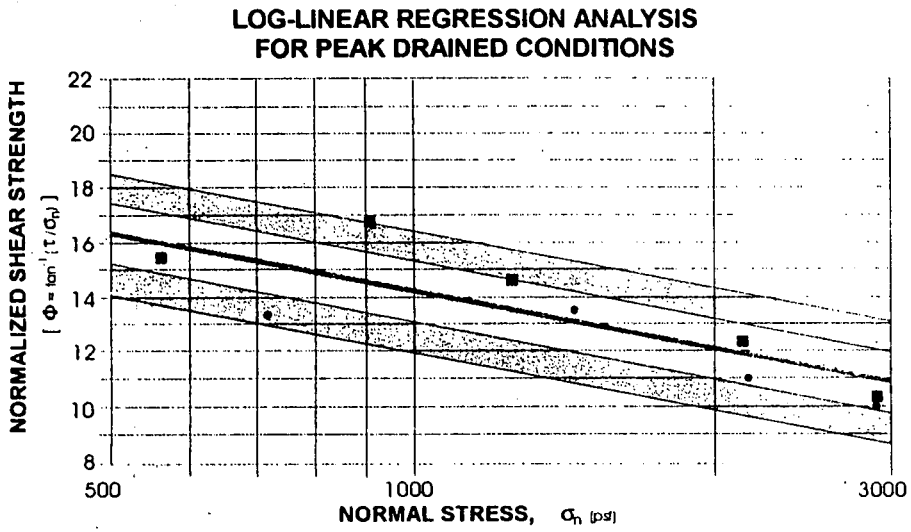
RB 95/10/5

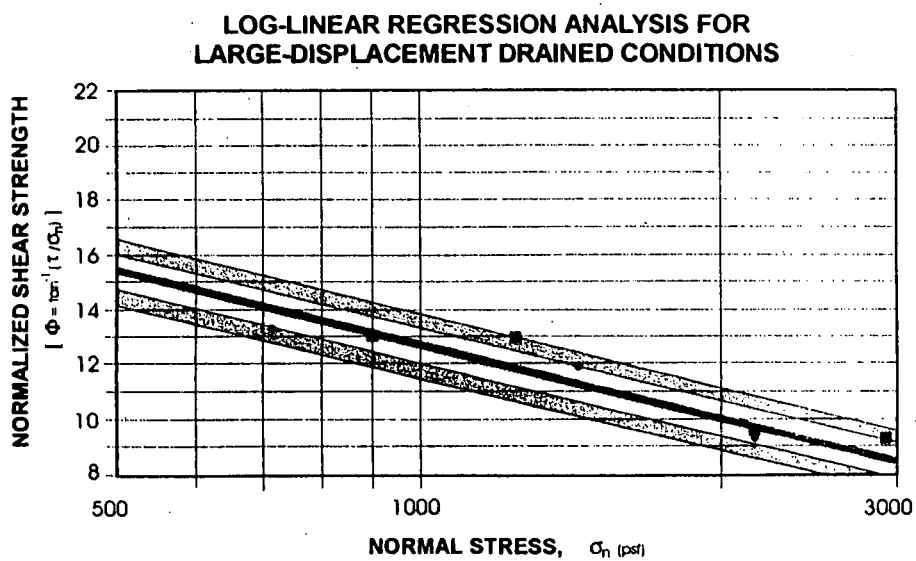
FIGURE 2 PARTIAL CLOSURE SECTION

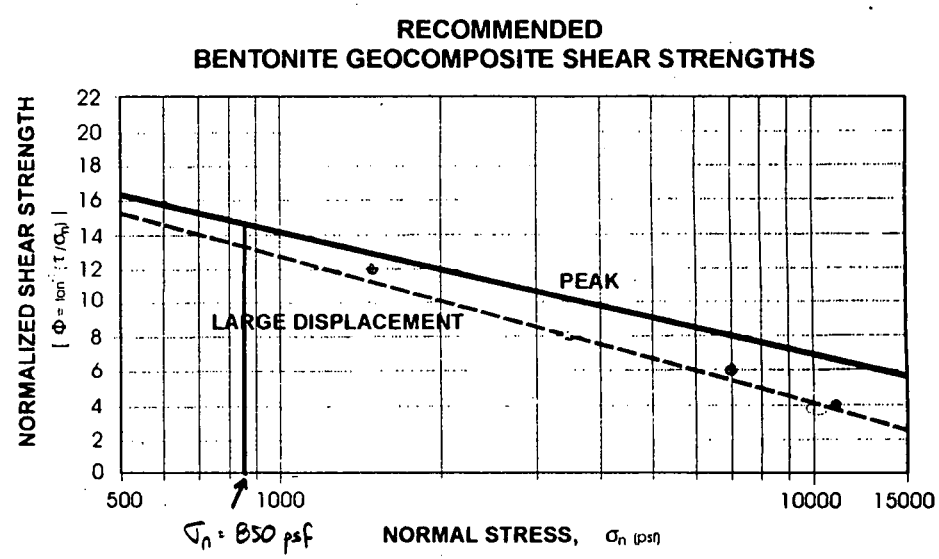


10. Use this space to provide any additional information or description of resources (including any computer design capabilities) supporting your firm's qualifications for the proposed project.

FIGURE 3 GCL SHEAR STRENGTHS
COVER SYSTEM STABILITY







- ● CLAYMAX
- ■ GUNDSEAL
- ● HSM = HOMION SODIUM MONTMORILLONITE, CONSOLIDATED FROM A SLURRY, AND TESTED IN TRIAXIAL COMPRESSION HSM DATA FROM MESRI,G AND OLSON, R E., "SHEAR STRENGTH OF MONTMORILLONITE", GEOTECHNIQUE, VOL NO 20, 1970, PP 2261-270
- ☐ 67% STANDARD ERROR RANGE
- ☐ 95% STANDARD ERROR RANGE

FIGURE 10-6
DRAINED SHEAR STRENGTH OF UNREINFORCED BENTONITE GEOCOMPOSITE

000723

F-186 14/14
RB 4/5/10/5

3.5 Perimeter Access Corridor

COMPUTATION COVER SHEET

SUBJECT OF CALCULATION: PERIMETER ACCESS CORRIDOR

Computations By: (Cognizant Engineer)
Signature [signature] Date 7 Oct 95
Printed Name and Title Gary R. Schmertmann, Senior Project Engineer

Assumptions and Procedures Checked by: (Checker)
Signature [signature] Date 7 Oct 95
Printed Name and Title Robert C. Bachus, Principal

Computations Checked by:
Signature [signature] Date 7 Oct 95
Printed Name and Title Robert C. Bachus, Principal

Computations Backchecked by: (Cognizant Engineer)
Signature [signature] Date 7 Oct 95
Printed Name and Title Gary R. Schmertmann, Sr. Project Engineer

Approved by: (PDP)
Signature [signature] Date 7 Oct 95
Printed Name and Title Gary R. Schmertmann, Sr. Project Engineer

Approved by: (DTL and TETL)
Signature [signature] Date 7 Oct 95
Printed Name and Title Rudolph Bonaparte

Record of Revision (Number and initial all revisions)

NO.	REASON	DATE	BY	CHECKED	APPROVAL	
Ø	30% Submittal	NA	NA	NA	NA	No Changes
B	Exec. Summary	13 Dec 95	GRS	RCB	RB	

Signature: _____
Number: _____
Registration Stamp (if applicable)

Written by: GRS Date (Y/M/D): 95/12/13 Reviewed by: QCB Date: 14 Dec '95

Client.: FERMCO Project: OSDF Project No.: GE3900 Task No.: 9.4

PERIMETER ACCESS CORRIDOR STABILITY

EXECUTIVE SUMMARY

Purpose of Calculations:

These calculations are performed to evaluate the stability of the outer berm of the perimeter access corridor for short-term and long-term conditions.

Methodology:

Stability is evaluated by first calculating the minimum slope stability factor of safety (FS) of the outboard slopes of the berm using the 2-dimensional limit equilibrium analysis chart solutions presented by Duncan et al. (1987) (reference no. 2 in Calculation Procedures/Methods package). The calculation considers the following: (i) location of cross section with the least stable outer berm slopes; (ii) potential traffic loading on the top of the berm; (iii) stability for both short-term (i.e., end-of-construction) and long-term conditions; (iv) appropriate shear strength of the berm material (i.e., compacted brown till) and underlying foundation material (i.e., in-situ brown till); and (v) pore pressures within the berm. The calculated minimum FS is then compared to the target value of FS given in the Design Criteria Package, i.e., 1.3 for short-term conditions and 1.5 for long-term conditions. Adequate stability is demonstrated if the calculated minimum FS is equal to or greater than the target value.

Conclusions:

- Calculated minimum slope stability FS for short-term conditions is 2.36. This value exceeds the target value of 1.3. Therefore, short-term stability is adequate.
- Calculated minimum slope stability FS for long-term conditions is 1.87. This value exceeds the target value of 1.5. Therefore, long-term stability is adequate.

End of Executive Summary

Written by: GRS Date: 95/10/7 (YY/MM/DD) Reviewed by: R Bonaparte Date: 95/10/7 (YY/MM/DD)

Client: FERMCO Project: OUDF Project/Proposal No.: GE 3900 Task No.: 9.4

RCB 95/10/7

PERIMETER ACCESS CORRIDOR STABILITY - CALCULATION PROCEDURES / METHODS

PURPOSE: Present procedures and methods for calculations to check short- and long-term stability of the perimeter access corridor which forms a portion of the landfill closure configuration

SCOPE: Step-by-step procedures References

The landfill perimeter access corridor (AC) includes an outer berm which supports a roadway. The berm is designed to be stable at the end of its construction and to remain stable thereafter. Stability is assessed by considering potential slip surfaces that pass through the berm and calculating a slope stability Factor of Safety (FOS) for the critical (i.e. least stable) surface.* The design is acceptable if the FOS exceeds a target value. Both short-term (end of construction) and long-term conditions will be considered. For both conditions, only the outboard slopes of the berm will be considered because the inboard slopes are stabilized by elements of the landfill final cover system

[* see conceptual sketch on following page]

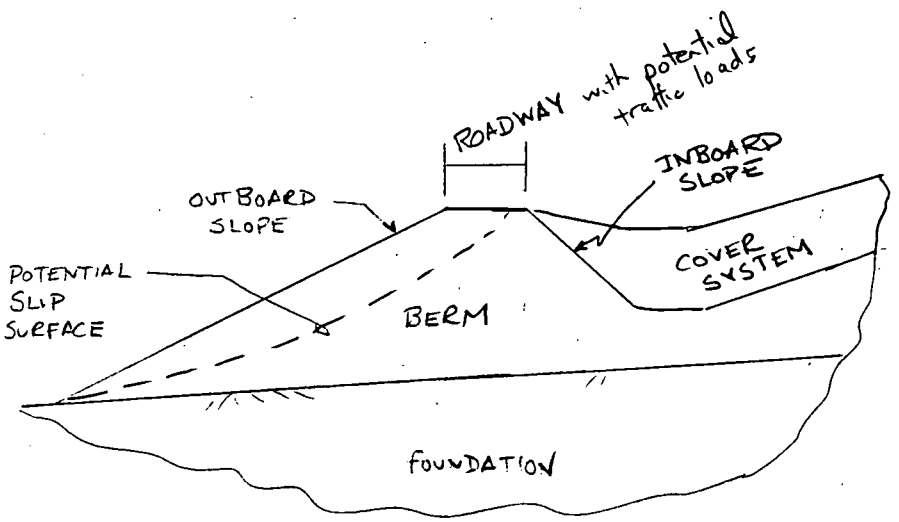
Written by: GRS Date: 95/10/7 (YY/MM/DD) Reviewed by: R Bonaparte Date: 95/10/7 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.4

RCB 95/10/7

ISSUES TO BE CONSIDERED IN ANALYSIS:

- location of critical cross section
- physical properties of berm materials
- shear strength of berm foundation
- pore pressures within berm



CONCEPTUAL SKETCH OF POTENTIAL SLIP SURFACE IN PERIMETER ACCESS CORRIDOR (A.C.) [NTS]

CALCULATION STEPS:

(1) Select location of critical cross section:

The most critical case for A.C. berm stability will involve the highest and steepest A.C. berm slopes. This statement implicitly involves the reasonable assumption that foundation and A.C. berm materials will be relatively uniform throughout the OSDF. The critical cross section will be located based on the project design drawings.

Written by: GRS Date: 95/10/7 (YY MM DD) Reviewed by: R. Bonaparte Date: 95/10/7 (YY MM DD)

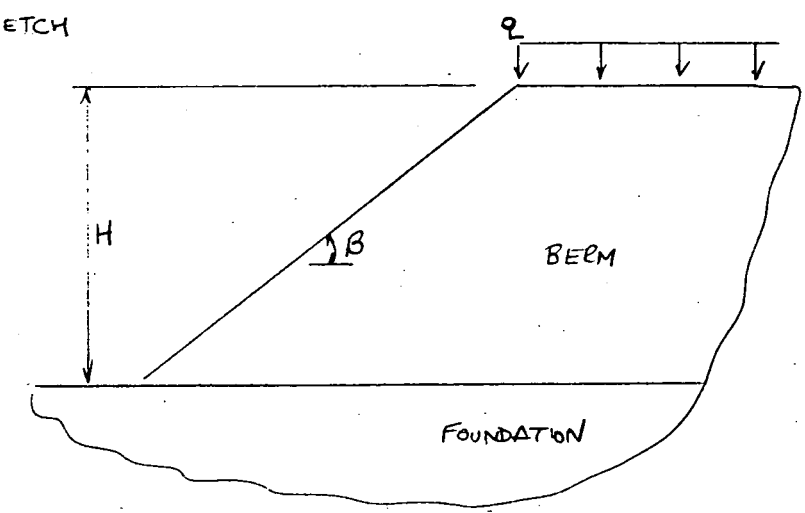
Client: FERMCO Project: OSDF Project/Proposal No.: GE3966 Task No.: 9.4

RGB 95/10/7

② Evaluate shear strength of A.C. berm material and foundation soils for end-of-construction and long-term conditions. Also evaluate moist unit weight of these materials. The evaluation should be based on information obtained from site geotechnical investigation (Reference 1), as interpreted in the "Foundation Stability" Calculation package (Doc. No. F953020.CDO)

③ Select geometry and material parameters for calculation of critical FOS:

KEY SKETCH



Geometry Parameters: H, β obtained from critical cross-section geometry

Material Parameters: Berm – ϕ_b, c_b, γ_b; Foundation – ϕ_f, c_f, γ_f } obtained from material properties evaluation for both short- and long-term.

Surcharge loading: Assume equal to 250 psf. This corresponds to the minimum surcharge recommended by AASHTO to represent traffic loading for retaining wall design (Reference 3)

Written by: GES Date: 95/10/7 (YY MM DD) Reviewed by: R. Bonaparte Date: 95/10/7 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.4

RCB 95/10/7

With respect to pore water pressures:

For short-term conditions the classical assumption that pore pressure effects are accounted for in selected values of undrained shear strength will be employed.

For long-term conditions, it is assumed that perched and aquifer ground-water levels will remain in the foundation materials such that no pore pressure will be present in the berm materials. This assumption is supported by site information, as summarized in "Hydrostatic Forces" calculation package (Document No. F9530014.CDO).

(4) Calculate critical FOS for short- and long-term conditions:

Use the methodology and chart solutions provided in Reference 2. This reference provides solutions for a range of conditions which encompass the conditions of concern herein.

(5) Compare calculated critical FOS to target values.

Target values are: end-of-construction: 1.3, long-term: 1.5 } Source is GeoSyntec Design Criteria (document no. F9530004)

Calculated critical FOS must be ≥ target values to establish adequate stability

Written by: GRS Date: 95/10/7 (YY MM DD) Reviewed by: R. Bonaparte Date: 95/10/7 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.4

RCB 95/10/7

REFERENCES

1. Parsons, "Disposal Facility Pre-Design Geotechnical Investigation, Soil Investigation Data Report" Operable Unit 2, Project Order 132, July 1995.

2. Duncan, J.M., Buchignani, A.L., and De Wet, M., "An Engineering Manual for Slope Stability Studies," Department of Civil Engineering, Virginia Polytechnic and State University, March 1987.

3. AASHTO, "Standard Specifications for Highway Bridges" 15th edition, 1992, article 3.20.3

Written by: GRS Date: 95/10/7 (YY/MM/DD) Reviewed by: R Bonaparte Date: 95/10/07 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.4

RCB 95/10/7

PERIMETER ACCESS CORRIDOR STABILITY — DATA VERIFICATION

PURPOSE: Evaluate data and parameters required to perform stability calcs. for perimeter access corridor outer berm

SCOPE: Covers all data and parameter requirements presented in the "calculation procedures/methods" package

REQUIRED DATA AND PARAMETERS:

This section is organized using the calculation step numbers presented in the "calculation procedures/methods" package.

(1) Select location of critical cross section:

Critical location is for highest and steepest outer berm slopes. Based on final cover system grading plan (see p. 2) all outer berm slopes are inclined at 4H:1V. Therefore, steepness is not a factor in selecting the critical location. Highest outer berm slopes occur on the west side of the OSDF at the location indicated on pages 2 and 3. The maximum slope height is 19 ft. Conclude that critical cross-section is at this location. Cross-section view at this location is shown on page 4.

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p. 2 of 6
RCB 95/10/7
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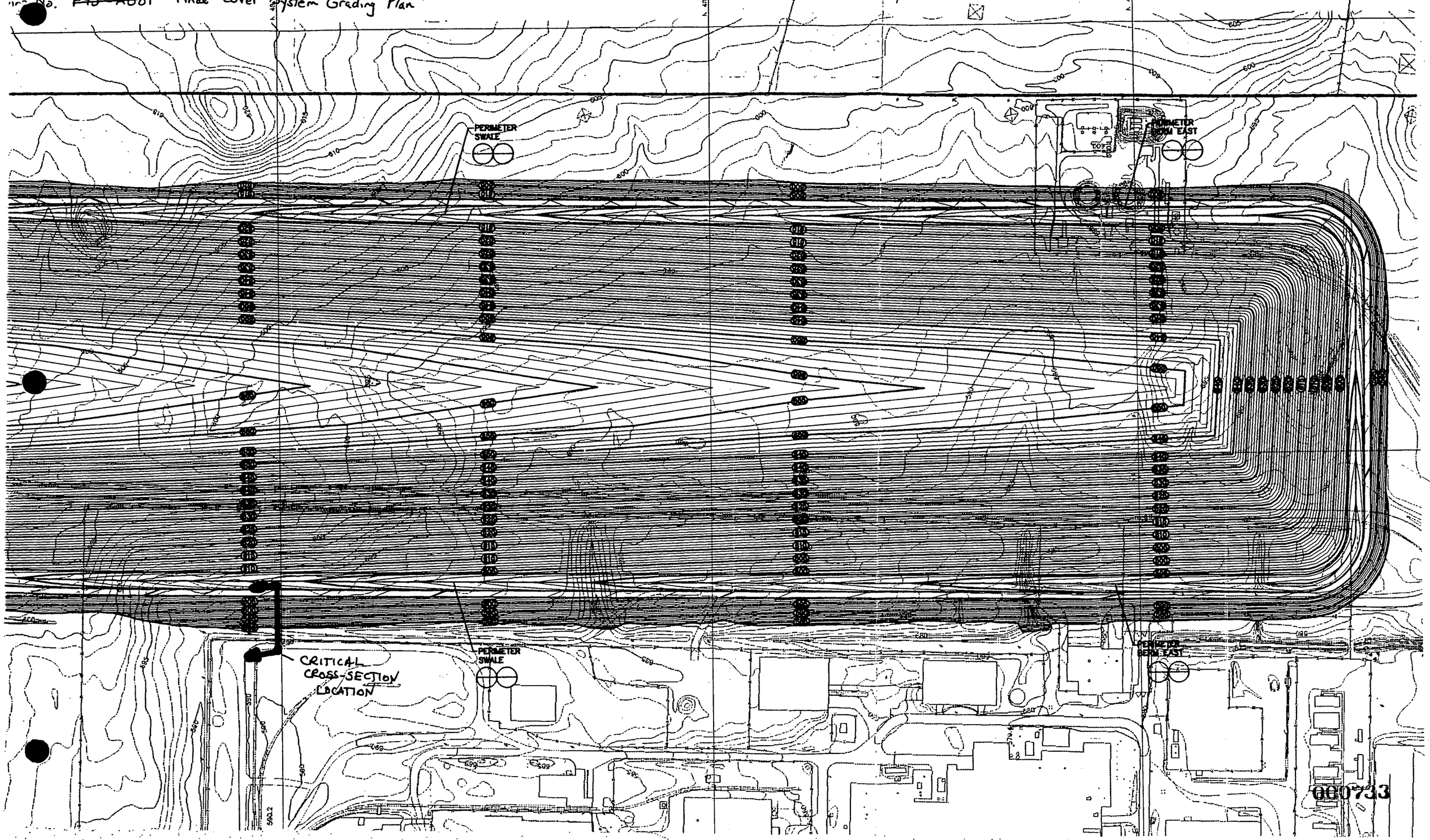
Dwg. No. ~~F95-A081~~ "Final Cover System Grading Plan"



000733

GRS 10/7/95

p. 3 of 6

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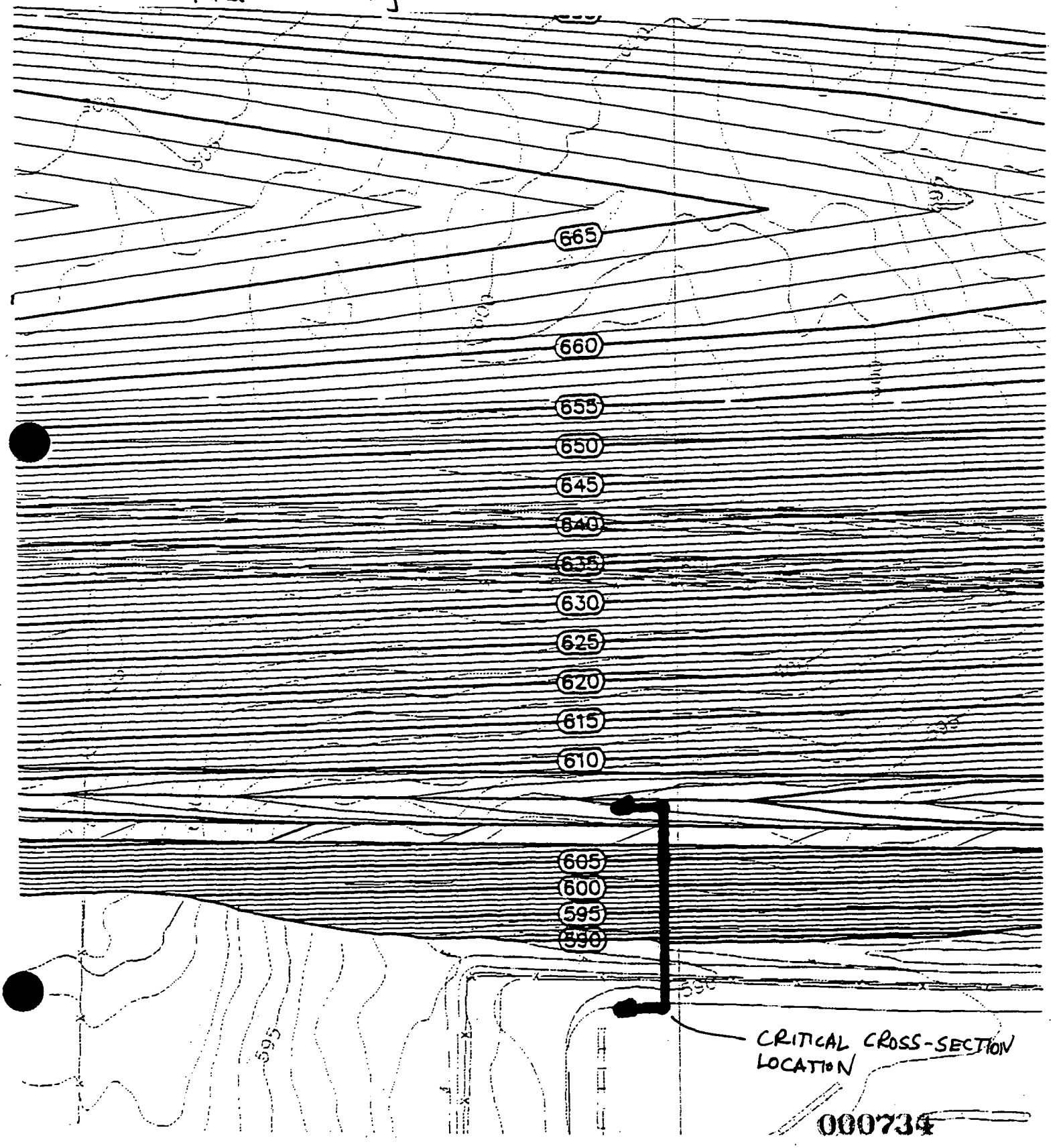
RCB 95/10/7
RB 95/10/07

Source: Design Drawing ~~No. FPS-A081~~
"Final Cover Grading Plan"



GRS 10/7/95

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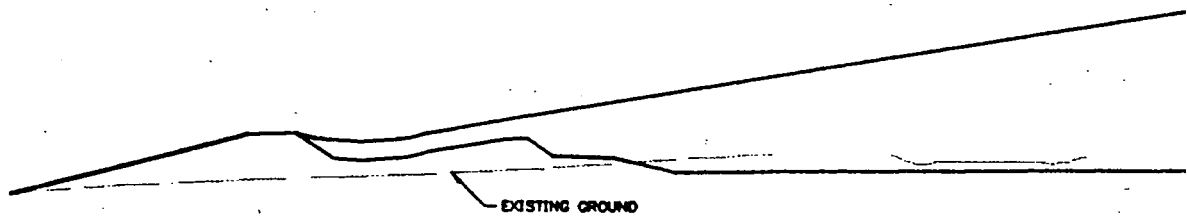
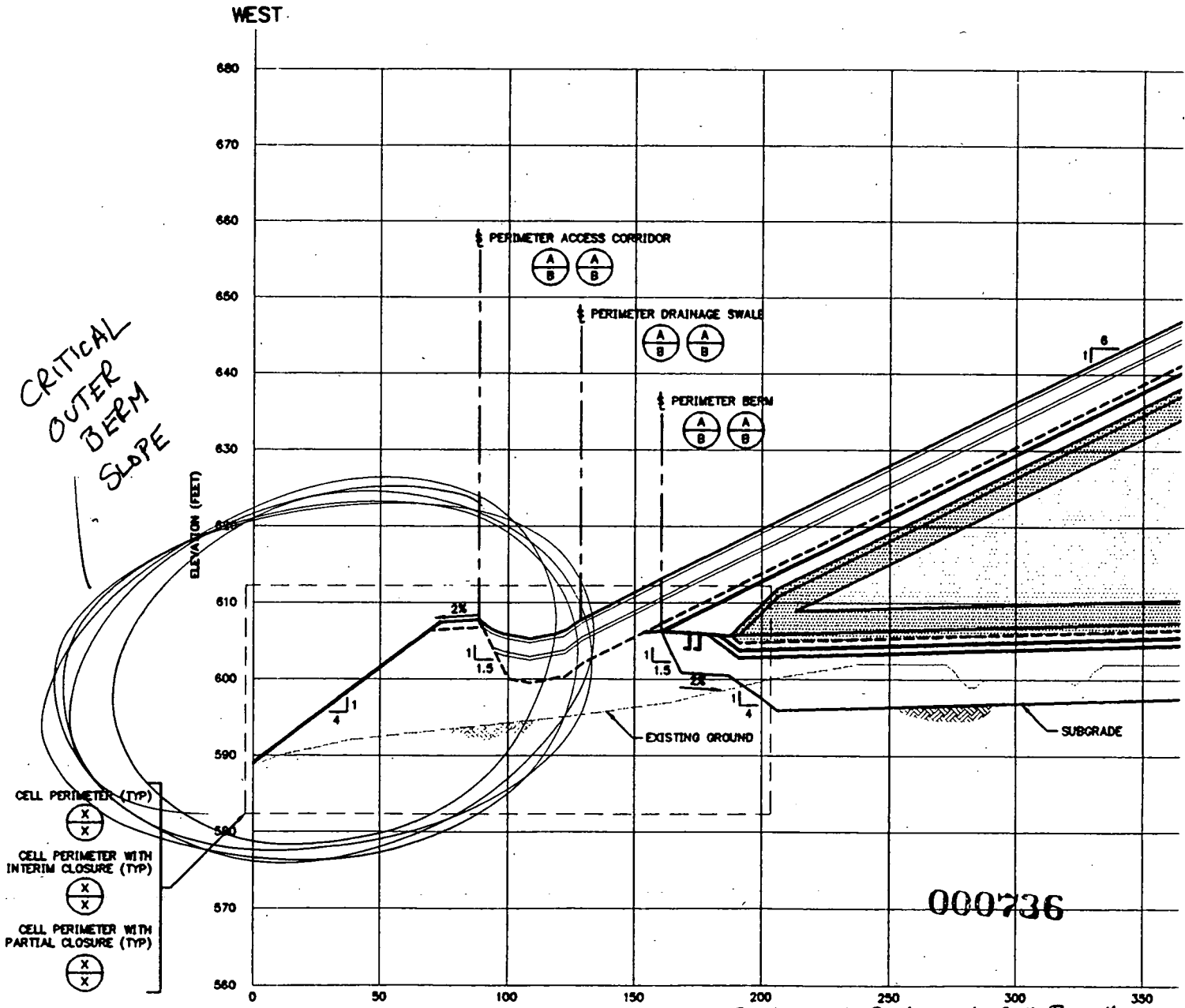
RCB 95/10/7
RB 95/10/07





000736

SOURCE: Design Drawing No. F95-A022 "East-West Section at Cell Base" ~~"OSDP Cross-Section West-East at Intercell Base"~~

Written by: GRS Date: 95/10/7 (YY MM DD) Reviewed by: R Bonaparte Date: 95/10/07 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.4

RCB 95/10/7

(2) Evaluate shear strength of berm and foundation material for end-of-construction and long-term conditions:

Berm material: Assume this will be recompacted "crown till." Based on the synthesis and interpretation provided in the 'Foundation Stability' calculation package (Doc. No. F953000200.CDO) appropriate shear strength parameters are as follows:-

end-of construction: $\phi = 0°$, $c = 1200$ psf

long-term: $\phi = 25°$, $c = 0$ psf

From the same source document, an appropriate value of moist unit weight is $\gamma = 135$ pcf.

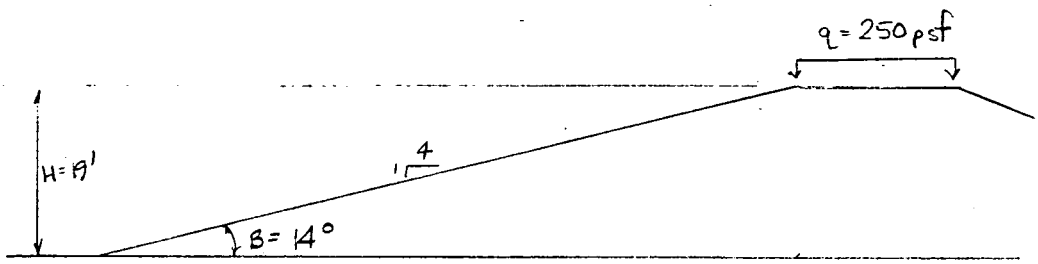
Foundation material: Based on the same synthesis and interpretation referenced above, natural "brown till" will underlie the berm to a depth of approximately 15 ft. The natural "brown till" is underlain by a stronger "gray till." For this calculation, assume that foundation is all "brown till." The synthesis and interpretation indicates that appropriate ~~the~~ shear strength and unit weight parameters for the natural "brown till" are the same as for the recompacted "brown till".

Written by: GRS Date: 95/10/7 (YY MM DD) Reviewed by: R Bonaparte Date: 95/10/07 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.4

RCB 95/10/7

(3) Select geometry and material parameters for calculation of critical FOS.



Geometry Parameters: $H = 19$ ft, $\beta = 14°$

Material Parameters:

	Berm	Foundation
Short-term shear strength	$\phi = 0°, c = 1200$ psf	$\phi = 0°, c = 1200$ psf
Long-term shear strength	$\phi = 25°, c = 0$	$\phi = 25°, c = 0$
unit weight	135 pcf	135 pcf

Surcharge: 250 psf

Written by: GPS Date: 95/10/7 (YY/MM/DD) Reviewed by: Date: / / (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.4

RCB 95/10/7

PERIMETER ACCESS CORRIDOR STABILITY – CALCULATIONS

PURPOSE: Present stability calculations for end-of-construction and long-term stability of perimeter access corridor outer berm

SCOPE: Calculations as described in "calculation procedures/methods" package beginning at step (4)

CALCULATIONS FOR CRITICAL FOS:

(4) * Summary of parameters from "Data Verification" package

Geometry: $H = 19$ ft $\beta = 14°$

Surcharge: 250 psf

Shear strength:

		Berm	Fdn.
Short-Term	ϕ	0	0
	c (psf)	1200	1200
Long-Term	ϕ	25	25
	c (psf)	0	0

Unit weight: Berm $\gamma = 135$ pcf

Fdn. $\gamma = 135$ pcf

Note: since berm and foundation material properties are the same, treat the berm and foundation as a uniform soil

Written by: GRS Date: 95/10/7 (YY/MM/DD) Reviewed by: _____ Date: __/__/__ (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9A

RCB 95/10/7

* End-of-Construction

Use methodology in Reference 2 from "calculation procedures/methods" package for uniform, $\phi = 0°$ soils

$$FOS = \frac{N_o c}{P_d}$$

where N_o = stability number, obtained from chart on p. 3 = 5.53

c = soil cohesion = 1200 psf

$$P_d = \frac{\gamma H + q - \gamma_w H_w}{\mu_q \mu_w \mu_t}$$

γ = 135 pcf H = 19 ft q = 250 psf

H_w = slope submergence height = 0

μ_q = surcharge correction factor, obtained from plot on p. 4 = 1.0

μ_w = submergence correction factor = 1.0 (i.e. no submergence)

μ_t = tension crack correction factor = 1.0 (i.e. no tension crack)

$$P_d = \frac{135\ lb/ft^3\ (19\ ft) + 250\ psf - 0}{(1.0)(1.0)(1.0)} = 2815\ psf$$

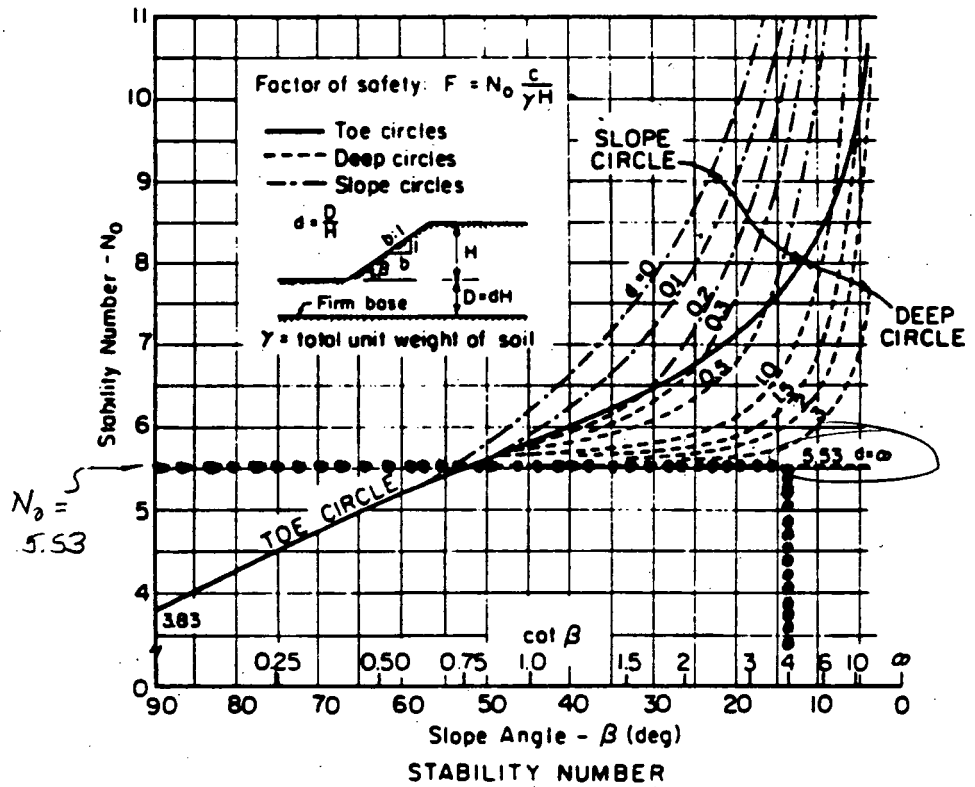
$$FOS = \frac{5.53\ (1200\ psf)}{2815\ psf} = \underline{2.36}$$

Written by: GES Date: 95/10/7 (YY MM DD) Reviewed by: Date: / / (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.1

RCB 95/10/7

Obtain N_0



Assume depth to firm base is infinite
use $\beta = 4°$

$N_0 = 5.53$

Base circle

Source: Fig 6 from Reference 2 of "calculation procedures/methods"

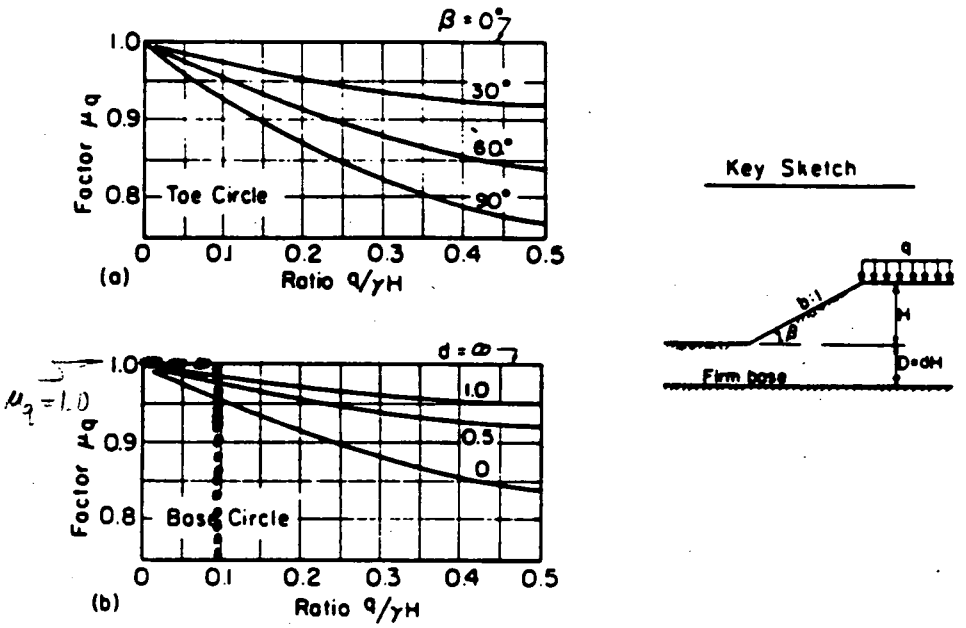
Written by: GRS Date: 95/10/7 (YY MM DD) Reviewed by: Date: / / (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.4

RCB 95/10/7

Obtain μ_q

REDUCTION FACTORS FOR SURCHARGE



Base Circle

Assume depth to firm base, D is infinite

$$q/\gamma H = \frac{250 \text{ psf}}{135 \text{ pcf } (9 \text{ ft})} = 0.098$$

$$\mu_q = 1.0$$

Source: Fig. 7(a) from Ref. 2 of "Calculation Procedures/Methods" package

Written by: GRS Date: 95/10/7 (YY/MM/DD) Reviewed by: Date: / / (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.4

RCO 95/10/7

* Long-Term

Use methodology in Ref. 2 from "Calculation Procedures/Methods" package for uniform, $\phi > 0°$ soils

$$FOS = \frac{P_e}{P_d} b \tan\phi \qquad \text{(for case of } c=0\text{)}$$

where

$$P_e = \frac{\gamma H + q - \gamma_w H'_w}{\mu_q \mu'_w}$$

$\gamma = 135$ pcf $H = 19$ ft

H'_w = height of water within slope = 0

μ_q = surcharge correction factor = 1.0 (from plot on p. 4)

μ'_w = seepage correction factor = 1.0 (no seepage)

P_d = same as for end-of-construction case = 2815 psf

b = slope ratio = cot B = 4.0

$\phi = 25°$

$$P_e = \frac{135(19) + 250 - 0}{1.0(1.0)} = 2915 \text{ psf}$$

$$FOS = \frac{2915}{2815} 4 \tan 25° = \underline{1.87}$$

Written by: GRS Date: 95/10/7 (YY MM DD) Reviewed by: _____ Date: __/__/__ (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.4

RCB 95/10/7

(5) Compare calculated critical FOS to target values:

End-of-construction:

FOS = 2.36 Target = 1.3 ✓

FOS > Target /OK ✓

Long-term:

FOS = 1.87 Target = 1.5 ✓

FOS > Target /OK ✓

Adequate stability is indicated for both cases ✓

3.6 Borrow Area Cut Slope Stability

SECTION 4

4. SEISMIC STABILITY

4.1 Seismic Hazard Assessment
4.2 Seismic Site Response Analysis
4.3 Seismic Performance Evaluation

4.1 Seismic Hazard Assessment

COMPUTATION COVER SHEET

SUBJECT OF CALCULATION: SEISMIC HAZARD ASSESSMENT

Computations By: (Cognizant Engineer)
Signature: Neven Matasovic — Date: 10-18-95
Printed Name and Title: Neven Matasovic, Assistant Project Engineer

Assumptions and Procedures Checked by: (Checker)
Signature: Mark H. Gleason — Date: 20 Oct '95
Printed Name and Title: MARK H. GLEASON, Assistant Project Engineer

Computations Checked by:
Signature: Mark H. Gleason — Date: 20 Oct '95
Printed Name and Title: MARK H. GLEASON, Assistant Project Engineer

Computations Backchecked by: (Cognizant Engineer)
Signature: Neven Matasovic — Date: 23 Oct. '95
Printed Name and Title: Neven Matasovic, Assistant Project Engineer

Approved by: (PDP)
Signature: Edward Kavazanjian, Jr. — Date: 10-23-'95
Printed Name and Title: Edward Kavazanjian, Jr., Principal

Approved by: (DTL and TETL)
Signature: Rudolph Bonaparte — Date: 24 Oct 95
Printed Name and Title: Rudolph Bonaparte, Principal

Record of Revision (Number and initial all revisions)

Rev. No.	Reason	Date	By	Checked	Approval
A	Draft submittal to FERMCO				
0	30-percent submittal	10-18-95	N.M.	MHG	RB
B	Preliminary Design - EPA Submittal	14 Dec 95	[illegible]	—	—

23900-09.10/FER9530028.CD

GEOSYNTEC CONSULTANTS

Written by: Neven Matasović N.M. Date: 17 Oct. 1995 Reviewed by: MHG Date: 20 OCT 95
Client: FERMCO Project: OSDF Project No.: GE3900 Task No.: 9.10
RB 24 Oct 95

SEISMIC HAZARD ASSESSMENT

1. EXECUTIVE SUMMARY

A seismic hazard assessment was performed for the Fernald Environmental Management Project (FEMP) On-Site Disposal Facility (OSDF). The analysis was performed for the purposes of assigning a magnitude to the design peak ground accelerations for the OSDF and selecting an acceleration time history for use in design analyses. Seismic sources within a 250-mile (400-km) radius of the facility were evaluated. Based on this evaluation, a maximum moment magnitude $M_w = 6.1$ was assigned to both the Grenville and Illinois Seismic Source Zones (SSZ). A maximum moment magnitude $M_w = 6.6$ was assigned to the Reelfoot Rift Complex Subzone B, which is a part of the New Madrid seismic source megazone. Based upon estimates of the peak horizontal acceleration in a hypothetical bedrock outcrop (PGA) at the OSDF from the maximum magnitude events, a moment magnitude of 6.1 was assigned to the design event. Based on the analysis, a PGA of 0.16 g was selected in accordance with USEPA 40CFR §258. A synthetic accelerogram, B2-SYN, developed at the California Institute of Technology was recommended for use in the seismic site response analysis.

2. PURPOSE

The purpose of the seismic hazard assessment is to evaluate the magnitude associated with peak ground acceleration (PGA) from DOE-STD-1020-94 and Algermissen et al. (1990) and to select design accelerogram(s).

3. PROCEDURE

3.1 Review available literature on regional and local seismic geology and geophysics (limit study area by 250-mile or 400 km radius). The study should include data published in scientific and technical literature (e.g., ATC, 1994) as well as technical reports for critical structures in the vicinity of the FEMP site.

3.2 Based on the literature review, identify and delineate seismic source zones (lateral extents and hypocentral depths). Make a clear distinction between a local (near-field) event (i.e., Grenville seismic zone) and a distant (far-field) event (i.e., Reelfoot Rift Complex B in the New Madrid Seismic Zone).

3.3 Based on the literature review, assign a maximum (credible) magnitude to each delineated zone.

3.4 Review available literature on attenuation relationships for rock conditions in the central United States. Select the most appropriate attenuation relationship. The latest update of the Boore and Atkinson (1987) attenuation relationship (Atkinson and Boore, 1990) will be used for seismic analysis of the OSDF.

3.5 Based on data identified in steps 2 and 3, using the acceleration relationship selected in step 4, estimate mean and mean plus one standard deviation peak horizontal ground acceleration (PGA) for the OSDF for both the near-field and far-field maximum credible events.

3.6 Compare estimated PGA value for the near-field and far-field events with the PGA-s obtained from applicable standards (e.g., the ground surface PGA for a 1000 years return period from DOE-STD-1020-94 and, in accordance with USEPA 40CFR 258, and the hypothetical bedrock outcrop PGA for a 2372 years return period obtained, as recommended in EPA (1993) and EPA (1995), by interpolation from the Algermissen et al. (1990) map. Based on this comparison, evaluate which source zone (or zones) is (are) the primary contributor(s) to the design PGA and assign a magnitude to the design event(s).

GEOSYNTEC CONSULTANTS

Written by: Neven Matasović N.M. Date: 17 Oct. 1995 Reviewed by: MHG Date: 20 Oct 95

Client: FERMCO Project: OSDF Project No.: GE3900 Task No.: 9.10

RB 24 Oct 95

3.7 Select a strong motion record (or records) on the basis of seismic geology data evaluated in step 2 and the design earthquake magnitude from step 6. If necessary, i.e., if historic strong motion records are unavailable or nonexistent, select a synthetic earthquake record (or records).

4. DATA VERIFICATION

4.1. PURPOSE

The purpose of this section is to provide the input data for the seismic hazard assessment for the OSDF. The data thus collected is provided for verification and further use in the seismic hazard analysis.

4.2 PARAMETERS FOR DESIGN

The parameters required for the seismic hazard assessment are the earthquake seismic sources (zones) and the corresponding magnitudes that may affect the OSDF. An assessment of the design earthquake sources and magnitudes is presented in this section.

Opinions vary widely about the best way to delineate and quantify the seismic sources (areal zones) in central United States. GeoSyntec adopted the most recent approach contained in the recent study by Johnston and Nava (1994) to evaluate design earthquake sources and magnitudes for the OSDF.

Johnston and Nava (1994) provide a map of seismic source zones and associated maximum credible magnitudes for the central United States. This map is reproduced in Figure 1. The seismic source zones delineated in the map are regions within which structures have similar seismogenic potential. Consequently, the approach by Johnston and Nava implies that the maximum credible earthquake must be allowed to occur anywhere within the boundaries of these seismic source zones.

According to Johnston and Nava, the following three seismic source zones are within a 250-mile (400 km) radius from OSDF: (i) the Grenville seismic source zone (SSZ); (ii) the Illinois SSZ; and (iii) the Reelfoot Rift Complex seismic source megazone, also known as the New Madrid seismic source zone.

The Grenville SSZ is classified by Johnston and Nava as a "Seismotectonic" SSZ, a source zone defined on the basis of a tectonic feature such as a fault zone, rift,

suture, or intrusion with which seismicity is spatially associated, but where a clear association with a specific fault or faults is lacking. Johnston and Nava estimate that the maximum credible earthquake for the Grenville SSZ is an event with a (short period) body wave magnitude $m_b = 5.7$, which according to the chart in Figure 2a from Heaton et al. (1986), corresponds to a moment magnitude $M_w \approx 6.1$. Based on the Johnston and Nava map (epicentral) distance of 17 miles (28 km), and a hypocentral depth estimate for the Grenville SSZ of 10 miles (16 km) (see Johnston and Nava), GeoSyntec estimates a hypocentral (site-to-source) distance of 20 miles (32 km) from the OSDF to the nearest point within the Grenville SSZ.

The Illinois SSZ is classified by Johnston and Nava as a "seismic" SSZ, a source zone defined on the basis of seismicity which is "enhanced over background", (i.e., a zone in which spatial clustering if microseismicity is evident, but where data are insufficient to associate the activity with seismogenic or seismotectonic crustal structures.) Johnston and Nava estimate that the maximum credible event in the Illinois SSZ is an event with a the body wave magnitude $m_b = 5.7$, corresponding to a moment magnitude $M_w \approx 6.1$ (see Figure 2a). Based on the Johnston and Nava map (epicentral) distance of 125 miles (200 km), and a hypocentral depth estimate for the Illinois SSZ of 10 miles (16 km) (see Johnston and Nava), GeoSyntec estimates a hypocentral distance of 125 miles (200 km) from the OSDF to the nearest point within the Illinois SSZ.

The Reelfoot Rift Complex seismic source megazone is subdivided by Johnston and Nava (1994) in two subzones called Zone A and Zone B. Subzone A is classified by Johnston and Nava (1994) as a "Seismic" source zone, identified on the basis of the linear trend of numerous small epicenters. The great New Madrid earthquakes of 1811-1814 occurred in Subzone A. Subzone A is more than 250-miles (400 km) from OSDF and therefore unlikely to impact the OSDF.

Reelfoot Rift Complex Seismic Subzone B is classified by Johnston and Nava (1994) as a "Seismotectonic" and has been delineated on the basis of the geophysically inferred limits of the Reelfoot complex. In accordance with the study by Johnston and Nava (1994), a maximum credible earthquake of (short period) body wave magnitude $m_b = 6.5$ is assigned to Subzone B. This magnitude has been converted to the moment magnitude scale using the upper bound curve from the Boore and Atkinson (1987) chart

(see Figure 2b), because the chart by Heaton et al. (1987) used for the other seismic source zones (see Figure 2a) saturates at $m_b \approx 6.4$. As indicated in Figure 2b, GeoSyntec conservatively assigned $M_w = 6.6$ to Subzone B. Based on the Johnston and Nava map (epicentral) distance of 60 miles (100 km), and a hypocentral depth estimate of 10 miles (16 km) (see Johnston and Nava, 1994), GeoSyntec estimates a hypocentral distance of 63 miles (100 km) from the OSDF to the nearest point within the Reelfoot Rift Complex Subzone B.

4.3 DESIGN VERIFICATION

The following calculation elements used in the seismic hazard assessment are presented below for verification.

- The equation presented below by Atkinson and Boore (1990) is used to attenuate the strong ground motions (i.e., to calculate the peak horizontal acceleration (mean and mean plus one standard deviation)) for the maximum credible earthquake estimated on the basis of data presented in Johnson and Nava (1994).

Atkinson and Boore (1990) attenuation relationship has the following form:

$$log(y) = a'' + b\,(M_w - 6) + c\,(M_w - 6)^2 - log(R) + k(R) + s$$

where:
- y = depending on the s-term in equation above, the mean or, the mean + one standard deviation peak horizontal acceleration value
- a = 3.65 (coefficient of attenuation equation)
- a'' = a - log(980.7) (a'' is coefficient a modified in order to get acceleration values in g-units)
- b = 0.42 (coefficient of attenuation equation)
- c = -0.03 (coefficient of attenuation equation)
- k = -0.00281 (coefficient of attenuation equation)
- s = standard error term (s = 0 yields mean acceleration value; s = 0.3 yields mean + one standard deviation peak horizontal acceleration value)

$R = [(R_E)^2+(h)^2)]^{0.5}$ (note: R_E = epicentral distance from Johnston and Nava Map; h = hypocentral depth from study by Johnston and Nava; R, R_E and h in kilometers).

- The following peak accelerations for the site are obtained from the literature.

  - DOE STD 1020-94 gives the peak acceleration at the ground surface with a mean recurrence interval of 1000 years at the OSDF as 0.13 g.

  - The peak bedrock acceleration with a probability of not being exceeded of 10 percent in a 250 year period as specified by EPA 40 CFR 258 evaluated as recommended by EPA (1993) and EPA (1995) is 0.16 g.

5. ANALYSIS

5.1 INTRODUCTION

Given the earthquake sources and magnitudes provided in the previous section, the seismic hazard analysis presented in this section consists of the following elements:

- assessment of source-to-site attenuation of design ground motions; and
- selection of a representative acceleration time history.

These elements are discussed in greater detail in the following section.

5.2 SOURCE-TO-SITE ATTENUATION OF DESIGN GROUND MOTION

The large earthquakes in the central United States associated with the Reelfoot Rift Complex seismic source zone occurred in the 19th century before the development of instrumental seismology and at a time when the area was sparsely populated. Consequently, available Modified Mercalli isoseismal maps are of relatively poor quality and strong motion recordings are practically nonexistent. Therefore, the attenuation of earthquake peak ground acceleration with distance for the Central United States is based primarily on theoretical models and experience from similar tectonic regimes in other parts of the world.

To attenuate strong ground motions in this study, GeoSyntec selected the latest update of the Boore and Atkinson (1987) Central United States attenuation relationship, as presented in Atkinson and Boore (1990). This attenuation relationship has been developed on the basis of a theoretical model of strong ground motion attenuation in the central United States. Based on the estimated moment magnitude and hypocentral (site-to-source) distance of a design earthquake, this attenuation relationship provides mean and standard deviation estimates of peak horizontal ground acceleration in a hypothetical bedrock outcrop at a site. The mean and mean plus one standard deviation peak horizontal ground acceleration estimates for a hypothetical bedrock outcrop at the

OSDF site calculated using the Atkinson and Boore (1990) attenuation relationship are provided in Table 1 along with the calculation details in footnote. The horizontal ground acceleration estimates are provided for the maximum credible earthquake from Johnston and Nava (1994) in all three seismic source zones identified in the previous section as contributing to the seismic exposure of the site.

5.3 DESIGN PEAK GROUND ACCELERATION AND EARTHQUAKE MAGNITUDE

The intensity of the design earthquake for the OSDF is the maximum of the peak acceleration at the ground surface as specified by DOE-STD-1020-94 and the peak ground acceleration as specified by EPA 40CFR 258 (Subtitle D of the Resource Conservation and Recovery Act). As stated in DOE-STD-1020-94, the design earthquake has mean recurrence interval of 1000 years and corresponds to a peak ground acceleration of 0.13g. The design seismic event specified by EPA 40CFR 258 is for peak ground accelerations for a hypothetical bedrock outcrop with a probability of not being exceeded of 10 percent in a 250 year period, corresponding to a mean recurrence interval of 2372 years. The peak ground accelerations as specified by EPA 40CFR 258 at the OSDF, evaluated as recommended in EPA (1993) and EPA (1995) by interpolation from the map provided by Algermissen et al. (1990), is 0.16 g.

The estimated mean value of the peak horizontal ground acceleration in a hypothetical rock outcrop at the OSDF from the maximum credible earthquakes defined by Johnston and Nava (1994) as the $M_w = 6.1$, $M_w = 6.1$ and $M_w = 6.6$ events in the Grenville, Illinois, and Reelfoot Subzone B seismic source zones respectively, is between 0.01 g and 0.13 g. The estimated mean plus one standard deviation peak horizontal ground acceleration in a hypothetical bedrock outcrop at the OSDF is between 0.01 g and 0.25 g for the maximum credible earthquakes from the same three seismic source zones. For both the mean and mean plus one standard deviation cases, the largest peak ground acceleration is associated with the Grenville source zone. The Subzone B of the Reelfoot Rift Complex Seismic Source Zone produces the second largest peak ground acceleration in a hypothetical bedrock outcrop in both cases. It should be noted that, even at the mean plus one standard deviation level, Subzone B of the Reelfoot Rift Complex Seismic Source Zone produces a peak ground acceleration

of only 0.08 g at the OSDF. On the basis that Subzone B of the Reelfoot Rift Complex is not capable of producing a peak ground acceleration in a hypothetical bedrock outcrop at the OSDF in excess of 0.08 g even at the mean plus one standard deviation level, the design peak ground accelerations of 0.16 g, evaluated in accordance with EPA 40CFR 258 will be used for the seismic site response analysis. This peak ground acceleration may conservatively be associated with the maximum earthquake moment magnitude $M_w = 6.1$, corresponding to a maximum credible earthquake (short period) body wave magnitude $m_b = 5.7$.

5.4 REPRESENTATIVE ACCELERATION TIME HISTORY

Selection of design strong motion records (acceleration time histories) for use in seismic response analyses is a key element of a seismic hazard analysis. Acceleration time histories from western United States earthquakes (western earthquakes) have often been used in the past for seismic response analyses of central United States sites, mainly because of the lack of acceleration time histories from strong central earthquakes. However, acceleration time histories from earthquakes in the western United States may not be the most appropriate time histories to use for the central United States for the following reasons:

- Central United States earthquakes are believed to be enriched in high frequency energy compared to western United States earthquakes (ATC-35, 1994).

- A rational method for predicting the duration of a central United States earthquake is not available. Earthquake duration typically increases with magnitude, but Nuttli and Herrman (1981, p. 43) reports that empirical data for duration of central United States earthquakes is not available.

- A recorded acceleration time history from a western United States earthquake of a given magnitude is not likely to have a peak acceleration and duration that are consistent with a similar magnitude event at an eastern site. This lack of consistency is because the relationship between magnitude, peak acceleration, and duration depends largely on the

attenuation of the motions between the source and the recording site. Available data indicate that attenuation in central United States geologic conditions is significantly less rapid than in western United States geologic conditions.

- Source mechanisms are believed to be different for central and western United States earthquakes. Typically, western United States earthquakes are associated with shallow surface faulting, while central United States earthquakes are generated by complex tectonic mechanisms (see discussion of Mechanisms for Grenville and Reelfoot Rift Complex provided in data verification section of this document).

Unfortunately, the catalog of strong motion acceleration time histories for the central United States is very limited (Friberg and Jacob, 1990). The strongest earthquakes that have been recorded in the New Madrid Seismic Zone after the strong motion network was installed are the Risco (M_w = 4.6) and Cape Girardeau (M_w = 4.8), Missouri earthquakes. Acceleration time histories recorded during these events can not by themselves constitute a representative set of time histories for the site because of their relatively moderate magnitude. Therefore, GeoSyntec selected a synthetic accelerogram, the B2-SYN accelerogram developed at the California Institute of Technology, for the site response analyses at the OSDF. The B2-SYN synthetic accelerogram was generated by Jennings et al. (1968) to simulate M_w = 7.0 earthquakes on alluvium. It should be noted that application of B2-SYN introduces in the seismic analysis at OSDF a twofold source of conservatism. First, the selected accelerogram is representative of the strong motion shaking of a significantly larger magnitude earthquake than the design magnitude. Second, the B2-SYN motion was developed to be characteristic of a soil site motion. As such, it has more energy at longer periods than typical rock site strong ground motions. As longer period motions are potentially more damaging than short period motions, an additional level of conservatism is introduced into the design through the use of the B2-SYN motion. B2-SYN synthetic accelerogram response spectrum, calculated for commonly used 5% viscous damping value, is shown in Figure 3.

6. REFERENCES

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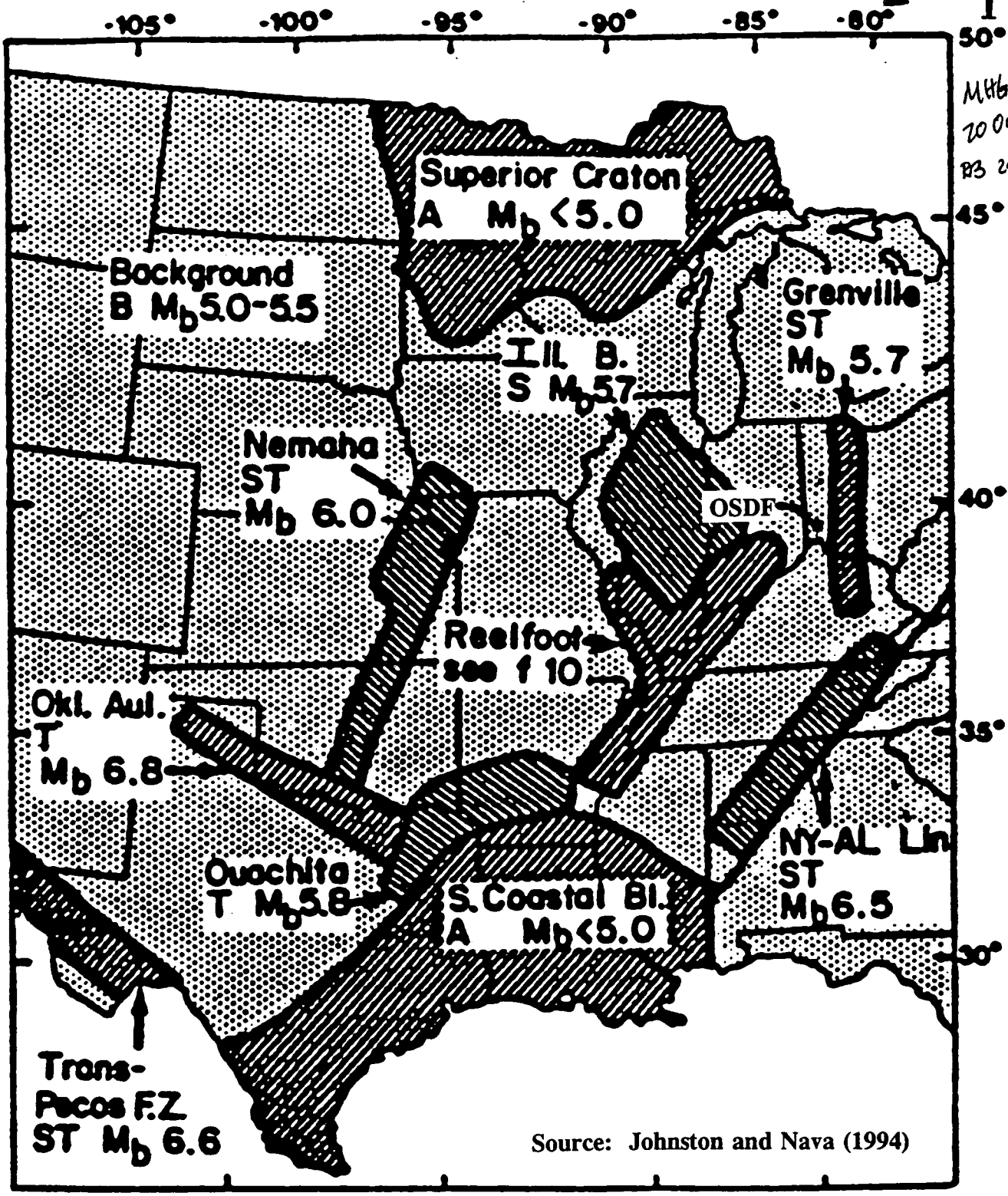
TABLE 1
RESULTS OF THE SEISMIC HAZARD ANALYSIS
FERNALD ENVIRONMENTAL MANAGEMENT PROJECT, ON-SITE DISPOSAL FACILITY
FERNALD, OHIO

SEISMIC SOURCE[1] (character)	ESTIMATED MAGNITUDE[2]	ESTIMATED EPICENT. DIST., R_E	ASSUMED HYPOCENT. DEPTH, h	HYPOCENT. DISTANCE, R	PEAK HORIZONTAL ACCELERATION[3] (mean)	PEAK HORIZONTAL ACCELERATION[3] (mean+one st. dev.)
Grenville SSZ (seismotectonic)	m_b = 5.7 ($M_w \approx$ 6.1)	17 miles (28 km)	10 miles (16 km)	20 miles (R = 32 km)	0.13 g	0.25 g
Illinois SSZ (Seismic)	m_b = 5.7 ($M_w \approx$ 6.1)	125 miles (200 km)	10 miles (16 km)	125 miles (R = 200 km)	0.01 g	0.01 g
Reelfoot Rift Complex, Zone B (seismotectonic)	m_b = 6.5 ($M_w \approx$ 6.6)	60 miles (100 km)	10 miles (16 km)	63 miles (R = 100 km)	0.04 g	0.08 g

[1]Seismic Source Zones as defined and characterized in Johnston and Nava (1994).
[2]m_b = (short-period) body wave magnitude; M_w = moment magnitude.
[3]Peak horizontal acceleration values in rock are estimated using Atkinson and Boore (1990) attenuation relationship which has the following form:

$$log(y) = a'' + b\,(M_w - 6) + c\,(M_w - 6)^2 - log(R) + k(R) + s$$

where:
- y = depending on the s-term in equation above, the mean or, the mean + one standard deviation peak horizontal acceleration value
- a = 3.65 (coefficient of attenuation equation)
- a'' = a - log(980.7) (a'' is coefficient a modified in order to get acceleration values in g-units)
- b = 0.42 (coefficient of attenuation equation)
- c = -0.03 (coefficient of attenuation equation)
- k = -0.00281 (coefficient of attenuation equation)
- s = standard error term (s = 0 yields mean acceleration value; s = 0.3 yields mean + one standard deviation peak horizontal acceleration value)
- R = $[(R_E)^2+(h)^2)]^{0.5}$ (note: all values are in km)



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N.M. 10-17-95

FIGURE 1

0 500km

Figure 9. Seismic source zones for the central U.S. The criteria for defining each zone is indicated (see categories of Table 2). The estimated maximum earthquake and zone boundaries are derived from arguments presented in the text. See Figure 10 for detail on the Reelfoot rift–New Madrid seismic zone. Abbreviations: T, tectonic; ST, seismotectonic; S, seismic; B, background; SG, seismogenic; A, aseismic.

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RB 24 Oct 95

NOTE: SATURATION @ $m_b \approx 6.4$ USE MODIFIED BOORE AND ATKINSON CHART IN FIGURE 2b

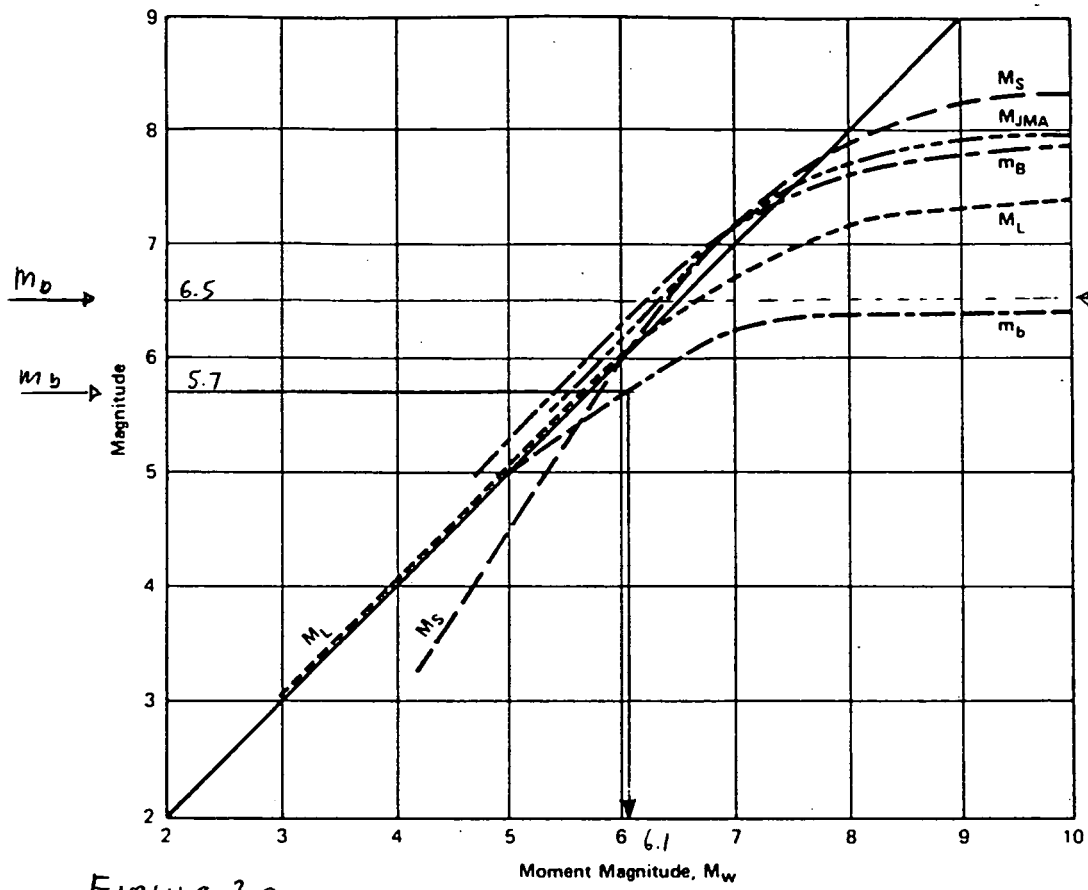

Figure 2a

N.M. 10-17-95

Fig. ~~12~~ 6 Relation Between Moment Magnitude and Various Magnitude Scales: M_L (local), M_s (surface wave), m_b (short-period body wave), m_B (long-period body wave), and M_{JMA} (Japan Meteorological Agency) (From Heaton et al, 198~~2~~)

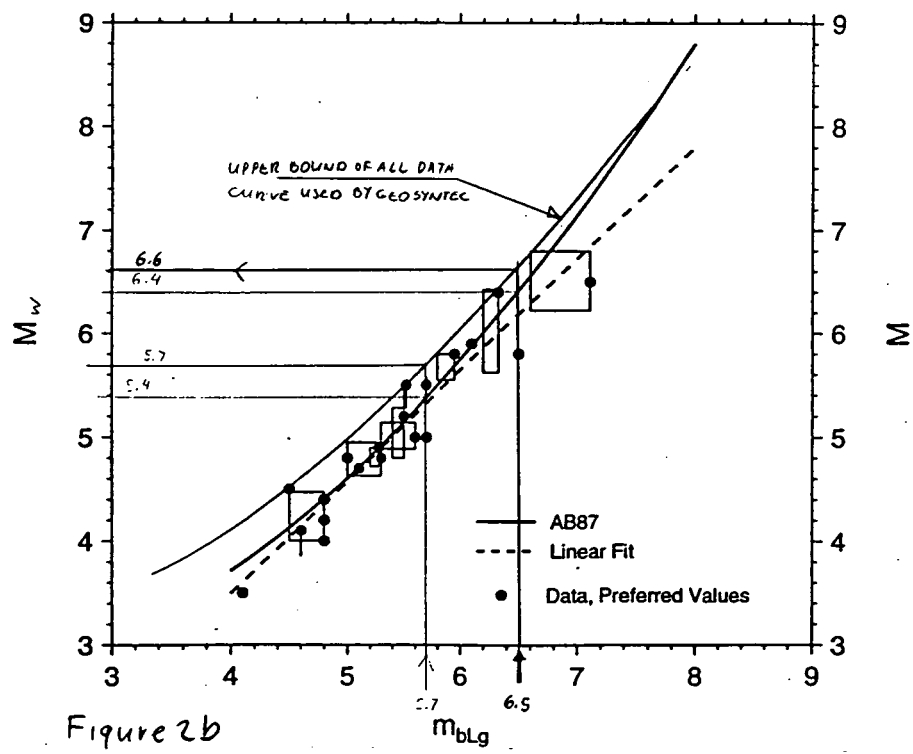

Figure 2b

N.M. 10-17-95.

Figure 2. M versus m_{bLg}, revised from Boore and Atkinson (1987). The curve labeled "AB87" is from Atkinson and Boore (1987). Note that although M is the more fundamental source parameter, the short-period magnitude m_{bLg} is used for the abscissa because in most applications in central and eastern North America, the design earthquake will be in terms of m_{bLg}, and a moment magnitude M must be derived from this in order to make ground-motion estimates using seismological models.

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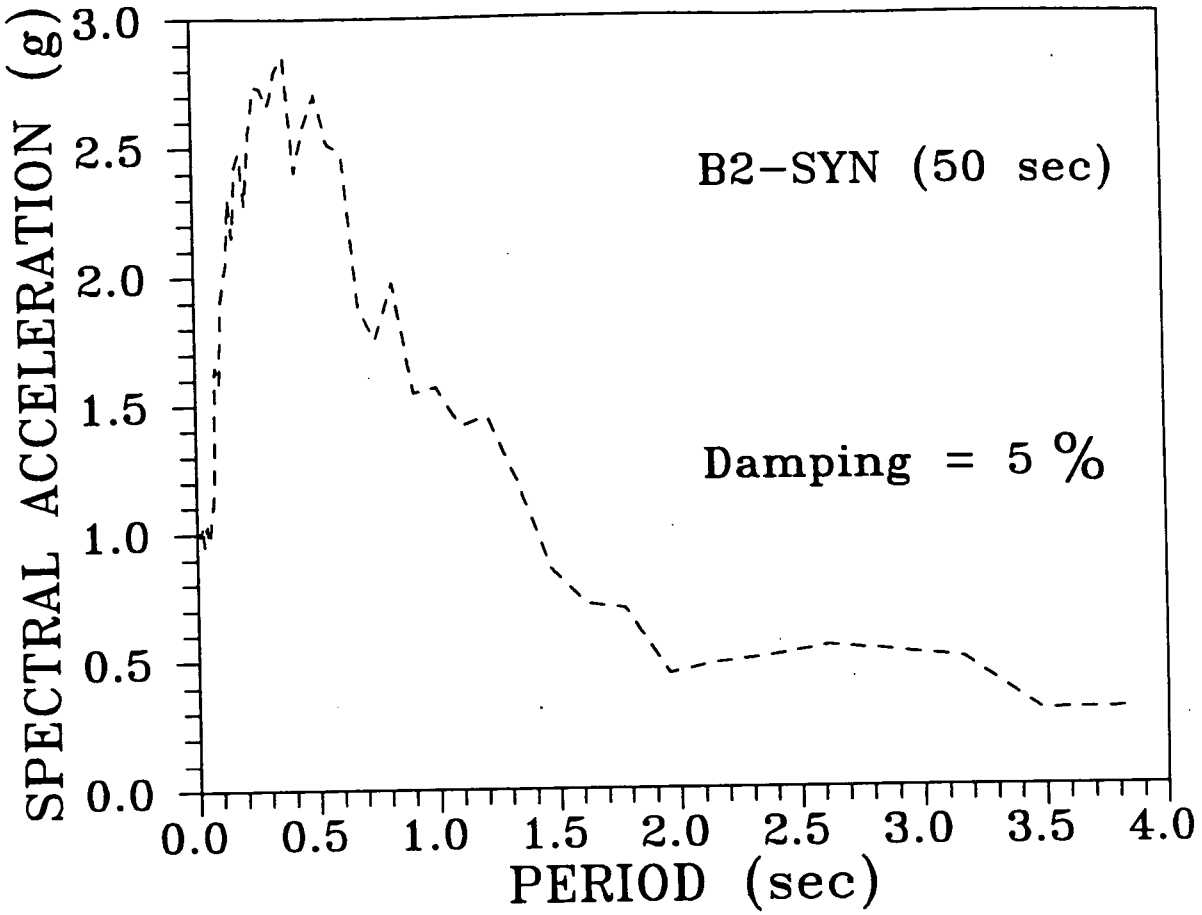

Figure 3 - Response Spectrum of B2-SYN Synthetic Accelerogram N.M. 10-17-95

4.2 Seismic Site Response Analysis

COMPUTATION COVER SHEET

SUBJECT OF CALCULATION: SEISMIC SITE RESPONSE ANALYSIS

Computations By: (Cognizant Engineer)
Signature Neven Matasovic — Date 10-17-95
Printed Name and Title: Neven MATASOVIC, Assistant Project Engineer

Assumptions and Procedures Checked by: (Checker)
Signature Mark H. Gleason — Date 20 Oct 95
Printed Name and Title: MARK H. GLEASON, Assistant Project Engineer

Computations Checked by:
Signature Mark H. Gleason — Date 20 Oct 95
Printed Name and Title: MARK H. GLEASON, Assistant Project Engineer

Computations Backchecked by: (Cognizant Engineer)
Signature Neven Matasović — Date 23 Oct. '95
Printed Name and Title: NEVEN MATASOVIC, Assistant Project Engineer

Approved by: (PDP)
Signature Edward Kavazanjian, Jr. — Date 10-23-95
Printed Name and Title: Edward Kavazanjian, Jr., Principal

Approved by: (DTL and TETL)
Signature Rudolph Bonaparte — Date 10-24-95
Printed Name and Title: Rudolph Bonaparte, Principal

Record of Revision (Number and initial all revisions)

Rev. No.	Reason	Date	By	Checked	Approval
A	Draft submittal to FERMCO				
Ø	30-percent submittal	10-18-95	N.M.	MHG	RB
B	Preliminary Design - EPA Submitted	14 Dec 95	[illegible]	—	—

GEOSYNTEC CONSULTANTS

Written by: Neven Matasović Date: 17 Oct. 1995 Reviewed by: MHG Date: 20 OCT 95

Client: FERMCO Project: OSDF Project No.: GE3900 Task No.: 9.10

RB 24 Oct 95

SEISMIC SITE RESPONSE ANALYSIS

1. EXECUTIVE SUMMARY

A seismic site response analysis was performed for the Fernald Environmental Management Project (FEMP) On-Site Disposal Facility (OSDF). The analysis was performed for the purpose of evaluating the average acceleration time history at the liner and final cover levels of the facility. A representative soil-landfill profile approximately 300-ft (91-m) thick was analyzed using the one-dimensional total-stress equivalent-linear computer program SHAKE91 (Idriss and Sun, 1992). A synthetic accelerogram B2-SYN scaled to a peak ground acceleration (PGA) of 0.16 g, established in the Seismic Hazard Assessment calculation package, was used in the analysis. Results of the seismic site response analysis indicate that the design seismic event induces a peak average acceleration of approximately 0.14 g at the OSDF final cover level and of approximately 0.11 g at the OSDF liner level.

2. PURPOSE

The purpose of these calculations is to evaluate the site-specific peak average acceleration values at the liner and final cover levels of the facility, and, if necessary, provide corresponding average acceleration time histories.

3. PROCEDURE

3.1 Perform one-dimensional total-stress equivalent-linear site response analysis of the OSDF using the latest update of the SHAKE program, SHAKE91 (Idriss and Sun, 1992).

3.2 Based on the results of geotechnical, geophysical and other investigations performed at the site and/or on the materials recovered from the site, develop a representative site profile(s). The representative profile(s) should reflect the soil conditions and waste and containment system material properties from the top of bedrock to the top of the landfill. The profile(s) should also be consistent with, but not necessarily exactly the same as, the profile(s) developed for settlement and stability analyses.

3.3 Assign dynamic soil properties (e.g., small strain shear modulus, mass density, and strain-dependant modulus reduction and equivalent viscous damping) to the representative site profile(s). Utilize site-specific data on the site soils and impacted materials to be disposed of in the OSDF in conjunction with published correlations from technical literature to establish dynamic properties. Evaluate small-strain shear moduli from correlations with Standard Penetration Test (SPT) blow counts (Imai and Tonouchi, 1982), from void ratios (Hardin and Black, 1968) and/or from undrained shear strengths for foundation materials (Seed and Idriss, 1970). Use the same values of unit weight as in settlement and slope stability calculation procedures. Based on the plasticity index of the site materials, select strain-dependant modulus reduction and equivalent viscous damping curves from a family of curves shown in Figure 1 following recommendations of Vucetic and Dobry [1992].

3.4 Perform the seismic response analysis for the profile(s) defined in step 3 using the strong motion data derived from the seismic hazard analysis procedure.

3.5 Present the peak average accelerations and the peak average acceleration time histories from the site-specific seismic response analyses in tabular or graphical form and evaluate the results. The upper bound values of peak average acceleration calculated in the site response analysis at the base foundation, liner,

and final cover system levels should be used in the seismic performance evaluation to determine whether or not a seismic deformation analysis is necessary.

4. DATA VERIFICATION

4.1 INTRODUCTION

The purpose of this section is to provide the data required for input for the Seismic Site Response Analysis. Also presented in this section is the methodology for calculating additional data required for the dynamic properties of the materials. The data and methodology are presented for verification and further use in the Seismic Site Response Analysis.

4.2 RESULTS OF SEISMIC HAZARD ASSESSMENT

The strong motion data derived from the seismic hazard analysis procedure is used in the Seismic Site Response Analysis. As stated in the Seismic Site Response Analysis, the characteristics of the design seismic event for the OSDF are as follows:

- peak bedrock acceleration of 0.16 g in accordance with EPA 40CFR 258;
- maximum credible earthquake moment magnitude $M_w = 6.1$ (corresponds to the maximum credible earthquake (short period) body wave magnitude of $m_b = 5.7$); and
- the design strong motion record (acceleration time history) represented by the synthetic accelerogram B2-SYN.

4.3 MATERIAL PROPERTIES

The properties of the materials used in the Seismic Site Response Analysis are derived from parameters defined in previous calculation packages. The properties for the site strata and the site profile are described in the following sections and are summarized in Table 1.

Based on the results of geotechnical investigations performed at the site and/or on the materials recovered from the site, a representative profile was developed for the

seismic response analysis. The profile is similar to that used for the foundation stability and foundation settlement analyses. The layers of the profile are as follows from the cover of the OSDF to bedrock:

- 7-ft (2.1-m) thick cover system;
- 50-ft (15-m) thickness of impacted materials;
- 3-ft (0.9-m) thick compacted clay liner;
- 10-ft (3-m) thick brown till layer;
- 45-ft (14-m) thick gray till layer;
- 172-ft (52-m) thick granular soil layer (Great Miami Aquifer Soils); and
- bedrock.

The material properties for these layers are summarized in Table 1. Specific sources for the properties listed in the table are described below.

- The unit weights for all materials and the undrained shear strength for the cohesive foundation soils were obtained from the data verification sections of the Foundation Stability and Impacted Materials Settlement analyses.

- For the cover system granular soils, a void ratio (e) of 0.7 and a plasticity index (PI) of 0 are assumed. These parameters are consistent with the granular nature of the soils to be used in the cover system.

- For the impacted materials on the OSDF a PI value of 15 was assumed for the analysis. The value of PI is an average value based on laboratory data presented in Parsons (July, 1995).

- For the subsurface cohesive soils, an average PI value of 15 was assumed for the analysis based on laboratory data presented in Parsons (July, 1995).

- For the granular soils in the Great Miami Aquifer, the SPT blow counts (N-values) range from 30 to greater than 50 blows per foot, based on data presented in Parsons (July, 1995). For this analysis, a conservative

average N-value of 40 is assumed.

- The bedrock at the site is defined as a shale with interbedded limestone (Parsons, [January, 1995]). A unit weight of 145 pcf (22.8 kN/m^3) is assumed for the bedrock.

4.4 MATERIAL DYNAMIC PROPERTIES

The purpose of this section is to define the dynamic properties of the materials used in the analysis. The dynamic properties are calculated using the following equations and the material properties identified in the previous section and presented in Table 1.

The unit weight values for the site materials, γ, presented in Table 1 and in calculation sheets attached to Table 1 are considered to be representative of the site materials. Shear wave velocity for each layer is evaluated from corresponding small strain shear modulus, G_m, using the basic principles of physics:

$$V_s = [(G_m\, g)/\gamma]^{0.5}$$

where g is acceleration of gravity. For underlying bedrock, a descriptive correlation from Clark [1966] was used.

The small strain shear moduli of granular cover system materials were evaluated from the Hardin and Black [1968] equation as:

$$G_m = [(22.52 - 10.6e)^2 / (1 + e)]\, (\sigma'_m)^{3/5} \qquad \text{(in psi)}$$

where e is the average void ratio and σ'_m is the mean effective stress in the mid-height of the layer calculated as a mean value of the vertical and horizontal stress acting in two perpendicular horizontal directions.

The small strain shear moduli of on-site natural and recompacted cohesive soils were evaluated from Seed and Idriss [1970] correlation as:

where S_u is the undrained shear strength of the material in consideration.

The small strain shear moduli of on-site natural cohesionless soils were evaluated from Imai and Tonouchi [1982] correlation as:

$$G_m = (\gamma / g)\ [87.8\ (N)^{0.292}]^2 \qquad \text{(in kPa)}$$

where N is the Standard Penetration Test (SPT) blow count and g is a constant of gravity.

Strain-dependant modulus reduction and equivalent viscous damping values were selected based on the plasticity index, PI, of the site materials following recommendations of Vucetic and Dobry [1992].

5. ANALYSIS

GeoSyntec used the theory of one-dimensional wave propagation through layered media to model the response of OSDF to strong ground shaking. The analysis was performed in time domain using total-stress equivalent-linear computer program SHAKE91 (Idriss and Sun, 1992), an updated version of the well-known program SHAKE (Schnabel et al., 1972). This computer program is publicly available through the Earthquake Engineering Research Center at University of California, Berkeley.

A seismic response analysis for the profile characterized in Table 1 and with Figure 1 was performed using the B2-SYN synthetic accelerogram. The B2-SYN synthetic accelerogram developed at the California Institute of Technology and characterized in the seismic hazard analysis procedure was scaled to 0.16 g peak value prior to site response analysis.

Results, which include reprint of all input parameters employed in site response analysis, are enclosed in the Appendix to this calculation package. These results indicate that the design seismic event induces a peak average acceleration of approximately 0.14 g at the facility final cover level and of approximately 0.11 g at the facility liner level. These calculated values for peak average accelerations will be used in the Seismic Performance Evaluation to estimate the potential for permanent seismic deformation of the OSDF.

6. REFERENCES

Clark, S.P., Jr. (1966), "*Handbook of Physical Constants*," Sidney P. Clark, Jr. Editor, Geological Society of America, Mem. 97.

Hardin, B.O. and Black, W.L. (1968), "Vibration Modulus of Normally Consolidated Clay," *Journal of the Soil Mechanics and Foundations Division*, ASCE, Vol. SM 2, pp. 353-369.

Idriss, I.M. and Sun, J.I. (1992), "SHAKE91 - A Computer Program for Conducting Equivalent Linear Seismic Response Analyses of Horizontally Layered Soil Deposits," *User's Manual*, Center for Geotech. Modeling, Department of Civil and Environmental Engineering, University of California, Davis, California, 13 p. (plus Appendices).

Imai, T. and Tonouchi, K. (1982), "Correlation of N Value with S-Wave Velocity," Proc. *2nd European Symposium on Penetration Testing*, Amsterdam, The Netherlands, pp. 67-72.

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Parsons, "Geotechnical Investigation Report, On-Site Disposal Facility," Operable Unit 2, *Fernald Environmental Management Project*, Fernald, Ohio, Revision A, September 1995.

Schnabel, P.B., Lysmer, J. and Seed, H.B. (1972), "SHAKE: A computer program for earthquake response analysis of horizontally layered sites," *Report No. EERC 72-12*, Earthquake Engineering Research Center, Univ. of California, Berkeley, California.

Seed, H.B. and Idriss, I.M. (1970), "Soil moduli and damping factors for dynamic response analyses." *Report No. EERC 70-10*, Earthquake Engineering Research Center, University of California, Berkeley, California, 40p.

Vucetic, M. and Dobry, R. (1991), "Effect of Soil Plasticity on Cyclic Response." *Journal of the Geotechnical Engineering*, ASCE, Vol. 117, No. 1, pp. 89-107.

TABLE 1
REPRESENTATIVE SITE PROFILE USED IN SITE RESPONSE ANALYSIS
FERNALD ENVIRONMENTAL MANAGEMENT PROJECT, ON-SITE DISPOSAL FACILITY
FERNALD, OHIO

LAYER NO.[1] (–)	TOTAL THICKNESS[2] (ft)	LAYER DESCRIPTION[3]	UNIT WEIGHT[4] γ (pcf)	OTHER MATERIAL PARAMETERS USED TO EVALUATE DYNAMIC MATERIAL PROPERTIES[5]	EVALUATED SHEAR WAVE VELOCITY[6] (ft/sec)	CORRELATION REFERENCE[7]
1 & 2	3 & 4	Final Cover System	125	$e = 0.7$; $K_o = 0.45$ PI ≈ 0	381	Hardin and Black (1968)
3	10	Impacted Materials (mostly soil fill)	125	$S_u = 1{,}000$ psf; PI ≈ 15	769	Seed and Idriss (1970)
4	10	Impacted Materials (mostly soil fill)	125	$S_u = 1{,}000$ psf; PI ≈ 15	769	Seed and Idriss (1970)
5	10	Impacted Materials (mostly soil fill)	125	$S_u = 1{,}000$ psf; PI ≈ 15	769	Seed and Idriss (1970)
6	10	Impacted Materials (mostly soil fill)	125	$S_u = 1{,}000$ psf; PI ≈ 15	769	Seed and Idriss (1970)
7	10	Impacted Materials (mostly soil fill)	125	$S_u = 1{,}000$ psf; PI ≈ 15	769	Seed and Idriss (1970)
8	3	Clay Liner (recompacted brown till)	130	$S_u = 1{,}200$ psf; PI ≈ 15	~~843~~ 826	Seed and Idriss (1970)
9 & 10	5 + 5	Natural Soil (brown till)	135	$S_u = 1{,}200$ psf; PI ≈ 15	811	Seed and Idriss (1970)
11 & 12	10 + 35	Natural Soil (gray till)	145	$S_u = 1{,}900$ psf; PI ≈ 15	984	Seed and Idriss (1970)
13	172	Granular Soil (dense sand)	135	N = 40; PI ≈ 0	846	Imai and Tonouchi (1982)
14	∞	Infinite Halfspace (shale with internal limestone)	145	Average Shear Wave Vel. Value for Shales from Literature	10,000	Clark (1966)

[1]Layer numbering system as used in SHAKE91 site response analysis.
[2]Total thickness of composite deposit (landfill + natural soil) analyzed is 287 ft.
[3]See text for more detailed description of on-site and solid waste materials.
[4]Average unit weight value employed in SHAKE91 analysis.
[5]Material parameters used to evaluate shear wave velocity, and strain-dependant modulus reduction and damping curves.
[6]Shear wave velocity values evaluated from small-strain shear moduli evaluated according to the reference provided in the reference column of this table. See attached sheet for calculations.
[7]See Note(6). Paper by Vucetic and Dobry (1992) was used to evaluate strain-dependant modulus reduction and damping curves in all layers above halfspace.

12

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Written by: Neven Matasovic Date: 95/10/17 (YY/MM/DD) Reviewed by: MHG Date: 95/10/20 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.10

ATTACHMENT TO TABLE 1 — RB 24 Oct 95

EVALUATION OF SMALL-STRAIN DYNAMIC MATERIAL PROPERTIES:

(a) Small-strain shear modulus for sand (final cover system)

Assume: $K_o = 0.45$ (coeff. of lateral pressure @ rest)

Use Hardin and Black (1968) correlation (for stress levels < 2000 psf, see p. 355 of the reference)

$$G_m = \frac{(22.52 - 10.6e)^2}{(1+e)} \cdot \sigma_m^{3/5}$$ (in pounds per square inch) (Eq. 1)

where e is a void ratio and σ_m is the mean efective stress defined as:

$$\sigma_m = \frac{\sigma_v + 2 \cdot \sigma_h}{3}$$ (in pounds per square foot) (Eq. 2)

where $\sigma_v = \gamma \cdot$ depth and $\sigma_h = K_o \cdot \sigma_v$.

In midheight of the final cover system, 3.5 ft below the surface, for assumed unit weight of 125 pcf, $\sigma_v = 125(3.5) = 437.5$ psf and

$$\sigma_m = \frac{437.5 + 2 \cdot 0.45 \cdot 437.5}{3} = 277.1 \text{ psf}$$

For $e = 0.7$, using Eq. 1 above, $G_m = 3918.2$ psi = = 564.2 KSF

For $\gamma = 125$ pcf, shear wave velocity V_s can be evaluated as

$$V_s = \sqrt{\frac{G_m \cdot g}{\gamma}}$$ (in ft/sec) (Eq. 3)

constant of gravity (32.174 ft/sec²)

$$= \sqrt{\frac{564.2\,(32.174)}{0.125}} = 381.1 \text{ ft/sec}$$

Written by: Neven Matasovic Date: 95/10/17 (YY MM DD) Reviewed by: MTG Date: 95/10/20 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.10

RB 24 Oct 95

(b) Small-strain shear modulus for clayey materials:

Use Seed and Idriss (1970) correlation which has the following form:

$$G_m = 2300 \cdot S_u \quad \text{(in psf)} \qquad (Eq.\ 4)$$

Where S_u is the undrained shear strength.

- For impacted materials:

  $S_u = 1000$ psf and $\gamma = 125$ pcf

  $G_m = 2300 \cdot 1000 = 2300$ ksf and corresponding

  $$V_s = \sqrt{\frac{G_m \cdot g}{\gamma}} = \sqrt{\frac{2300 \cdot 32.174}{0.125}} = 769 \text{ ft/sec}$$

- For clay liner (recompacted brown till):

  $S_u = 1200$ psf and $\gamma = 130$ pcf

  $G_m = 2300 \cdot 1200 = 2760$ ksf; $V_s = \cancel{843}$ 826 ft/sec

  Error not relevant for analysis - MTG.

- For natural soil (brown till)

  $S_u = 1200$ psf and $\gamma = 135$ pcf

  $G_m = 2300 \cdot 1200 = 2760$ ksf; $V_s = 811$ ft/sec

- For natural soil (gray till)

  $S_u = 1900$ psf and $\gamma = 145$ pcf

  $G_m = 2300 \cdot 1900 = 4370$ ksf; $V_s = 984$ ft/sec

Written by: Neven Matasovic Date: 95 / 10 / 17 (YY / MM / DD) Reviewed by: MHG Date: 95 / 10 / 20 (YY / MM / DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3400 Task No.: 9.10

RB 24 Oct 95

(c) Small-strain shear modulus for granular soil:

Use Imai and Tonouchi (1982) correlation which has the following form:

$$G_{max} = \gamma / g \cdot [87.8 (N)^{0.292}]^2 \ (kPa) \ (E_{2.5})$$

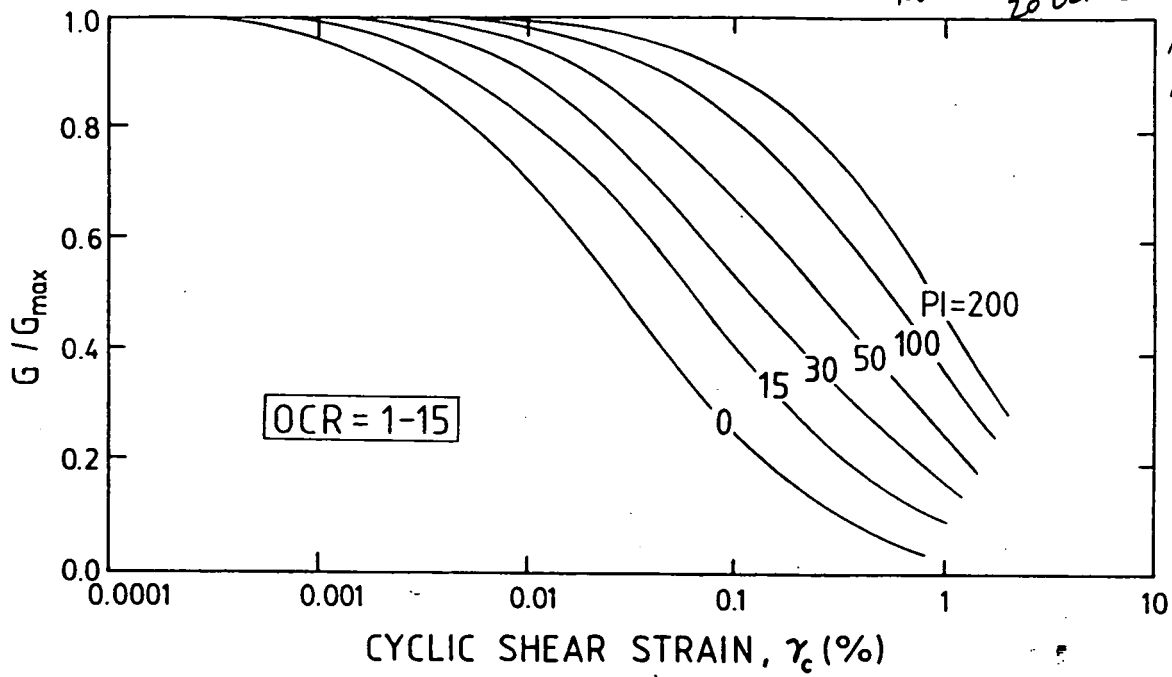
where N is standard penetration test blow count, γ is unit weight and g is constant of gravity (32.174 ft/sec² or 9.81 m/sec)

For N = 40 and γ = 135 pcf (21.2 kN/m³)

G_{max} = 143848 kPa = 3004 ksf

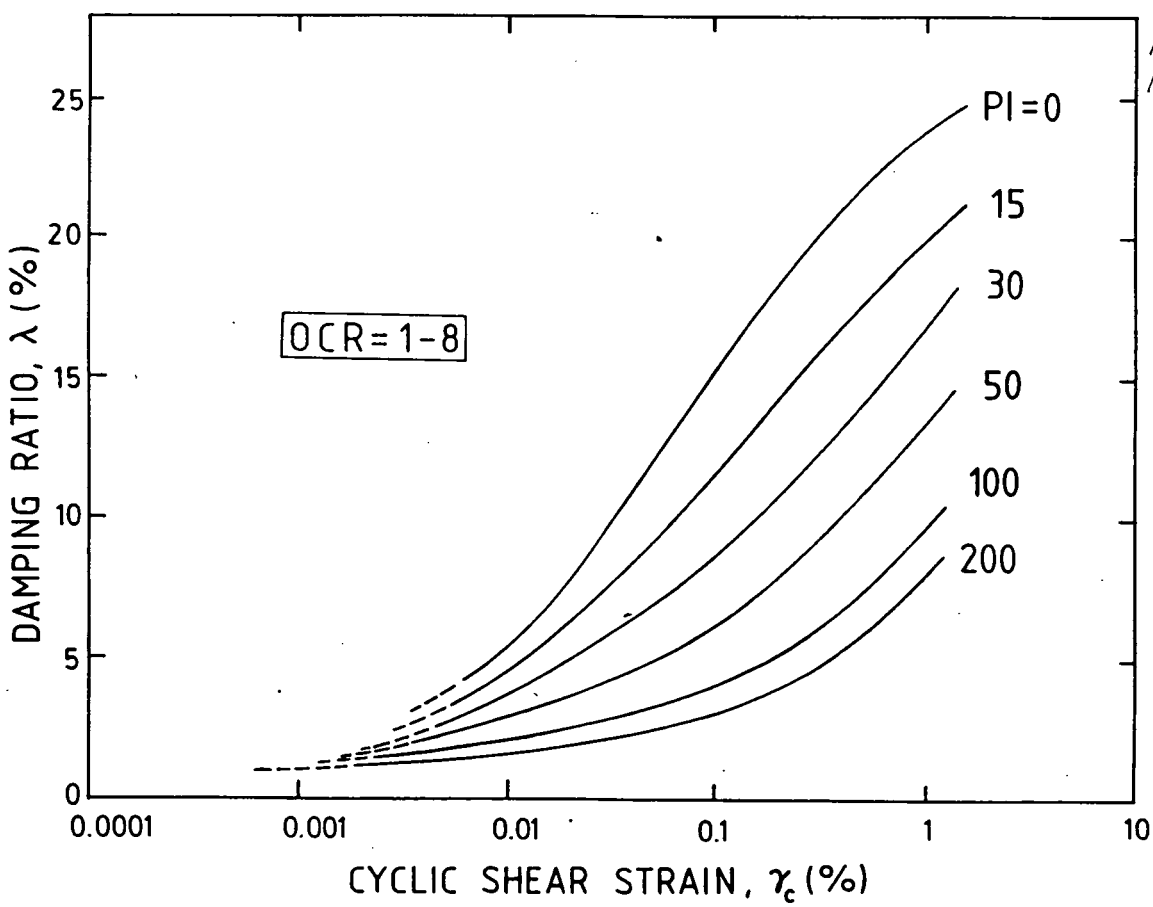
$$V_s = \sqrt{\frac{3004 \cdot (32.174)}{0.135}} = 846 \text{ ft/sec}$$

RB 24 Oct 95
MHG 20 Oct 95



N.M.
10-17-95

(a)



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(b)

FIG. ~~6~~ 1. Relations between G/G_{max} versus γ_c and λ versus γ_c Curves and Soil Plasticity for Normally and Overconsolidated Soils (Vucetic and Dobry, 1992)

APPENDIX

SHAKE 91 OUTPUT

```
*************************************************************
* SHAKE  --   A COMPUTER PROGRAM FOR EARTHQUAKE RESPONSE    *
*             ANALYSIS OF HORIZONTALLY LAYERED SITES        *
*             by: Per B. Schnabel & John Lysmer -- 1970     *
* ----------------------------------------------------------*
* Shake85   : IBM-PC version of SHAKE                       *
*             by: S.S. (Willie) Lai, January 1985           *
* ----------------------------------------------------------*
* Shake88   : New modulus reduction curves for clays        *
*             added using results from Sun et al. (1988)    *
*             by: J. I. Sun & Ramin Golesorkhi              *
*             February 26, 1988                             *
* ----------------------------------------------------------*
* Shake90/91: Adjust last iteration; Input now is either    *
*             Gmax or max Vs; up to 13 material types can   *
*             be specified by user; up to 50 Layers can     *
*             be specified; object motion can be read in    *
*             from a separate file and can have user        *
*             specified format; Different periods for       *
*             response spectral calculations; options       *
*             are renumbered; and general cleanup           *
*             by: J. I. Sun, I. M. Idriss & P. Dirrim       *
*             June 1990 - February 1991                     *
* ----------------------------------------------------------*
* Shake91   : General cleanup and finalization of input /   *
*             output format ... etc                         *
*             by: I. M. Idriss                              *
*             December 1991                                 *
* ----------------------------------------------------------*
* Shake94   : Routine for direct calculation of average     *
*   (B1)      acceleration is added to the program. Out-    *
*             put format is modified to enable the two -    *
*             - page landscape printing.  The following     *
*             modulus reduction and  damping curves are     *
*             added:  Kavazanjian & Matasovic (1995) for    *
*             municipal solid waste; Matasovic & Vucetic    *
*             (1993) for SMB sand; and Vucetic and Dobry    *
*             (1991) for clays of various plasticities.     *
*             by: Neven Matasovic                           *
*             August 1993 - May 1994                        *
*************************************************************

 MAX. NUMBER OF TERMS IN FOURIER TRANSFORM  =      4096
 NECESSARY LENGTH OF BLANK COMMON X         =     25619

******   OPTION  1  ***  READ RELATION BETWEEN SOIL PROPERTIES AND STRAIN


*********************
 MATERIAL TYPE NO. 5
*********************

CURVE NO.  9:      #5 Modulus for CL (PI=15) (Vucetic and Dobry, 1991)
CURVE NO. 10:      #5 Damping for CL (PI=15) (Vucetic and Dobry, 1991)


    CURVE NO. 9              CURVE NO.10
 =================        =================
  STRAIN    G/Gmax         STRAIN   DAMPING
 -------   -------        --------  -------
```

c3-b.out N.M. Created Wed Oct 18 19:28:38 1995

```
   .0001     1.000          .0001      .82
   .0003     1.000          .0003     1.04
   .0010      .992          .0010     1.55
   .0040      .917          .0030     2.58
   .0100      .824          .0100     4.64
   .0400      .597          .0300     7.77
   .1000      .407          .1000    11.67
   .4000      .179          .3000    16.08
   .6000      .134         1.0000    20.12
  1.0000      .092          .0000      .00

*********************
 MATERIAL TYPE NO. 2
*********************

CURVE NO.  3:      #2 Modulus for Sand (Seed & Idriss, 1970) - upper Range
CURVE NO.  4:      #2 Damping for Sand (Idriss, 1990) - (about LRng from S


    CURVE NO. 3              CURVE NO. 4
 =================        =================
  STRAIN    G/Gmax         STRAIN   DAMPING
 -------   -------        --------  -------
   .0001     1.000          .0001      .24
   .0003     1.000          .0003      .42
   .0010      .990          .0010      .80
   .0030      .960          .0030     1.40
   .0100      .850          .0100     2.80
   .0300      .640          .0300     5.10
   .1000      .370          .1000     9.80
   .3000      .180          .3000    15.50
  1.0000      .080         1.0000    21.00
  3.0000      .050         3.0000    25.00
 10.0000      .035        10.0000    28.00

*********************
 MATERIAL TYPE NO. 3
*********************

CURVE NO.  5:      #3 ATTENUATION OF  ROCK  AVERAGE
CURVE NO.  6:      #3 DAMPING IN ROCK


    CURVE NO. 5              CURVE NO. 6
 =================        =================
  STRAIN    G/Gmax         STRAIN   DAMPING
 -------   -------        --------  -------
   .0001     1.000          .0001      .40
   .0003     1.000          .0010      .80
   .0010      .988          .0100     1.50
   .0030      .952          .1000     3.00
   .0100      .900         1.0000     4.60
   .0300      .810          .0000      .00
   .1000      .725          .0000      .00
  1.0000      .550          .0000      .00

******   OPTION  2  ***  READ SOIL / WASTE PROFILE

SOIL PROFILE NO.      1   CASE 3 - The Most Crit. Prof.
```

Printed Wed Oct 18 19:29:13 1995 Page 1

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NUMBER OF LAYERS 14
DEPTH TO BEDROCK 287.0

NO.	TYPE	THICKNESS (ft)	DEPTH (ft)	TOT. PRESS. (psf)	MODULUS (ksf)	DAMPING (%)	UNIT WT. (pcf)	SH. VEL. (fps)
1	2	3.00	1.50	187.50	564.	5.00	125.00	381.0
2	2	4.00	5.00	625.00	564.	5.00	125.00	381.0
3	5	10.00	12.00	1500.00	2296.	5.00	125.00	769.0
4	5	10.00	22.00	2750.00	2296.	5.00	125.00	769.0
5	5	10.00	32.00	4000.00	2296.	5.00	125.00	769.0
6	5	10.00	42.00	5250.00	2296.	5.00	125.00	769.0
7	5	10.00	52.00	6500.00	2296.	5.00	125.00	769.0
8	5	3.00	58.50	7320.00	2869.	5.00	130.00	843.0
9	5	5.00	62.50	7852.50	2758.	5.00	135.00	811.0
10	5	5.00	67.50	8527.50	2758.	5.00	135.00	811.0
11	5	10.00	75.00	9590.00	4360.	5.00	145.00	984.0
12	5	35.00	97.50	12852.50	4360.	5.00	145.00	984.0
13	2	172.00	201.00	27000.00	3001.	5.00	135.00	846.0
14	BASE				450311.	10.00	145.00	10000.0

PERIOD = 1.364 sec FROM AVERAGE SHEAR WAVE VELOCITY OF 841.6 ft/sec

FREQUENCY AMPLITUDE:
MAXIMUM AMPLIFICATION = 12.74
FOR FREQUENCY (f) = .75 c/sec
FOR PERIOD (1 / f) = 1.34 sec

****** OPTION 3 *** READ INPUT MOTION

FILE NAME FOR INPUT MOTION = B2-SYN.sar
NO. OF INPUT ACCEL. POINTS = 2000
NO. OF POINTS USED IN FFT = 4096
NO. OF HEADING LINES = 3
NO. OF POINTS PER LINE = 8
TIME STEP FOR INPUT MOTION = .0250
FORMAT FOR OF TIME HISTORY = (8F9.6)

***** A C C E L E R O G R A M H E A D E R *****

B2 SYNTHETIC M 7 EARTHQUAKE (Jennings et al., 1968)
Max. (in file) = 0.315077 g @ 4.68 sec; RMS freq. = 3.28 Hz
8 * 250 = 2000 pts. @ 0.025 sec; 8F9.6

** FIRST & LAST 5 LINES OF INPUT MOTION *****

1	.000000	-.000191	-.000399	-.000632	-.000888	-.001092	-.001243	-.001437
2	-.001835	-.002398	-.002842	-.002946	-.003019	-.002256	-.000859	-.000274
3	-.001190	-.002239	-.001787	-.000404	.001028	.000773	-.000755	-.002586
4	-.004002	-.004247	-.004716	-.006834	-.008546	-.009391	-.008594	-.007142
5	-.003566	.000028	.004129	.004172	.001735	.003682	.002997	-.000622

..... INPUT MOTION READ NOT ECHOED.....

246	-.002408	-.003898	-.005588	-.004314	.001070	.002833	.003657	.005944
247	.009774	.008337	.004462	.006259	.007700	.007975	.009049	.007827
248	.000034	-.004254	-.005640	-.011432	-.014924	-.016667	-.012866	-.009277
249	-.007880	-.005180	-.003704	-.007066	-.013307	-.012550	-.009212	-.005912
250	-.001681	.002323	.007857	.009733	.005098	.001221	-.002116	-.006346

MAXIMUM ACCELERATION = .315077

AT TIME = 4.68 sec

THE VALUES WILL BE MULTIPLIED BY A FACTOR = .50781240
TO GIVE NEW MAXIMUM ACCELERATION = .16000000

MEAN SQUARE FREQUENCY = 3.28 c/sec

****** OPTION 4 *** READ WHERE OBJECT MOTION IS GIVEN

OBJECT MOTION IN LAYER NUMBER 14 OUTCROPPING

****** OPTION 5 *** OBTAIN STRAIN COMPATIBLE SOIL PROPERTIES

MAXIMUM NUMBER OF ITERATIONS = 10
FACTOR FOR UNIFORM STRAIN IN TIME DOMAIN = .65

ACCELEROGRAM - B2-SYN.sar
P R O F I L E - CASE 3 - The Most Crit. Prof.

ITERATION NUMBER 1

VALUES IN TIME DOMAIN

NO	TYPE	DEPTH (ft)	UNIFRM. STRAIN	<---- DAMPING ----> NEW	USED	ERROR	<---- SHEAR MODULUS -----> NEW	USED	ERROR	G/Go RATIO
1	2	1.5	.00731	.024	.050	-105.3	495.1	563.5	-13.8	1.000
2	2	5.0	.02408	.046	.050	-7.8	384.3	563.5	-46.6	1.000
3	5	12.0	.01365	.055	.050	9.6	1774.6	2295.7	-29.4	1.000
4	5	22.0	.02391	.071	.050	29.8	1564.0	2295.7	-46.8	1.000
5	5	32.0	.03298	.081	.050	38.1	1443.0	2295.7	-59.1	1.000
6	5	42.0	.04087	.088	.050	43.0	1360.3	2295.7	-68.8	1.000
7	5	52.0	.04817	.093	.050	46.3	1282.0	2295.7	-79.1	1.000
8	5	58.5	.04230	.089	.050	43.7	1679.6	2869.1	-70.8	1.000
9	5	62.5	.04639	.092	.050	45.5	1561.5	2757.5	-76.6	1.000
10	5	67.5	.04931	.094	.050	46.7	1526.6	2757.5	-80.6	1.000
11	5	75.0	.03434	.082	.050	39.1	2711.9	4360.2	-60.8	1.000
12	5	97.5	.04308	.089	.050	44.1	2535.9	4360.2	-71.9	1.000
13	2	201.0	.08139	.090	.050	44.4	1248.8	3000.7	-140.3	1.000

ACCELEROGRAM - B2-SYN.sar
P R O F I L E - CASE 3 - The Most Crit. Prof.

ITERATION NUMBER 2

VALUES IN TIME DOMAIN

NO	TYPE	DEPTH (ft)	UNIFRM. STRAIN	<---- DAMPING ----> NEW	USED	ERROR	<---- SHEAR MODULUS -----> NEW	USED	ERROR	G/Go RATIO
1	2	1.5	.00380	.017	.024	-45.4	528.8	495.1	6.4	.879
2	2	5.0	.01613	.038	.046	-22.1	427.5	384.3	10.1	.682
3	5	12.0	.00812	.043	.055	-29.0	1940.3	1774.6	8.5	.773
4	5	22.0	.01631	.060	.071	-18.0	1707.8	1564.0	8.4	.681
5	5	32.0	.02474	.072	.081	-11.8	1551.1	1443.0	7.0	.629
6	5	42.0	.03295	.081	.088	-8.6	1443.4	1360.3	5.8	.593
7	5	52.0	.04093	.088	.093	-6.0	1359.5	1282.0	5.7	.555
8	5	58.5	.03359	.081	.089	-9.2	1794.8	1679.6	6.4	.585
9	5	62.5	.03750	.085	.092	-8.1	1675.3	1561.5	6.8	.568

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10	5	[illegible]	.03985	.087	.094	-7.9	1648.0	1526.6	7.4	.554
11	5	75.0	.02376	.071	.082	-15.5	2975.0	2711.9	8.8	.622
12	5	97.5	.02823	.076	.089	-17.7	2851.7	2535.9	11.1	.582
13	2	201.0	.08898	.093	.090	3.7	1188.9	1248.8	-5.0	.416

ACCELEROGRAM - B2-SYN.sar
P R O F I L E - CASE 3 - The Most Crit. Prof.

ITERATION NUMBER 3

VALUES IN TIME DOMAIN

NO	TYPE	DEPTH (ft)	UNIFRM. STRAIN	<---- DAMPING ----> NEW	USED	ERROR	<---- SHEAR MODULUS -----> NEW	USED	ERROR	G/Go RATIO
1	2	1.5	.00340	.015	.017	-8.4	534.6	528.8	1.1	.938
2	2	5.0	.01391	.035	.038	-8.9	443.4	427.5	3.6	.759
3	5	12.0	.00726	.041	.043	-4.7	1966.4	1940.3	1.3	.845
4	5	22.0	.01474	.057	.060	-5.0	1745.8	1707.8	2.2	.744
5	5	32.0	.02274	.070	.072	-3.4	1582.7	1551.1	2.0	.676
6	5	42.0	.03055	.078	.081	-3.1	1471.9	1443.4	1.9	.629
7	5	52.0	.03800	.085	.088	-2.8	1389.8	1359.5	2.2	.592
8	5	58.5	.03096	.079	.081	-3.4	1833.1	1794.8	2.1	.626
9	5	62.5	.03444	.082	.085	-3.4	1713.9	1675.3	2.2	.608
10	5	67.5	.03638	.084	.087	-3.5	1689.1	1648.0	2.4	.598
11	5	75.0	.02110	.068	.071	-5.0	3059.8	2975.0	2.8	.682
12	5	97.5	.02355	.071	.076	-7.3	2981.2	2851.7	4.3	.654
13	2	201.0	.09427	.096	.093	2.4	1150.0	1188.9	-3.4	.396

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ACCELEROGRAM - B2-SYN.sar
P R O F I L E - CASE 3 - The Most Crit. Prof.

ITERATION NUMBER 4

VALUES IN TIME DOMAIN

NO	TYPE	DEPTH (ft)	UNIFRM. STRAIN	<---- DAMPING ----> NEW	USED	ERROR	<---- SHEAR MODULUS -----> NEW	USED	ERROR	G/Go RATIO
1	2	1.5	.00328	.015	.015	-2.7	536.3	534.6	.3	.949
2	2	5.0	.01307	.034	.035	-3.9	450.1	443.4	1.5	.787
3	5	12.0	.00697	.040	.041	-1.7	1975.8	1966.4	.5	.857
4	5	22.0	.01400	.056	.057	-2.6	1765.1	1745.8	1.1	.760
5	5	32.0	.02159	.068	.070	-2.2	1602.4	1582.7	1.2	.689
6	5	42.0	.02920	.077	.078	-1.8	1488.8	1471.9	1.1	.641
7	5	52.0	.03614	.084	.085	-1.9	1408.6	1389.8	1.3	.605
8	5	58.5	.02946	.077	.079	-2.0	1856.5	1833.1	1.3	.639
9	5	62.5	.03267	.080	.082	-2.1	1737.6	1713.9	1.4	.622
10	5	67.5	.03441	.082	.084	-2.2	1714.2	1689.1	1.5	.613
11	5	75.0	.01989	.066	.068	-2.5	3101.8	3059.8	1.4	.702
12	5	97.5	.02176	.069	.071	-3.3	3037.7	2981.2	1.9	.684
13	2	201.0	.09620	.096	.096	.8	1136.3	1150.0	-1.2	.383

ACCELEROGRAM - B2-SYN.sar
P R O F I L E - CASE 3 - The Most Crit. Prof.

ITERATION NUMBER 5

VALUES IN TIME DOMAIN

NO	TYPE	DEPTH (ft)	UNIFRM. STRAIN	<---- DAMPING ----> NEW	USED	ERROR	<---- SHEAR MODULUS -----> NEW	USED	ERROR	G/Go RATIO
1	2	1.5	.00325	.015	.015	-.7	536.8	536.3	.1	.952
2	2	5.0	.01280	.033	.034	-1.3	452.4	450.1	.5	.799
3	5	12.0	.00689	.040	.040	-.5	1978.5	1975.8	.1	.861
4	5	22.0	.01375	.056	.056	-.9	1771.9	1765.1	.4	.769
5	5	32.0	.02116	.068	.068	-.8	1609.9	1602.4	.5	.698
6	5	42.0	.02865	.076	.077	-.7	1495.9	1488.8	.5	.649
7	5	52.0	.03538	.083	.084	-.8	1416.7	1408.6	.6	.614
8	5	58.5	.02885	.077	.077	-.8	1866.4	1856.5	.5	.647
9	5	62.5	.03195	.080	.080	-.9	1747.6	1737.6	.6	.630
10	5	67.5	.03361	.081	.082	-.9	1724.8	1714.2	.6	.622
11	5	75.0	.01945	.065	.066	-1.0	3117.7	3101.8	.5	.711
12	5	97.5	.02117	.068	.069	-1.1	3057.2	3037.7	.6	.697
13	2	201.0	.09624	.097	.096	.0	1136.1	1136.3	.0	.379

ACCELEROGRAM - B2-SYN.sar
P R O F I L E - CASE 3 - The Most Crit. Prof.

ITERATION NUMBER 6

VALUES IN TIME DOMAIN

NO	TYPE	DEPTH (ft)	UNIFRM. STRAIN	<---- DAMPING ----> NEW	USED	ERROR	<---- SHEAR MODULUS -----> NEW	USED	ERROR	G/Go RATIO
1	2	1.5	.00326	.015	.015	.1	536.7	536.8	.0	.953
2	2	5.0	.01277	.033	.033	-.1	452.6	452.4	.0	.803
3	5	12.0	.00690	.040	.040	.1	1978.1	1978.5	.0	.862
4	5	22.0	.01375	.056	.056	.0	1772.0	1771.9	.0	.772
5	5	32.0	.02114	.068	.068	.0	1610.1	1609.9	.0	.701
6	5	42.0	.02857	.076	.076	-.1	1497.0	1495.9	.1	.652
7	5	52.0	.03526	.083	.083	-.1	1417.9	1416.7	.1	.617
8	5	58.5	.02877	.077	.077	-.1	1867.7	1866.4	.1	.651
9	5	62.5	.03186	.080	.080	-.1	1749.0	1747.6	.1	.634
10	5	67.5	.03350	.081	.081	-.1	1726.3	1724.8	.1	.625
11	5	75.0	.01941	.065	.065	-.1	3119.3	3117.7	.1	.715
12	5	97.5	.02112	.068	.068	-.1	3059.1	3057.2	.1	.701
13	2	201.0	.09619	.096	.097	.0	1136.4	1136.1	.0	.379

ACCELEROGRAM - B2-SYN.sar
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ITERATION NUMBER 7

VALUES IN TIME DOMAIN

NO	TYPE	DEPTH (ft)	UNIFRM. STRAIN	<---- DAMPING ----> NEW	USED	ERROR	<---- SHEAR MODULUS -----> NEW	USED	ERROR	G/Go RATIO
1	2	1.5	.00326	.015	.015	.1	536.7	536.7	.0	.952
2	2	5.0	.01278	.033	.033	.0	452.6	452.6	.0	.803
3	5	12.0	.00691	.040	.040	.0	1977.8	1978.1	.0	.862
4	5	22.0	.01376	.056	.056	.0	1771.6	1772.0	.0	.772

5	5		.02116	.068	.068	.0	1609.8	1610.1	.0	.701
6	5	42.0	.02857	.076	.076	.0	1497.0	1497.0	.0	.652
7	5	52.0	.03525	.083	.083	.0	1418.0	1417.9	.0	.618
8	5	58.5	.02877	.077	.077	.0	1867.7	1867.7	.0	.651
9	5	62.5	.03185	.080	.080	.0	1749.1	1749.0	.0	.634
10	5	67.5	.03350	.081	.081	.0	1726.3	1726.3	.0	.626
11	5	75.0	.01942	.065	.065	.0	3119.0	3119.3	.0	.715
12	5	97.5	.02112	.068	.068	.0	3058.9	3059.1	.0	.702
13	2	201.0	.09618	.096	.096	.0	1136.4	1136.4	.0	.379

ACCELEROGRAM - B2-SYN.sar
P R O F I L E - CASE 3 - The Most Crit. Prof.

ITERATION NUMBER 8

VALUES IN TIME DOMAIN

NO	TYPE	DEPTH (ft)	UNIFRM. STRAIN	<---- DAMPING ----> NEW	USED	ERROR	<---- SHEAR MODULUS -----> NEW	USED	ERROR	G/Go RATIO
1	2	1.5	.00326	.015	.015	.0	536.7	536.7	.0	.952
2	2	5.0	.01278	.033	.033	.0	452.6	452.6	.0	.803
3	5	12.0	.00691	.040	.040	.0	1977.8	1977.8	.0	.862
4	5	22.0	.01376	.056	.056	.0	1771.6	1771.6	.0	.772
5	5	32.0	.02117	.068	.068	.0	1609.7	1609.8	.0	.701
6	5	42.0	.02857	.076	.076	.0	1497.0	1497.0	.0	.652
7	5	52.0	.03525	.083	.083	.0	1418.0	1418.0	.0	.618
8	5	58.5	.02877	.077	.077	.0	1867.7	1867.7	.0	.651
9	5	62.5	.03185	.080	.080	.0	1749.1	1749.1	.0	.634
10	5	67.5	.03350	.081	.081	.0	1726.3	1726.3	.0	.626
11	5	75.0	.01942	.065	.065	.0	3119.0	3119.0	.0	.715
12	5	97.5	.02113	.068	.068	.0	3058.9	3058.9	.0	.702
13	2	201.0	.09618	.096	.096	.0	1136.4	1136.4	.0	.379

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ACCELEROGRAM - B2-SYN.sar
P R O F I L E - CASE 3 - The Most Crit. Prof.

ITERATION NUMBER 9

VALUES IN TIME DOMAIN

NO	TYPE	DEPTH (ft)	UNIFRM. STRAIN	<---- DAMPING ----> NEW	USED	ERROR	<---- SHEAR MODULUS -----> NEW	USED	ERROR	G/Go RATIO
1	2	1.5	.00326	.015	.015	.0	536.7	536.7	.0	.952
2	2	5.0	.01278	.033	.033	.0	452.6	452.6	.0	.803
3	5	12.0	.00691	.040	.040	.0	1977.8	1977.8	.0	.862
4	5	22.0	.01376	.056	.056	.0	1771.5	1771.6	.0	.772
5	5	32.0	.02117	.068	.068	.0	1609.7	1609.7	.0	.701
6	5	42.0	.02857	.076	.076	.0	1497.0	1497.0	.0	.652
7	5	52.0	.03525	.083	.083	.0	1418.0	1418.0	.0	.618
8	5	58.5	.02877	.077	.077	.0	1867.7	1867.7	.0	.651
9	5	62.5	.03185	.080	.080	.0	1749.1	1749.1	.0	.634
10	5	67.5	.03350	.081	.081	.0	1726.3	1726.3	.0	.626
11	5	75.0	.01942	.065	.065	.0	3119.0	3119.3	.0	.715
12	5	97.5	.02113	.068	.068	.0	3058.8	3058.8	.0	.702
13	2	201.0	.09618	.096	.096	.0	1136.4	1136.4	.0	.379

ACCELEROGRAM - B2-SYN.sar
P R O F I L E - CASE 3 - The Most Crit. Prof.

ITERATION NUMBER 10

VALUES IN TIME DOMAIN

NO	TYPE	DEPTH (ft)	UNIFRM. STRAIN	<---- DAMPING ----> NEW	USED	ERROR	<---- SHEAR MODULUS -----> NEW	USED	ERROR	G/Go RATIO
1	2	1.5	.00326	.015	.015	.0	536.7	536.7	.0	.952
2	2	5.0	.01278	.033	.033	.0	452.6	452.6	.0	.803
3	5	12.0	.00691	.040	.040	.0	1977.8	1977.8	.0	.862
4	5	22.0	.01376	.056	.056	.0	1771.5	1771.5	.0	.772
5	5	32.0	.02117	.068	.068	.0	1609.7	1609.7	.0	.701
6	5	42.0	.02857	.076	.076	.0	1497.0	1497.0	.0	.652
7	5	52.0	.03525	.083	.083	.0	1418.0	1418.0	.0	.618
8	5	58.5	.02877	.077	.077	.0	1867.7	1867.7	.0	.651
9	5	62.5	.03185	.080	.080	.0	1749.1	1749.1	.0	.634
10	5	67.5	.03350	.081	.081	.0	1726.3	1726.3	.0	.626
11	5	75.0	.01942	.065	.065	.0	3119.0	3119.0	.0	.715
12	5	97.5	.02113	.068	.068	.0	3058.8	3058.8	.0	.702
13	2	201.0	.09618	.096	.096	.0	1136.4	1136.4	.0	.379

VALUES IN TIME DOMAIN

LAYER	MAT. TYPE	THICKNESS (ft)	DEPTH (ft)	MAX. STRAIN (%)	MAX. STRESS (psf)	AVG. ACC. (g)	TIME (sec)
1	2	3.0	1.5	.00502	26.92	.14359 COVER	9.35
2	2	4.0	5.0	.01966	88.97	.14236 ←	9.35
3	5	10.0	12.0	.01063	210.23	.14015	9.35
4	5	10.0	22.0	.02117	375.12	.13641	9.35
5	5	10.0	32.0	.03257	524.27	.13107	9.35
6	5	10.0	42.0	.04395	657.94	.12532	9.38
7	5	10.0	52.0	.05423	769.00	.11831 LINER	9.38
8	5	3.0	58.5	.04426	826.60	.11292 ←	9.38
9	5	5.0	62.5	.04901	857.15	.10916	9.38
10	5	5.0	67.5	.05154	889.76	.10434	9.38
11	5	10.0	75.0	.02987	931.76	.09716	9.38
12	5	35.0	97.5	.03250	994.13	.07735	9.38
13	2	172.0	201.0	.14797	1681.63	.06228	16.02

PERIOD = 1.935 sec FROM AVERAGE SHEAR WAVE VELOCITY OF 593.3 ft/sec

FREQUENCY AMPLITUDE:
MAXIMUM AMPLIFICATION = 6.39
FOR FREQUENCY (f) = .47 c/sec
FOR PERIOD (1 / f) = 2.15 sec

****** OPTION 6 *** COMPUTE MOTION IN NEW SUBLAYERS

ACCELEROGRAM - B2-SYN.sar
D E P O S I T - CASE 3 - The Most Crit. Prof.

LAYER	DEPTH (ft)	MAX. ACC. (g)	TIME (sec)	MN.SQ.FR. (c/sec)	ACC. RATIO QUIET ZONE	TH SAVED ACC.REC.
WITHIN	.0	.14413	9.35	1.69	.001	0

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WITHIN	3.0	.14369	9.35	1.67	.001	0
WITHIN	7.0	.14101	9.35	1.58	.001	0
WITHIN	17.0	.13620	9.35	1.49	.001	0
WITHIN	27.0	.12556	9.35	1.36	.001	0
WITHIN	37.0	.10988	9.38	1.23	.001	0
WITHIN	47.0	.09768	10.13	1.13	.001	0
WITHIN	57.0	.08389	10.13	1.10	.001	0
WITHIN	60.0	.08075	12.50	1.10	.002	0
WITHIN	65.0	.07838	16.20	1.12	.001	0
WITHIN	287.0	.15123	4.68	3.27	.001	0
OUTCR.	287.0	.15983	4.68	3.28	.001	0

```
******   OPTION  7  ***  COMPUTE STRESS/STRAIN HISTORY

COMPUTE STRESS OR STRAIN HISTORY AT THE TOP OF  LAYER    2
SCALE FOR PLOTTING      .0000
IDENTIFICATION -  -- stress in level 2

COMPUTE STRESS OR STRAIN HISTORY AT THE TOP OF  LAYER    2
SCALE FOR PLOTTING      .0000
IDENTIFICATION -  -- strain in level 2

******   OPTION  7  ***  COMPUTE STRESS/STRAIN HISTORY

COMPUTE STRESS OR STRAIN HISTORY AT THE TOP OF  LAYER    9
SCALE FOR PLOTTING      .0000
IDENTIFICATION -  -- stress in level 8

COMPUTE STRESS OR STRAIN HISTORY AT THE TOP OF  LAYER    9
SCALE FOR PLOTTING      .0000
IDENTIFICATION -  -- strain in level 8
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APPENDIX A

COMPUTER SOFTWARE USED TO PREPARE CALCULATION PACKAGE

SHAKE91

Idriss, I.M. and Sun, J.I., "SHAKE91 - A Computer Program for Conducting Equivalent Linear Seismic Response Analyses of Horizontally Layered Soil Deposits," *User's Manual*, Center for Geotechnical Modeling, Department of Civil and Environmental Engineering, University of California, Davis, California, 1992, 13 p. (plus Appendicies).

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USER'S MANUAL FOR

SHAKE91

A Computer Program for Conducting Equivalent Linear
Seismic Response Analyses of Horizontally Layered Soil Deposits

Program Modified based on the Original ***SHAKE*** program published in
December 1972 by Schnabel, Lysmer & Seed

Modifications by

I. M IDRISS
JOSEPH I. SUN

Sponsored by

Structures Division
Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, Maryland

Center for Geotechnical Modeling
Department of Civil & Environmental Engineering
University of California
Davis, California

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USER'S MANUAL FOR

SHAKE91

A Computer Program for Conducting Equivalent Linear Seismic Response Analyses of Horizontally Layered Soil Deposits

Program Modified based on the Original *SHAKE* program published in December 1972 by Schnabel, Lysmer & Seed

Modifications by

I. M Idriss[1] and Joseph I. Sun[2]

INTRODUCTION

The computer program **SHAKE** was written in 1970-71 by Dr. Per Schnabel and Professor John Lysmer and was published in December 1972 by Dr. Per Schnabel and Professors John Lysmer and H. Bolton Seed in report No. UCB/EERC 72/12, issued by the Earthquake Engineering Research Center at the University of California in Berkeley. This has been by far the most widely used program for computing the seismic response of horizontally layered soil deposits.

The program computes the response of a semi-infinite horizontally layered soil deposit overlying a uniform half-space subjected to vertically propagating shear waves. The analysis is done in the frequency domain, and, therefore, for any set of properties it is a linear analysis. An iterative procedure is used to account for the nonlinear behavior of the soils as summarized below.

The object motion (ie, the motion that is considered to be known) can be specified at the top of any sublayer within the soil profile or at the corresponding outcrop.

The program **SHAKE** was originally written for a main frame computer. It was converted for use on a personal computer by Dr. S. S. Lai in 1985; almost everything else remained identical to the original computer program. While there have been many modifications and several editions of the program **SHAKE** have been referenced in recent publications, the version included herein constitutes the most extensive modifications to

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the original program. The intent of the modifications was to make the program more convenient for use with a personal computer.

MODIFICATIONS IMPLEMENTED IN SHAKE91

The main modifications incorporated in ***SHAKE91*** include the following:

- The number of sublayers was increased from 20 to 50; this should permit a more accurate representation of deeper and/or softer soil deposits.

- All built-in modulus reduction and damping relationships were removed. These relationships are now specified by the user; up to 13 different relations of modulus reduction, G/G_{max}, versus shear strain and damping ratio, λ, versus shear strain can be specified as part of the input file. A number of published variations of G/G_{max} and λ with shear strain are available in the literature (eg, Hardin and Drnevich, 1970; Seed and Idriss, 1970; Seed et al, 1986; Sun et al, 1988; Vucetic and Dobry, 1991).

- The maximum shear velocity or the maximum modulus are now specified for each sublayer; again these are part of the input and therefore the program no longer calculates modulus values as a function of either confining pressure or shear strength. The user specifies the maximum values, which are derived by the user.

- Object motion is now read from a separate file; the number of header lines and format are specified by the user.

- Other clean-up include: renumbering of options, elimination of infrequently used options, user specified periods for calculating spectral ordinates ... etc.

DESCRIPTION OF THE PROGRAM

The soil profile is idealized as a system of homogeneous, visco-elastic sublayers of infinite horizontal extent; the idealized soil profile is shown in Fig. 1. The response of this system is calculated considering vertically propagating shear waves. The algorithm in the original program **SHAKE** (Schnabel et al, 1972) is based on the continuous solution to the wave equation (Kanai, 1951; Matthiesen et al, 1964; Roesset and Whitman, 1969; Lysmer et al 1971), which was adapted for transient motions using the Fast Fourier Transform techniques of Cooley and Tukey (1965). The program ***SHAKE91*** retains this feature of the original program. Details pertinent to the derivation of the applicable equations of motion and solution of these equations are summarized in the original **SHAKE** manual, in the aforementioned references and in most textbooks on wave propagation. Therefore, they are not repeated in this user's manual.

An equivalent linear procedure (Idriss and Seed, 1968; Seed and Idriss, 1970) is used to account for the nonlinearity of the soil using an iterative procedure to obtain values for

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modulus and damping that are compatible with the equivalent uniform strain induced in each sublayer. Thus, at the outset, a set of properties (shear modulus, damping and total unit weight) is assigned to each sublayer of the soil deposit. The analysis is conducted using these properties and the shear strains induced in each sublayer is calculated. The shear modulus and the damping ratio for each sublayer are then modified based on the applicable relationship relating these two properties to shear strain. The analysis is repeated until strain-compatible modulus and damping values are arrived at. Starting with the maximum shear modulus for each sublayer and a low value of damping, essentially strain-compatible properties (ie, difference less than about one percent) are obtained in 5 to 8 iterations for most soil profiles.

The following assumptions are incorporated in the analysis (Schnabel et al, 1972):

- Each sublayer, m, is completely defined by its shear modulus, G_m, damping ratio, λ_m, total unit weight, γ_{tm} (or corresponding mass density, ρ_m) and thickness, h_m; these properties are independent of frequency.

- The responses in the soil profile are caused by the upward propagation of shear waves from the underlying rock half-space.

- The shear waves are specified as acceleration ordinates at equally spaced time intervals. (Cyclic repetition of the acceleration time history is implied in the solution).

- The strain dependence of the shear modulus and damping in each sublayer is accounted for by an equivalent linear procedure based on an equivalent uniform strain computed in that sublayer. The ratio of this equivalent uniform shear strain divided by the calculated maximum strain is specified by the user (see Option 5 below); the same value of this ratio is used for all sublayers.

Available Options

The options incorporated into ***SHAKE91*** are as follows:

Option Number	Description
1	dynamic soil properties
2	data for soil profile
3	input (object) motion
4	assignment of object motion to the top of a specified sublayer or to the corresponding outcrop
5	number of iterations specified & ratio of uniform strain to maximum strain

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6	sublayers at top of which peak accelerations & time histories are computed and saved
7	sublayer at top of which time history of shear stress or strain is computed and saved
8	time history of object motion
9	response spectrum
10	amplification spectrum
11	Fourier amplitudes

Note that the original program **SHAKE** included 16 options and that the modified program includes only 11; the five options eliminated pertain mostly to plotting and to adjusting the time increment. Such operations can best be done in auxiliary programs.

INPUT DATA

The input data are provided in an input file; the name and location of this input file is specified directly from the key board at the time of program execution. A sample input is presented in Table 1. As can be noted in the table, each option starts with the following two lines:

Line No. 1 (Format: A80)

columns 1 - 80 Identification information for this option (this line cannot be blank)

Line No. 2 (Format: I5)

columns 1 - 5 Option Number

The specific inputs for each option are presented below.

Option 1 – Dynamic Soil Properties

- first line after option number (Format: I5)

columns 1 - 5 Number of materials included (maximum is 13)

then, for each material, the following input should be supplied:

first line (Format: I5, 11A6)

columns 1 - 5 number of strain values to be read (maximum is 20)

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columns 6 - 71 identification for this set of modulus reduction values

second & consecutive lines (Format: 8F10.0)

columns 1 - 80 strain values, in percent, beginning with the lowest value. Eight entries per line using 8F10.0 Format (maximum is 20)

consecutive lines (Format: 8F10.0)

columns 1 - 80 values of modulus reduction (G/G_{max}) each corresponding to the shear strain provided in the previous lines; these values should be in decimal not in percent.

the second set for the same material will consist of identical information except that values of damping (in percent) are provided as illustrated in Table 1.

After the last set is completed, the following information is to be provided (Format: 16I5):

columns 1 - 5	number, N, of materials to be used in this analysis
columns 6 - 10	first material number which will be used
columns 11 - 15	second material number to be used
columns 16 - 20	third material number to be used
.	.....
.	.....
.	etc until all N materials are identified.

Values of G/G_{max} and λ versus strain for these N materials will then be saved in output file No. 1 (see section on OUTPUT below) so that only the material properties used in this analysis are saved in this file. This feature was added for the convenience of the user who can include up to 13 sets of material properties in the input file but for any one analysis uses fewer than 13. This feature also provides a check that the intended material properties were utilized in the analysis.

Option 2 – Soil Profile

- first line after option number (Format: 2I5, 5X, 6A6)

columns 1 - 5	soil deposit number; may be left blank
columns 6 - 10	number of sublayers, including the half-space
columns 16 - 51	identification for soil profile

Bug:
11-15 : # of first subverged layer
Enter # of half space.

Doesn't effect computation only effects "Total Pressure" in output.

- second and subsequent lines; one line for each sublayer, including the half-space (Format: 2I5, 5X, 5F10.0)

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columns 1 - 5	sublayer number
columns ~~1~~ 6 - 10	soil type (corresponding to numbers assigned to each material in Option 1). [Note that if this material type is given as 0 (zero) for ***all*** sublayers, then the calculations are conducted for only one iteration using the properties (modulus, or shear wave velocity, and damping) specified in this input].
columns 16 - 25	thickness of sublayer, in feet
columns 26 - 35	maximum shear modulus for the sublayer, in ksf (leave blank if maximum shear wave velocity for the sublayer is given)
columns 36 - 45	initial estimate of damping (decimal)
columns 46 - 55	total unit weight, in ksf
columns 56 - 65	maximum shear wave velocity for the sublayer, in ft/sec (leave blank if maximum shear modulus for the sublayer is given)

For the half-space, leave columns 16 to 25 blank; ie, no thickness should be specified for the half-space.

<u>Option 3 – Input (Object) Motion</u>

- first line after option number (Format: 2I5, F10.3, A30, A12)

columns 1 - 5	number, NV, of acceleration values to be read for input motion
columns 6 - 10	number, MA, of values for use in Fourier Transform; MA should be a power of 2 (typically, this number is 1024, 2048 or 4096). Note that MA should always be greater than NV. The following may be used as a guide: for NV ≤ 800, MA can be 1024, for NV ≤ 1800, MA can be 2048 and for NV ≤ 3800, MA can be 4096. The current program is limited to a maximum value of 4096 for MA.
columns 11 - 20	time interval between acceleration values, in seconds
columns 21 - 50	name of file for input (object) motion
columns 51 - 62	format for reading acceleration values

Bug: There must be at least 2 values per line to get correct results

- second line after option number (Format: 3F10.0, 2I5)

columns 1 - 10	multiplication factor for adjusting acceleration values; use only if columns 11 - 20 are left blank
columns 11 - 20	maximum acceleration to be used, in g's; the acceleration values read-in will be scaled to provide the maximum acceleration specified in these columns; leave columns 11 - 20 blank if a multiplication factor is specified in columns 1 - 10.
columns 21 - 30	maximum frequency (ie, frequency cut-off) to be used in the analysis

Corrects in the program of N.M.

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columns 31 - 35	number of header lines in file containing object motion
columns 36 - 40	number of acceleration values per line in file containing object motion

Option 4 -- Assignment of Object Motion to a Specific Sublayer

- first line after option number (Format: 2I5)

columns 1 - 5	number of sublayer at the top of which the object motion is assigned
columns ~~11~~ 6 - 10	use 0 (zero) if the object motion is to be assigned as outcrop motion, otherwise use 1 (one) if the object motion is applied within the soil profile at the top of the assigned sublayer

Option 5 -- Number of Iterations & Ratio of Equivalent Uniform Strain to Maximum Strain

- first line after option number (Format: 2I5, F10.0)

columns 1 - 5	parameter used to specify whether the strain-compatible soil properties are saved after the final iteration; set = 1 if these properties are to be saved; otherwise leave columns 1 - 5 blank
columns ~~1~~ 6 - 10	number of iterations
→ columns 11 - 20	ratio of equivalent uniform strain divided by maximum strain; typically this ratio ranges from 0.4 to 0.75 depending on the input motion and which magnitude earthquake it is intended to represent. The following equation may be used to estimate this ratio: [ratio = (M - 1)/10] in which M is the magnitude of the earthquake. Thus, for M = 5, the ratio would be 0.4, for M = 7.5, the ratio would be 0.65 ... etc.

Option 6 -- Computation of Acceleration at Top of Specified Sublayers

(Note that a maximum of fifteen sublayers can be specified at a time; if accelerations for more than 15 sublayers are desired, then Option 6 can be repeated as many times as needed).

- first line after option number (Format: 15I5)

columns 1 - 75	array to indicate the numbers of the sublayers at the top of which the acceleration is to be calculated

- second line after option number (Format: 15I5)

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columns 1 - 75	array to specify type of each sublayer: 0 (zero) for outcropping or 1 (one) for within the soil profile

- third line after option number (Format: 15I5)

columns 1 - 75	array to specify the mode of output for the computed accelerations: 0 (zero) if only maximum acceleration is desired or 1 (one) if both the maximum acceleration and the time history of acceleration are to be calculated and saved

Option 7 -- Computation of Shear Stress or Strain Time History at Top of Specified Sublayers

(Note that a maximum of two sublayers can be specified; if stress or strain time histories for more than two sublayers are desired, then Option 7 can be repeated as many times as needed).

- first line after option number (Format: 5I5, F10.0, 5A6)

columns 1 - 5	number of sublayer
columns 11 - 10	set equal to 0 (zero) for strain or 1 (one) for stress
columns 11 - 15	set equal to one to save time history of strain or stress
columns 16 - 20	leave blank
columns 21 - 25	number of values to be saved; typically this should be equal to the number NV (see Option 3 above) 2049 max.
columns 26 - 35	leave blank
columns 36 - 65	identification information

- second line after option number (Format: 5I5, F10.0, 5A6)

same as the above line for the second sublayer

Note that the time histories of shear stresses or strains are calculated at the top of the specified sublayer. Thus, if the time history is needed at a specific depth within the soil profile, that depth should be made the top of a sublayer. The time history of stresses or strains is saved in the second Output file.

This options should be specified after Option 6 as shown in Table 1 and in Table B-1.

Option 8 -- Time History of Object Motion

Although this option was retained, its purpose is most easily accomplished in Option 6.

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Option 9 – Response Spectrum

- first line after option number (Format: 2I5)

columns 1 - 5	sublayer number
columns 6 - 10	set equal to 0 (zero) for outcropping or equal to 1 (one) for within

- second line after option number (Format: 2I5, F10.0)

columns 1 - 5	number of damping ratios to be used
columns 6 - 10	set equal to 0 (zero) or >0 to input periods from a file
columns 11 -20	acceleration of gravity

File Containing Periods:
1st line:
col. 1-5 ϕ col. 5-10: # of periods
following lines: periods separated by a single space

- third line after option number (Format: 6F10.0)

columns 1 - 60	array for damping ratios (in decimal)

- fourth line: name of file to read periods from (start at 1st col.) ex: PERIODS.DAT

Option 10 – Amplification Spectrum

- first line after option number (Format: 4I5, F10.0, 8A6)

columns 1 - 5	number of first sublayer
columns 6 - 10	set equal to 0 (zero) for outcropping or equal to 1 (one) for within
columns 11 -15	number of second sublayer
columns 16 - 20	set equal to 0 (zero) for outcropping or equal to 1 (one) for within
columns 21 - 30	frequency step (in cycles per second); the amplification spectrum is calculated for 200 frequencies using this frequency step and starting with 0
columns 31 - 78	identification information

[The amplification spectrum is the ratio of the amplitude of motion at the top of the second sublayer divided by that at the top of the first sublayer].

If the amplification spectrum is desired for two other sublayers. Option 10 can be repeated as many times as needed.

Option 11 – Fourier Spectrum

- first line after option number (Format: 5I5)

columns 1 - 5	number of the sublayer
columns 6 - 10	set equal to 0 (zero) for outcropping or equal to 1 (one) for within
columns 11 -15	set equal to 2 (two) if spectrum is to be saved to file
columns 16 - 20	number of times the spectrum is to be smoothed
columns 21 - 25	number of values to be saved

The following expression (Schnabel et al, 1972) is used to smooth the Fourier spectrum:

$$A_i = \frac{A_{i-1} + 2A_i + A_{i+1}}{4}$$

in which A_i is the amplitude of the spectrum for the ith frequency.

A second line is always needed when using Option 11. Thus, the user should either provide a second line for another sublayer or repeat the information provided in the first line in a second line.

It may be noted that calculation of Fourier amplitudes for a specific accelerogram is best accomplished in an auxiliary program.

Program Termination

For program termination, the user should provide a line that contains information that execution will terminate when the number is encountered as an option number; the line following this information should have 0 (zero) with a format of I5. Execution will then terminate.

OUTPUT

The output of the program is contained in two files. The first file echoes much of the input information and contains the results of each iteration, the listing of calculated maximum shear stresses and strains, maximum acceleration, response spectrum, Fourier spectrum and amplification spectrum, as appropriate. The second file contains all the time histories requested. The name of each file is specified by the user at the time of program execution directly from the key-board.

COMPUTER LISTING

The FORTRAN listing of program ***SHAKE91*** is given in Appendix A.

SAMPLE PROBLEM

The results for a sample problem are given in Appendix B.

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CONCLUDING REMARKS

The computer program SHAKE has been widely used throughout the United States and in many parts of the world for conducting ground response studies. Its use in recent studies involving recordings obtained at several sites from the 1989 Loma Prieta earthquake (eg, Idriss, 1990; Dickenson et al, 1991; Idriss, 1991; Rollins et al, 1992; Yokel, 1992) have indicated that the calculated surface motions are in reasonably good agreement with the recorded values when the appropriate soil properties and input rock motions are used.

Therefore, this program remains a convenient tool for conducting such analyses at many sites and for a variety of applications.

ACKNOWLEDGMENTS

The modification of the original SHAKE program was completed as part of a research study regarding earthquake ground motions being completed at the University of California at Davis. The study is being supported by a research grant from the National Institute of Standards and Technology (NIST); Dr. Felix Y. Yokel of NIST is the Contract monitor for this study. The writers gratefully acknowledge the support of NIST and thank Dr. Yokel for his timely input and support during this study.

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Table 1
Sample Input

```
option 1 - dynamic soil properties - (max is thirteen):
    1
    3
   11      #1 modulus reduction for clay (Sun et al, 1988) upper range
 0.0001    0.0003    0.001     0.003     0.01      0.03      0.1       0.3
 1.        3.        10.
 1.000     1.000     1.000     0.981     0.941     0.847     0.656     0.438
 0.238     0.144     0.110
   11      damping for clay (Idriss 1990) -
 0.0001    0.0003    0.001     0.003     0.01      0.03      0.1       0.3
 1.        3.16      10.
 0.24      0.42      0.8       1.4       2.8       5.1       9.8       15.5
 21.       25.       28.
   11      #2 modulus reduction for sand (seed & idriss 1970) - upper Range
 0.0001    0.0003    0.001     0.003     0.01      0.03      0.1       0.3
 1.        3.        10.
 1.000     1.000     0.990     0.960     0.850     0.640     0.370     0.180
 0.080     0.050     0.035
   11      damping for sand (Idriss 1990) - (LRng from seed & idriss) 1970)
 0.0001    0.0003    0.001     0.003     0.01      0.03      0.1       0.3
 1.        3.        10.
 0.24      0.42      0.8       1.4       2.8       5.1       9.8       15.5
 21.       25.       28.
    8      #3 modulus for rock half space (Schnabel et al, 1972)
 .0001     0.0003    0.001     0.003     0.01      0.03      0.1       1.0
 1.000     1.000     0.9875    0.9525    0.900     0.810     0.725     0.550
    5      Damping in Rock (Schnabel et al, 1972)
 .0001     0.001     0.01      0.1       1.
  0.4      0.8       1.5       3.0       4.6
    2    1    3
option 2 -- soil profile:
    2
    1    9          EXAMPLE SITE
    1    1          7.00  1500.     0.05      0.120
    2    1         13.00  1000.     0.05      0.100
    3    1         10.00  1800.     0.05      0.100
    4    1         12.00  2000.     0.05      0.100
    5    1         20.00  2500.     0.05      0.125
    6    1         18.00  3000.     0.05      0.125
    7    1         20.00  4000.     0.05      0.125
    8    1         20.00  5000.     0.05      0.125
    9    3                          0.01      0.150     3000.
option 3 -- input motion:
    3
  800 2048   .02    PAS.acc                        (8f9.6)
             .1      25.          1    8
option 4 -- sublayer where input motion is applied (within or outcropping):
    4
    9    0
option 5 -- number of iterations & ratio of avg. strain to max strain:
    5
    1    7     0.65
option 6 -- sublayers for which accn. time histories are to computed & saved:
    6
    1    2    3    4    5    6    7    8    9    9
    1    1    1    1    1    1    1    1    1    0
    1    0    0    0    0    0    0    0    1    0
```

Table 1 MBG 20 Oct 95 V.G. 10-17-95

Sample Input

```
option 7 -- sublayer for which shear stresses or strains are computed & saved:
    7
    4    1    1       809            -- stress in level 4
    4    0    1       809            -- strain in level 4
option 9 -- compute & save response spectrum:
    9
    1    0
    1    0     981.0
   0.05
option 10 -- compute & save amplification spectrum:
   10
    9    0    1    0    0.125
option 11 -- compute & save Fourier spectrum:
   11
    1    0    1    1 1000
    1    0    1    3 1000
execution will stop when program encounters 0
    0
```

Mtg 20 Oct 95 N.M. 10-17-95 A20/20

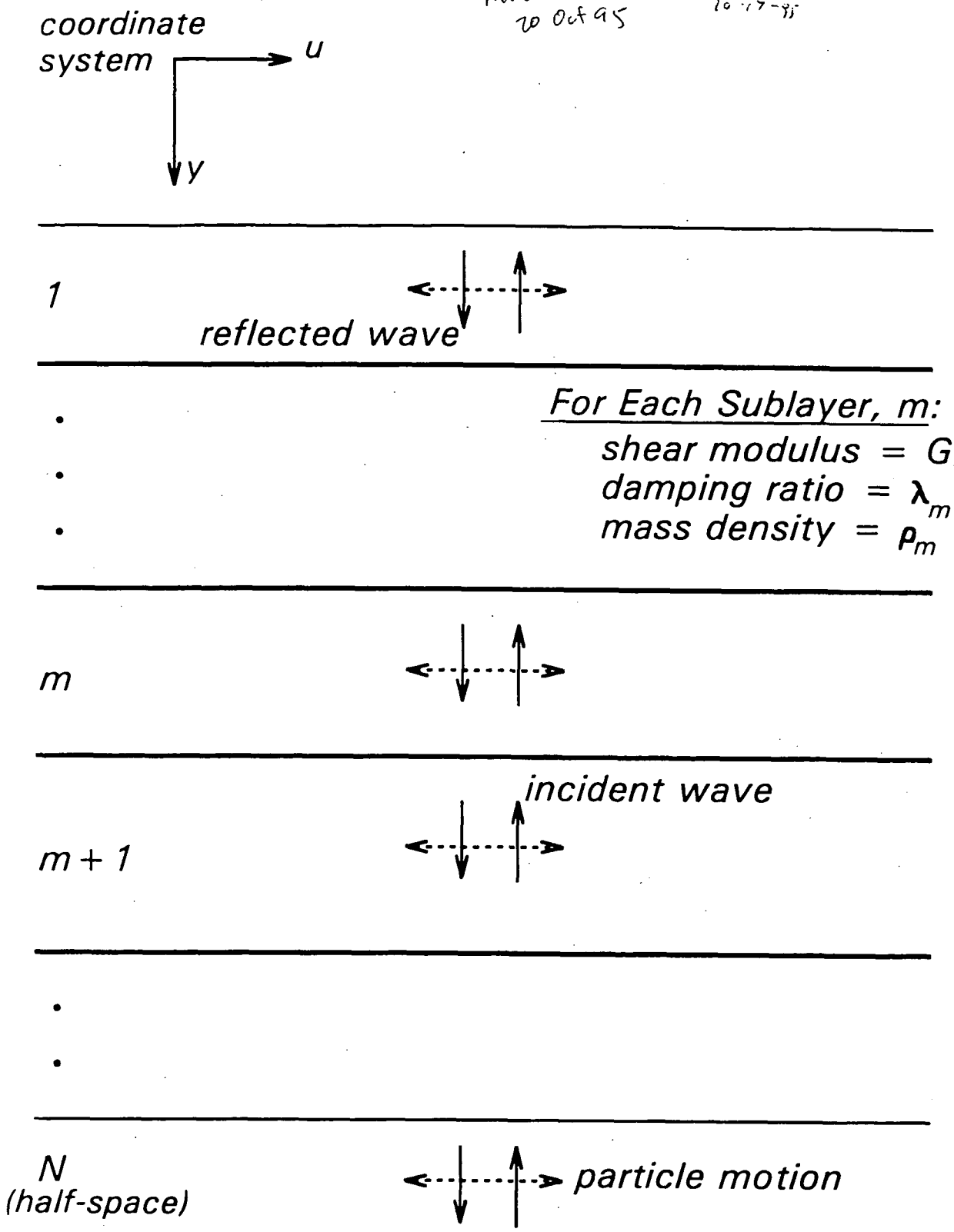

Fig. 1 One-Dimensional Idealization of a Horizontally-Layered Soil Deposit Over a Uniform Half-Space

4.3 Seismic Performance Evaluation

COMPUTATION COVER SHEET

SUBJECT OF CALCULATION: SEISMIC PERFORMANCE EVALUATION

Computations By: (Cognizant Engineer)
Signature: Mark H. Gleason — Date: 16 Oct 95
Printed Name and Title: MARK H. GLEASON, ASSISTANT PROJECT ENGINEER

Assumptions and Procedures Checked by: (Checker)
Signature: Eric S. Steinhausson — Date: 16 Oct '95
Printed Name and Title: ERIC S. STEINHASSON, PROJECT ENGINEER

Computations Checked by:
Signature: Eric S. Steinhausson — Date: 16 Oct '95
Printed Name and Title: ERIC S. STEINHASSON, PROJECT ENGINEER

Computations Backchecked by: (Cognizant Engineer)
Signature: Mark H. Gleason — Date: 16 Oct 95
Printed Name and Title: MARK H. GLEASON, ASSISTANT PROJECT ENGINEER

Approved by: (PDP)
Signature: Mark H. Gleason — Date: 16 Oct 95
Printed Name and Title: MARK H. GLEASON, ASSISTANT PROJECT ENGINEER

Approved by: (DTL and TETL)
Signature: Rudolph Bonaparte — Date: 17 Oct 95
Printed Name and Title: Rudolph Bonaparte, Principal

Record of Revision (Number and initial all revisions)

Rev. No.	Reason	Date	By	Checked	Approval
A	Draft submittal to FERMCO	17 Oct 95	NA	NA	NA
Ø	30% Submittal	20 Oct '95	MHG	SSS	RB
B	Preliminary Design - EPA Submittal	15 Dec 95	[illegible]		

Written by: M. GLEASON Date: 95/10/20 Reviewed by: [illegible] Date: 95/10/20

Client: FEMMIO Project: OSDF Proj./Proposal No.: GE 3900 Task No.: 9.11

SEISMIC PERFORMANCE EVALUATION

EXECUTIVE SUMMARY

The potential for seismic deformation of the On-Site Disposal Facility (OSDF) during the design seismic event is evaluated in this calculation package. For the relevant stability conditions presented in the static stability analysis, a pseudo-static stability analysis is performed to obtain a yield acceleration. The yield acceleration is the horizontal acceleration (reported as a percentage of gravity) at which the factor of safety is equal to 1.0. This value is compared to the peak average acceleration obtained in the Seismic Site Response Evaluation. For three cases of concern, the yield acceleration is less than the peak average acceleration for the design seismic event. For these cases, a seismic deformation analysis was performed. Based on the results of this analysis, the maximum permanent seismic deformation for the OSDF during the design seismic event is expected to be less than 0.1 ft (3 mm). This calculated deformation is within the limits of acceptable permanent seismic deformations described in Seed and Bonaparte (1992) and Anderson and Kavazanjian (1995). Therefore, the seismic performance of the OSDF during the design seismic event is acceptable.

Written by: M. GLEASON Date: 95/10/16 Reviewed by: RSS Date: 95/10/16

Client: FERMCO Project: OSDF Proj./Proposal No.: GE 3900 Task No.: 9.11

RB 95/10/16

SEISMIC PERFORMANCE EVALUATION

PURPOSE

The purpose of this document is to provide the engineering calculations for the evaluation for seismic performance of the On-Site Disposal Facility (OSDF). The calculations provide an evaluation, and if necessary, a calculation of the potential for permanent seismic deformation of the OSDF during the design seismic event.

The potential for permanent seismic deformation is calculated for the base (foundation), the impacted material mass, along the liner system, the OSDF perimeter berm, and the OSDF final cover system. The permanent seismic deformation is calculated for each configuration in which the yield acceleration (calculated in a pseudo-static stability analysis) exceeds the upper bound peak average acceleration (calculated in the Seismic Site Response Evaluation).

Several of the parameters and data used in these calculations are obtained from other calculations. These reference calculations are as follows:

- Seismic Hazard Assessment;
- Seismic Site Response Analysis;
- OSDF Foundation Stability;
- OSDF Interim/Final Waste Stability;
- OSDF Perimeter Berm Stability; and
- OSDF Cover System Stability.

PROCEDURE

1. Using the sections evaluated in the static stability analyses indicated above, perform a pseudo-static stability analysis to calculate the yield acceleration. The yield acceleration is the value of horizontal acceleration (measured as a percentage of gravity) at which the factor of safety for the critical slope stability interface is equal to 1.0. The computer program XSTABL (Sharma, 1994) is used in the pseudo-static stability analysis. Circular failure surfaces are evaluated using Bishop's Simplified Method (Bishop, 1955). Wedge failure surfaces are analyzed using Janbu's Method (Janbu, 1973).

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RB 95/10/16

SEISMIC PERFORMANCE EVALUATION

2. For each case, compare the yield acceleration calculated in the previous step to the upper bound peak average acceleration for the foundation liner and cover system of the OSDF as presented in the results of the Seismic Site Response Analysis. Identify the conditions that require an evaluation of permanent seismic deformation as follows:

   - For conditions in which the yield acceleration exceeds the upper bound peak average acceleration as calculated in the Seismic Site Response Analysis, it is concluded that no permanent seismic deformations will occur and the analysis is complete.

   - For conditions in which the yield acceleration is smaller than the upper bound peak average acceleration, permanent seismic deformations may occur during the seismic event and a Seismic Deformation Analysis is required.

3. For each stability condition requiring evaluation of permanent seismic deformations, perform a quantitative Newmark deformation analysis using the calculated yield acceleration from the pseudo-static limit equilibrium analysis and the acceleration time histories for the design earthquakes calculated in the Seismic Site Response Analysis. The yield acceleration and the average acceleration time history are entered into the validated Newmark computer program YSLIP_C (Yan, 1991). The permanent seismic deformation for cases requiring evaluation is then calculated.

4. For each case considered in Step 3, evaluate the potential for seismic upset to the OSDF by comparing the calculated deformation to the deformation levels considered to have the potential for impairment to the OSDF (i.e., greater than 6 to 12 inches of deformation) as reported by Seed and Bonaparte (1992) and Anderson and Kavazanjian (1995). Consider the lower bound limit of 6 inches for the OSDF.

Written by: M. Bilekson Date: 95/10/20 Reviewed by: [illegible] Date: 95/10/20

Client: Fermio Project: OSDF Proj./Proposal No.: GE 3900 Task No.: 9.11

RB 10/23/95

SEISMIC PERFORMANCE EVALUATION

DATA VERIFICATION

Each of the parameters used in the pseudo-static stability analysis come from parameters defined in previous calculation packages. Listed on Table 1 and Table 2 are the material, geosynthetics, and interface properties used in the pseudo-static stability analysis. The location of the original data verification package for each parameter is also specified in the tables.

The sections used for the pseudo-static stability analysis are identical to the sections defined in previous static stability analyses.

ANALYSIS

A pseudo-static stability analysis using XSTABL is performed to calculate the yield acceleration for the cases listed in Table 3. The yield acceleration is the value of horizontal acceleration (reported as a percentage of gravity) at which the factor of safety is 1.0. The minimum yield acceleration for each case is reported. The yield acceleration, the peak average acceleration, and the acceleration ratio for each case is presented in Table 3. The XSTABL output for each yield acceleration case is attached to these calculations.

For the cases indicated in Table 3 for which the yield acceleration is less than the peak average acceleration, a seismic deformation analysis was performed according to the procedures outlined in the procedure section. The cases for which the analysis was performed are as follows: (i) OSDF Foundation - Interim Configuration Condition; (ii) OSDF Liner System and Impacted Materials - Final Configuration; and (iii) OSDF Final Cover System - Long-Term Conditions.

To perform the seismic deformation analysis the shear stress time history for the final cover layer and the base of the impacted materials layer (liner) was obtained from the Seismic Site Response Analysis. The shear stress time history for each layer is used to obtain a peak average acceleration time history for the layer. The peak average acceleration time history for each layer is input into the validated Newmark computer program YSLIP_C (Yan, 1991). The permanent seismic deformation for each case requiring evaluation was then calculated. The files for the seismic deformation analysis are attached to this calculation package.

RB 10/23/95

SEISMIC PERFORMANCE EVALUATION

RESULTS

Presented in Table 3 are the yield acceleration, the peak average acceleration and the acceleration ratio for all cases considered in this analysis. For those cases for which the calculated peak average acceleration is less than the calculated yield acceleration, the permanent seismic deformation is considered to be negligible and no further analysis is required.

For the three cases for which the calculated peak average acceleration is greater than the calculated peak average acceleration, a seismic deformation analysis is performed. The results of this analysis are summarized in Table 4. As indicated in the Table, the maximum permanent seismic deformation for the OSDF during the design seismic event is expected to be less than 0.1 ft (3 mm) for each case. This calculated deformation is within the limits of acceptable permanent seismic deformations described in Seed and Bonaparte (1992) and Anderson and Kavazanjian (1995). Therefore, the seismic performance of the OSDF during the design seismic event is considered acceptable.

RB 10/23/95

SEISMIC PERFORMANCE EVALUATION

REFERENCES

1. Anderson, D.G. and Kavazanjian, E. Jr., "Performance of Landfills under Seismic Loading," *Proceedings of the 3rd International Conference on recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics*, St. Louis, Missouri, Vol. 3, 1995.

2. Seed, R.B., and Bonaparte, R., "Seismic Analysis and Design of Lined Waste Fills: Current Practice," *Proceedings, Stability and Performance of Slopes and Embankments-II*, Vol. 2, ASCE Geotechnical Special Publication No. 31, Berkeley, California, pp 1521-1545, 1992.

3. Sharma, S., "*XSTABL: An Integrated Slope Stability Analysis Program for Personal Computers, Version 5*", Interactive Software Designs, Moscow, ID, 1994.

4. Yan, L.P., "*Seismic Deformation Analysis of Earth Dams: A Simplified Method*", Research Report No. SML-91-01, California Institute of Technology, Soil Mechanics Laboratory, Pasadena, California, 1991.

5. Janbu, N., "Slope Stability Computations", *Embankment Dam Engineering*, Cassagrande Memorial Volume, Hirschfeld and Poulos, (Eds), John Wiley, New York, 1978 pp 47-86.

6. Bishop, A.W., "The Use of the Slip Circle in the Stability Analysis of Slopes," *Geotechnique*, Vol. 5, No. 1, March 1955, pp 7-17.

Written by: M. GLEASON Date: 95/10/16 Reviewed by: [illegible] Date: 95/10/16

Client: FERMCO Project: OSDF Proj./Proposal No.: GE 3900 Task No.: 9.11

RB 95/10/16

TABLE 1

DATA VERIFICATION
MATERIAL PARAMETERS

Seismic Performance Evaluation
Fernald Environmental Management Project
On-Site Disposal Facility
Fernald, Ohio

Material	Unit Weight (pcf)	Shear Strength	Source Calculation Package
Granular Soils in Liner and Cover System	125	friction angle = 30°	Foundation Stability
Impacted Materials			
• short term	125	friction angle = 25°, c = 200 psf	Foundation Stability
• long term	125	friction angle = 25°	Foundation Stability
Compacted Clay			
• short term	130	Su = 1,200 psf	Foundation Stability
• long term	130	friction angle = 25°	Foundation Stability
Brown Till			
• short term	135	Su = 1,200 psf	Foundation Stability
• long term	135	friction angle = 25°	Foundation Stability
Gray Till			
• short term	145	Su = 1,900 psf	Foundation Stability
• long term	145	friction angle = 30°	Foundation Stability
Great Miami Aquifer Soils	135	friction angle = 35°	Foundation Stability

Written by: M. Gleason Date: 95/10/16 Reviewed by: [illegible] Date: 95/10/16

Client: FERMCO Project: OSDF Proj./Proposal No.: GE 3900 Task No.: 9.11

RB 95/10/16

TABLE 2

DATA VERIFICATION
GEOSYNTHETICS AND INTERFACE PARAMETERS

Seismic Performance Evaluation
Fernald Environmental Management Project
On-Site Disposal Facility
Fernald, Ohio

Geosynthetics/Interface	Shear Strength	Source Calculation Package
Final Cover System • HDPE/GCL and/or Internal GCL Strength	friction angle = 15°	Cover System Stability
Liner System and Impacted Materials • Interim Configuration · Reinforced GCL	friction angle = 15° @ σ_n = 7,500 psf friction angle = 17° @ σ_n = 5,600 psf friction angle = 23° @ σ_n = 1,900 psf friction angle = 30° @ σ_n = 200 psf	Interim/Final Waste Slope Stability
· Dry GCL	friction angle = 20°	Interim/Final Waste Slope Stability
• Final Configuration · Hydrated GCL	friction angle = 8° @ σ_n = 7,500 psf friction angle = 8° @ σ_n = 6,300 psf friction angle = 10° @ σ_n = 3,900 psf	Interim/Final Waste Slope Stability

Written by: M. GLEASON Date: 95/10/20 Reviewed by: [illegible] Date: 95/10/20

Client: FERMCO Project: OSDF Proj./Proposal No.: GE 3900 Task No.: 9.11

RB 10/23/95

TABLE 3

EVALUATION SUMMARY

Seismic Performance Evaluation
Fernald Environmental Management Project
On-Site Disposal Facility
Fernald, Ohio

Case	Yield Acceleration[1] (g)	Peak Average Acceleration[2]	Acceleration Ratio[3]
OSDF Foundation • Interim Configuration • Final Configuration	0.10 0.30	0.11 0.11	0.9 - Deformation Analysis Required 2.7 - No Seismic Deformation
OSDF Liner System and Impacted Materials • Interim Configuration • Final Configuration	0.20 0.11	0.11 0.11	1.8 - No Seismic Deformation 1.0 - Deformation Analysis Required
OSDF Interim Closure	N/A	N/A	N/A
OSDF Final Cover System • Long-Term Conditions	0.12	0.14	0.9 - Deformation Analysis Required
OSDF Perimeter Berm • Long-Term Conditions	0.20	0.11	1.8 - No Seismic Deformation

Notes:

(1) Calculated in pseudo-static stability analysis.
(2) Calculated in the Seismic Site Response Analysis.
(3) Ratio of yield acceleration to peak average acceleration. If the acceleration ratio is greater than 1.0, no permanent seismic deformation is expected.

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Written by: M. Gleason Date: 95/10/20 Reviewed by: [illegible] Date: 95/10/20

Client: FERMCO Project: OSDF Proj./Proposal No.: GE 3900 Task No.: 9.11

RB 10/23/95

TABLE 4

DEFORMATION ANALYSIS

Seismic Performance Evaluation
Fernald Environmental Management Project
On-Site Disposal Facility
Fernald, Ohio

Case	Acceleration Ratio	Calculated Permanent Seismic Deformation (ft)	Comment
OSDF Foundation • Interim Condition	0.9	< 0.1 ft	Acceptable
OSDF Liner System and Impacted Materials • Final Configuration	1.0	< 0.1 ft	Acceptable
OSDF Final Cover System • Long-Term Conditions	0.9	< 0.1 ft	Acceptable

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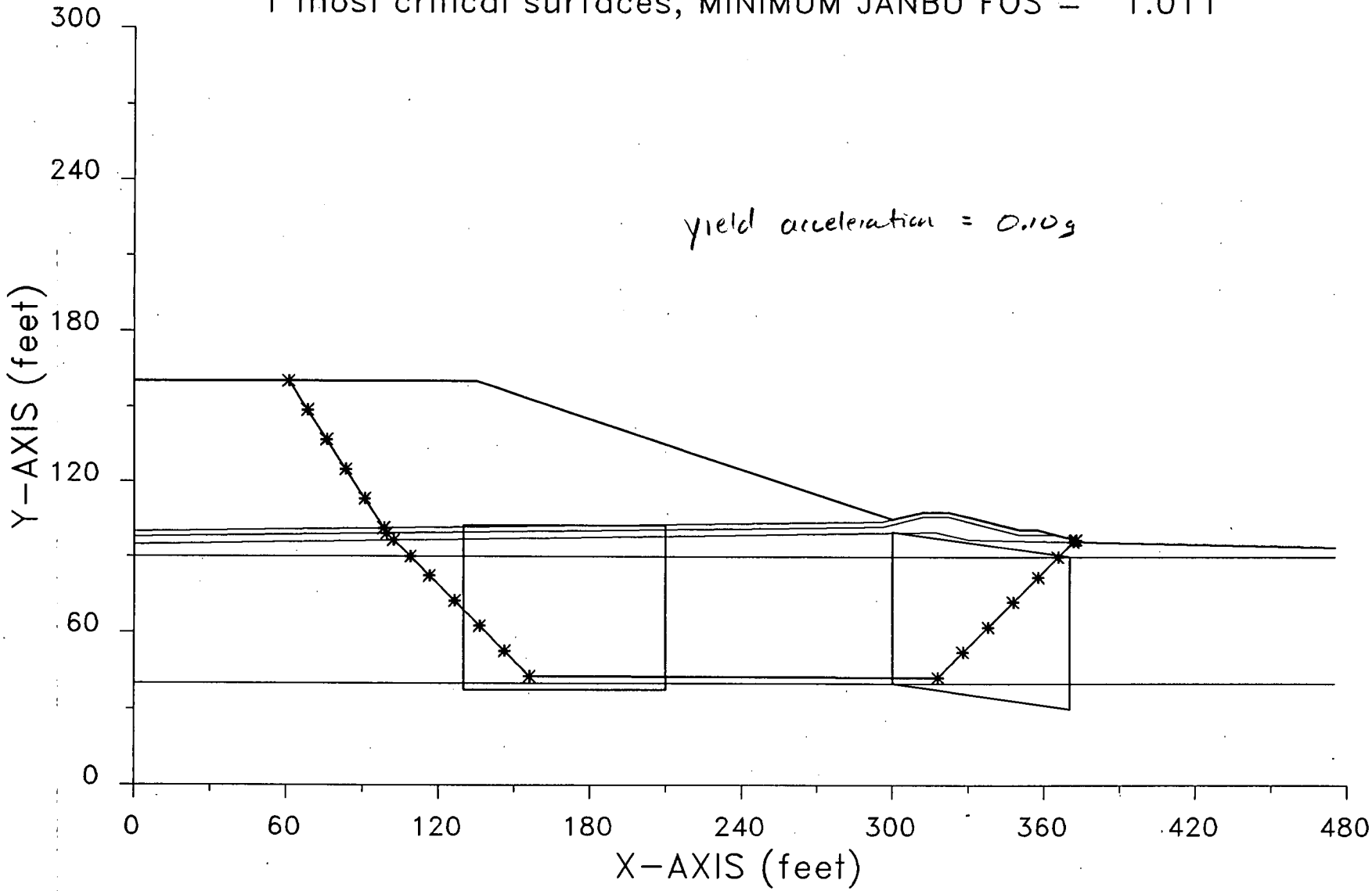
XSTABL OUTPUT FILES

FERMCO/INTERMED. CONFIG./SHORT TERM

1 most critical surfaces, MINIMUM JANBU FOS = 1.011



M. Gleason 95/10/16

F-186 95/10/16

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XSTABL File: STWR1Y 10-16-95 15:42

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*               using the               *
*            Method of Slices           *
*                                       *
*         Copyright (C) 1992 á 94       *
*   Interactive Software Designs, Inc.  *
*        Moscow, ID 83843, U.S.A.       *
*                                       *
*          All Rights Reserved          *
*                                       *
*  Ver. 5.100                95 á 1305  *
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Problem Description : FERMCO/INTERMED. CONFIG./SHORT TERM

SEGMENT BOUNDARY COORDINATES
---

8 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	160.0	135.0	160.0	1
2	135.0	160.0	300.0	105.0	1
3	300.0	105.0	312.0	108.0	2
4	312.0	108.0	322.0	108.0	2
5	322.0	108.0	350.0	101.0	2
6	350.0	101.0	357.0	101.0	2
7	357.0	101.0	376.0	96.0	2
8	376.0	96.0	475.0	94.0	4

14 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	100.0	296.0	104.0	2
2	296.0	104.0	300.0	105.0	2
3	.0	98.0	296.0	102.0	3
4	296.0	102.0	312.0	106.0	3
5	312.0	106.0	322.0	106.0	3
6	322.0	106.0	350.0	99.0	3
7	350.0	99.0	365.0	99.0	3
8	365.0	99.0	374.0	96.0	3
9	.0	95.0	317.0	100.0	4
10	317.0	100.0	330.0	97.0	4
11	330.0	97.0	374.0	96.0	4

000825

M. Gleason 95/10/10

12	374.0	96.0	376.0	96.0	4
13	.0	90.0	475.0	90.0	5
14	.0	40.0	475.0	40.0	6

14/77 (15) 95/10/10

ISOTROPIC Soil Parameters
---

6 Soil unit(s) specified

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	125.0	125.0	200.0	25.00	.000	.0	0
2	125.0	125.0	.0	30.00	.000	.0	0
3	130.0	130.0	1200.0	.00	.000	.0	0
4	135.0	135.0	1200.0	.00	.000	.0	0
5	145.0	145.0	1900.0	.00	.000	.0	0
6	135.0	135.0	.0	35.00	.000	.0	0

A horizontal earthquake loading coefficient
of .100 has been assigned

A vertical earthquake loading coefficient
of .000 has been assigned

A critical failure surface searching method, using a random technique for generating sliding BLOCK surfaces, has been specified.

The active and passive portions of the sliding surfaces are generated according to the Rankine theory.

500 trial surfaces will be generated and analyzed.

2 boxes specified for generation of central block base

* * * * * DEFAULT SEGMENT LENGTH SELECTED BY XSTABL * * * * *

Length of line segments for active and passive portions of sliding block is 14.0 ft

Box no.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Width (ft)
1	300.0	70.0	370.0	60.0	60.0
2	130.0	70.0	210.0	70.0	65.0

M. Gleason 95/10/16 186 15/77 95/10/16

****
ERROR # 39
****
The program calculated a point for the ACTIVE wedge that is outside the defined slope geometry. The analysis will continue, but the user should adjust the search box or slope geometry to allow an active wedge to be formed from all points within last box.
****

Factors of safety have been calculated by the :

* * * * * SIMPLIFIED JANBU METHOD * * * * *

The 1 most critical of all the failure surfaces examined are displayed below - the most critical first

Failure surface No. 1 specified by 23 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	372.41	96.95
2	371.95	96.68
3	371.33	96.06
4	365.27	90.00
5	357.34	82.07
6	347.44	72.18
7	337.54	62.28
8	327.64	52.38
9	317.74	42.48
10	156.23	42.82
11	146.33	52.72
12	136.43	62.62
13	126.53	72.52
14	116.63	82.42
15	109.05	90.00
16	102.43	96.62
17	99.70	99.35
18	98.55	101.33
19	91.03	113.14
20	83.51	124.95
21	75.99	136.75
22	68.47	148.56
23	61.18	160.00

** Corrected JANBU FOS = 1.011 ** (Fo factor =1.087)

The following is a summary of the TEN most critical surfaces

Problem Description : FERMCO/INTERMED. CONFIG./SHORT TERM

M. Gleason 95/10/16

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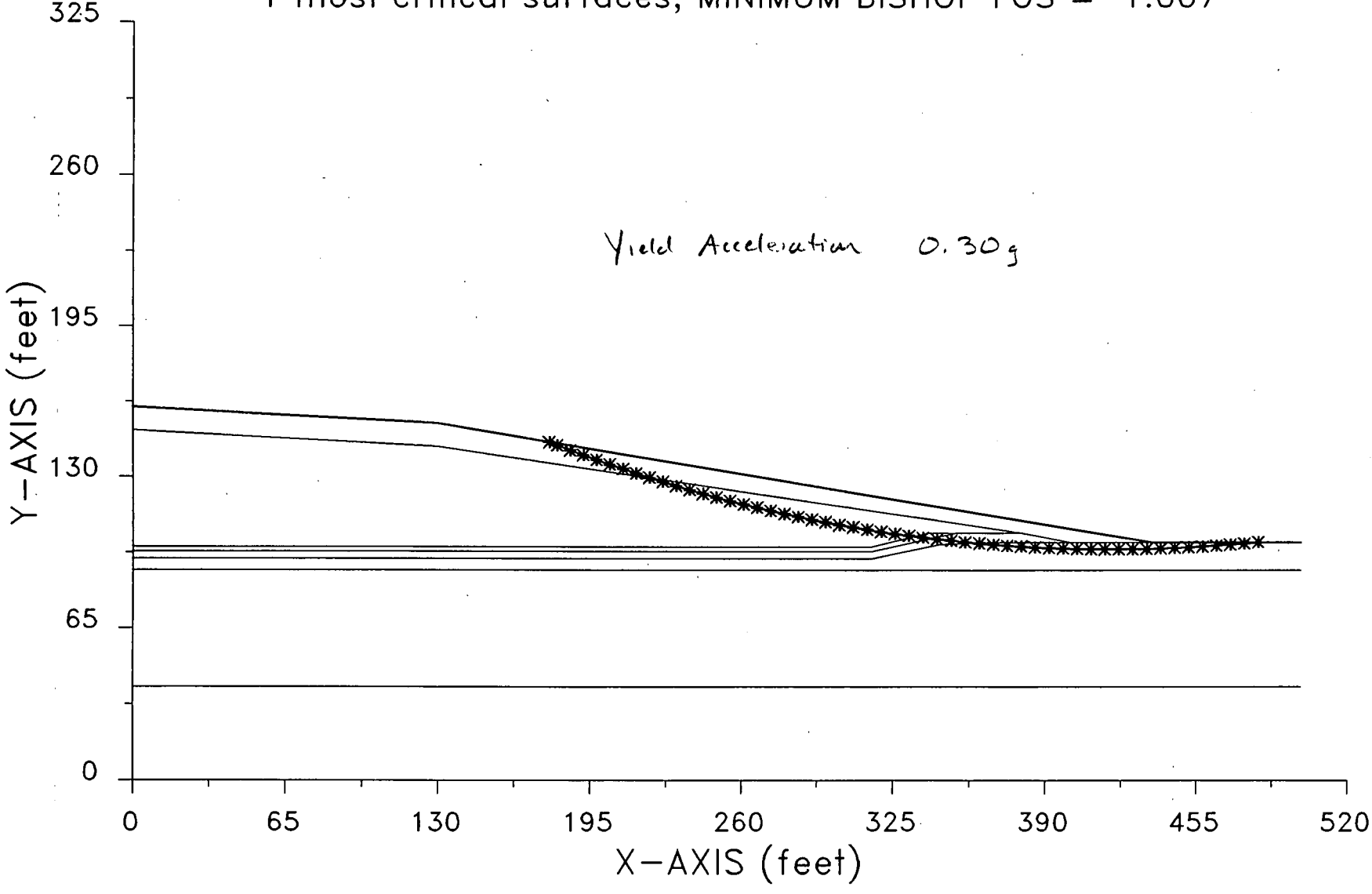
	Modified JANBU FOS	Correction Factor	Initial x-coord (ft)	Terminal x-coord (ft)	Available Strength (lb)
1.	1.011	1.087	372.41	61.18	6.677E+05
2.	1.015	1.086	372.76	48.10	6.923E+05
3.	1.020	1.084	404.69	61.32	7.280E+05
4.	1.023	1.084	418.50	65.74	7.482E+05
5.	1.024	1.085	403.03	62.00	7.216E+05
6.	1.032	1.085	376.78	39.48	7.127E+05
7.	1.033	1.085	415.79	78.57	7.182E+05
8.	1.035	1.087	365.22	33.63	7.044E+05
9.	1.041	1.084	410.02	40.64	7.735E+05
10.	1.041	1.086	395.76	63.80	6.989E+05

* * * END OF FILE * * *

10-16-95 15:51

FERMCO/ FINAL CONFIG./ DRAINED

1 most critical surfaces, MINIMUM BISHOP FOS = 1.007



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M. Gleason 95/10/16

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95/12/16

XSTABL File: FCY 10-11-95 9:30

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*              X S T A B L              *
*                                       *
*        Slope Stability Analysis       *
*              using the                *
*            Method of Slices           *
*                                       *
*         Copyright (C) 1992 á 94       *
*   Interactive Software Designs, Inc.  *
*        Moscow, ID 83843, U.S.A.       *
*                                       *
*          All Rights Reserved          *
*                                       *
*  Ver. 5.100                95 á 1305  *
*****************************************
```

Problem Description : FREMCO/ FINAL CONFIG./ DRAINED

SEGMENT BOUNDARY COORDINATES
---

3 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	160.0	130.0	153.0	7
2	130.0	153.0	436.0	102.0	7
3	436.0	102.0	500.0	102.0	4

17 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	150.0	130.0	143.0	1
2	130.0	143.0	380.0	106.0	1
3	.0	100.0	316.0	100.0	2
4	316.0	100.0	340.0	106.0	2
5	340.0	106.0	352.0	106.0	2
6	.0	98.0	316.0	98.0	3
7	316.0	98.0	352.0	106.0	3
8	352.0	106.0	380.0	106.0	3
9	380.0	106.0	401.0	102.0	3
10	.0	95.0	316.0	95.0	4
11	316.0	95.0	345.0	101.0	4
12	345.0	101.0	364.0	102.0	4
13	364.0	102.0	401.0	102.0	4
14	401.0	102.0	436.0	102.0	4
15	436.0	102.0	500.0	102.0	4
16	.0	90.0	500.0	90.0	5

000830

17 .0 40.0 500.0 40.0 6 95/10/16 19/77

M. Gleason 95/10/16

ISOTROPIC Soil Parameters
---

7 Soil unit(s) specified

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	125.0	125.0	.0	25.00	.000	.0	0
2	125.0	125.0	.0	30.00	.000	.0	0
3	130.0	130.0	.0	25.00	.000	.0	0
4	135.0	135.0	.0	25.00	.000	.0	0
5	145.0	145.0	.0	30.00	.000	.0	0
6	135.0	135.0	.0	35.00	.000	.0	0
7	125.0	125.0	.0	30.00	.000	.0	0

A horizontal earthquake loading coefficient
of .300 has been assigned

A vertical earthquake loading coefficient
of .000 has been assigned

A critical failure surface searching method, using a random technique for generating CIRCULAR surfaces has been specified.

200 trial surfaces will be generated and analyzed.

10 Surfaces initiate from each of 20 points equally spaced along the ground surface between x = 450.0 ft
and x = 500.0 ft

Each surface terminates between x = 10.0 ft
and x = 350.0 ft

Unless further limitations were imposed, the minimum elevation at which a surface extends is y = .0 ft

* * * * * DEFAULT SEGMENT LENGTH SELECTED BY XSTABL * * * * *

6.0 ft line segments define each trial failure surface.

ANGULAR RESTRICTIONS :

The first segment of each failure surface will be inclined within the angular range defined by :

Lower angular limit := -20.0 degrees
Upper angular limit := (slope angle - 5.0) degrees

M. Gleason
95/10/16

Factors of safety have been calculated by the :

* * * * * SIMPLIFIED BISHOP METHOD * * * * *

The most critical circular failure surface is specified by 53 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	481.58	102.00
2	475.60	101.46
3	469.62	100.97
4	463.64	100.53
5	457.65	100.15
6	451.66	99.83
7	445.67	99.56
8	439.67	99.34
9	433.67	99.18
10	427.67	99.07
11	421.67	99.02
12	415.67	99.03
13	409.67	99.09
14	403.67	99.20
15	397.68	99.37
16	391.68	99.59
17	385.69	99.87
18	379.70	100.20
19	373.71	100.59
20	367.73	101.04
21	361.75	101.53
22	355.77	102.09
23	349.80	102.69
24	343.84	103.35
25	337.88	104.07
26	331.93	104.84
27	325.99	105.67
28	320.05	106.55
29	314.13	107.48
30	308.21	108.47
31	302.30	109.51
32	296.40	110.61
33	290.51	111.76
34	284.63	112.96
35	278.77	114.22
36	272.91	115.53
37	267.07	116.89
38	261.24	118.31

M. Gleason 95/10/16

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95/10/16

39	255.42	119.78
40	249.62	121.31
41	243.83	122.88
42	238.06	124.51
43	232.30	126.20
44	226.55	127.93
45	220.83	129.72
46	215.12	131.56
47	209.42	133.46
48	203.75	135.40
49	198.09	137.40
50	192.45	139.45
51	186.83	141.55
52	181.23	143.70
53	177.87	145.02

**** Simplified BISHOP FOS = 1.007 ****

The following is a summary of the TEN most critical surfaces

Problem Description : FREMCO/ FINAL CONFIG./ DRAINED

	FOS (BISHOP)	Circle Center x-coord (ft)	Circle Center y-coord (ft)	Radius (ft)	Initial x-coord (ft)	Terminal x-coord (ft)	Resisting Moment (ft-lb)
1.	1.007	419.12	754.67	655.66	481.58	177.87	1.028E+08
2.	1.008	394.57	890.02	793.40	486.84	96.33	2.596E+08
3.	1.008	395.40	576.61	478.71	457.89	194.00	8.051E+07
4.	1.009	377.23	710.22	613.90	460.53	118.26	1.863E+08
5.	1.009	400.10	554.86	456.53	457.89	210.46	6.563E+07
6.	1.010	394.15	569.79	472.47	460.53	192.28	8.397E+07
7.	1.011	402.66	899.65	803.56	500.00	101.81	2.575E+08
8.	1.012	418.19	505.16	405.66	463.16	261.14	3.222E+07
9.	1.013	421.16	409.49	309.37	455.26	300.68	1.474E+07
10.	1.014	425.04	505.27	405.60	468.42	273.37	2.689E+07

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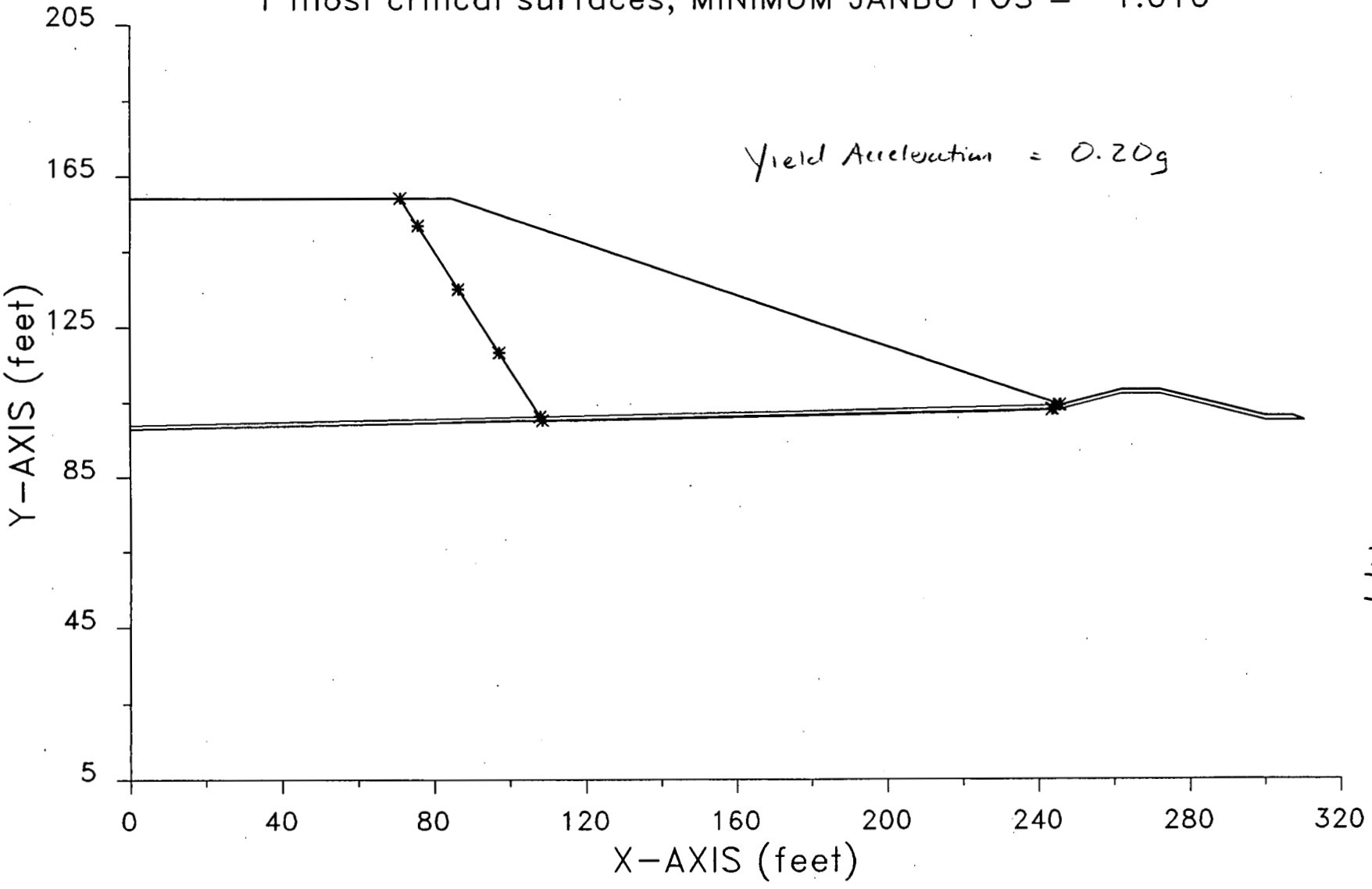
SHORT-TERM HYDRATED GCL STRENGTHS

1 most critical surfaces, MINIMUM JANBU FOS = 1.010



M. Blossom
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M. Gleason 95/10/14

555 23/77 95/10/16

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*****************************************
*              X S T A B L              *
*                                       *
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*               using the               *
*            Method of Slices           *
*                                       *
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*****************************************
```

Problem Description : SHORT-TERM HYDRATED GCL STRENGTHS

SEGMENT BOUNDARY COORDINATES
---

8 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	159.0	85.0	159.0	1
2	85.0	159.0	246.0	104.0	1
3	246.0	104.0	262.0	108.0	2
4	262.0	108.0	272.0	108.0	2
5	272.0	108.0	300.0	101.0	2
6	300.0	101.0	307.0	101.0	2
7	307.0	101.0	310.0	100.0	2
8	310.0	100.0	310.3	99.9	6

14 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	99.0	246.0	104.0	2
2	.0	98.0	85.0	99.7	3
3	85.0	99.7	170.0	101.4	4
4	170.0	101.4	246.0	103.0	5
5	246.0	103.0	250.0	104.0	5
6	250.0	104.0	262.0	107.0	6
7	262.0	107.0	272.0	107.0	6
8	272.0	107.0	300.0	100.0	6
9	300.0	100.0	310.0	100.0	6
10	.0	97.9	246.0	102.9	7
11	246.0	102.9	262.0	106.9	7

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12	262.0	106.9	272.0	106.9	7
13	272.0	106.9	300.0	99.9	7
14	300.0	99.9	310.3	99.9	7

SSS 24/77
95/10/16

ISOTROPIC Soil Parameters

M. Gleason
95/10/16

7 Soil unit(s) specified

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	125.0	125.0	200.0	25.00	.000	.0	0
2	125.0	125.0	.0	30.00	.000	.0	0
3	125.0	125.0	.0	15.00	.000	.0	0
4	125.0	125.0	.0	17.00	.000	.0	0
5	125.0	125.0	.0	23.00	.000	.0	0
6	125.0	125.0	.0	30.00	.000	.0	0
7	130.0	130.0	.0	25.00	.000	.0	0

A horizontal earthquake loading coefficient
of .200 has been assigned

A vertical earthquake loading coefficient
of .000 has been assigned

A critical failure surface searching method, using a random technique for generating sliding BLOCK surfaces, has been specified.

The active and passive portions of the sliding surfaces are generated according to the Rankine theory.

500 trial surfaces will be generated and analyzed.

2 boxes specified for generation of central block base

Length of line segments for active and passive portions of sliding block is 20.0 ft

Box no.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Width (ft)
1	226.0	102.5	246.0	102.9	.0
2	85.0	99.7	225.9	102.5	.0

E-180

Factors of safety have been calculated by the :

.155 25/77
95/10/16

* * * * * SIMPLIFIED JANBU METHOD * * * * *

M. Blaser
95/10/16

The 1 most critical of all the failure surfaces examined are displayed below - the most critical first

Failure surface No. 1 specified by 11 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	245.66	104.12
2	245.46	103.99
3	243.67	102.95
4	243.51	102.85
5	108.76	100.17
6	108.76	100.18
7	108.16	101.20
8	97.42	118.07
9	86.67	134.93
10	75.93	151.80
11	71.34	159.00

** Corrected JANBU FOS = 1.010 ** (Fo factor =1.081)

The following is a summary of the TEN most critical surfaces

Problem Description : SHORT-TERM HYDRATED GCL STRENGTHS

	Modified JANBU FOS	Correction Factor	Initial x-coord (ft)	Terminal x-coord (ft)	Available Strength (lb)
1.	1.010	1.081	245.66	71.34	2.229E+05
2.	1.011	1.080	245.95	68.22	2.305E+05
3.	1.012	1.081	245.39	75.44	2.128E+05
4.	1.012	1.081	245.02	74.88	2.143E+05
5.	1.013	1.081	244.59	71.37	2.231E+05
6.	1.013	1.080	245.94	65.99	2.360E+05
7.	1.013	1.081	245.98	78.38	2.054E+05
8.	1.015	1.081	243.75	70.05	2.265E+05
9.	1.015	1.081	244.58	77.33	2.083E+05
10.	1.015	1.081	243.46	69.69	2.275E+05

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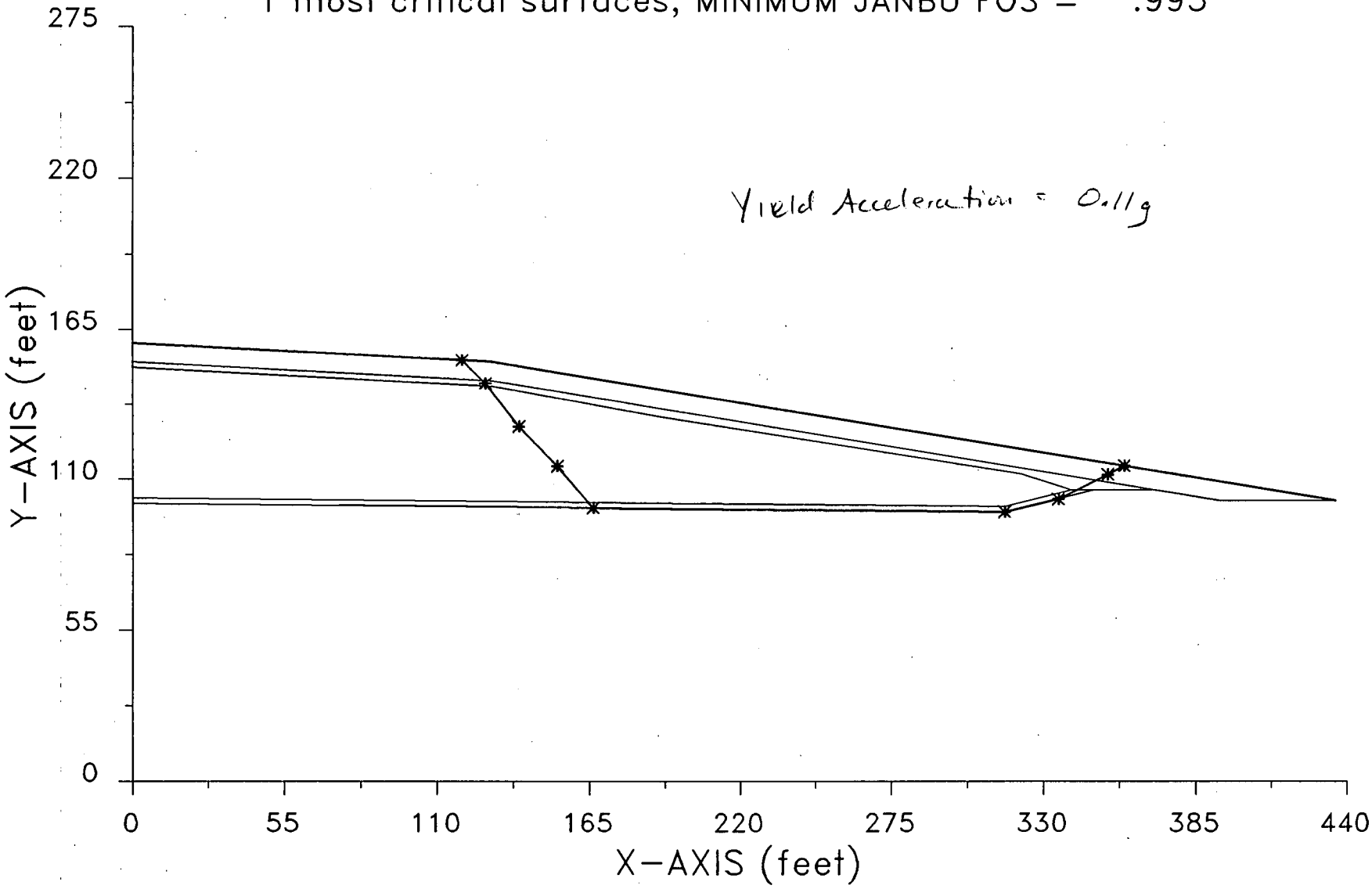
FINAL CONFIGURATION – PEAK STRENGTHS

1 most critical surfaces, MINIMUM JANBU FOS = .995



M. Gleason 9/10/96

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M. Gleason 95/10/16

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*****************************************
```

Problem Description : FINAL CONFIGURATION - PEAK STRENGTHS

SEGMENT BOUNDARY COORDINATES
---

2 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	160.0	130.0	153.0	6
2	130.0	153.0	436.0	102.0	6

18 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	153.0	130.0	146.0	7
2	130.0	146.0	370.0	106.0	7
3	370.0	106.0	394.0	102.0	7
4	394.0	102.0	436.0	102.0	7
5	.0	151.0	130.0	144.0	1
6	130.0	144.0	190.0	133.0	1
7	190.0	133.0	322.0	112.0	1
8	322.0	112.0	340.0	106.0	1
9	340.0	106.0	348.0	106.0	2
10	348.0	106.0	348.4	106.0	5
11	348.4	106.0	370.0	106.0	7
12	.0	103.2	316.0	100.0	2
13	316.0	100.0	340.0	106.0	2
14	.0	101.2	130.0	99.9	3
15	130.0	99.9	316.0	98.0	4
16	316.0	98.0	348.0	106.0	5
17	.0	101.1	316.0	97.9	7

18	316.0	97.9	348.4	106.0	7

M. Gleason 95/10/16

ISOTROPIC Soil Parameters
---

7 Soil unit(s) specified

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	125.0	125.0	.0	25.00	.000	.0	0
2	125.0	125.0	.0	30.00	.000	.0	0
3	125.0	125.0	.0	8.00	.000	.0	0
4	125.0	125.0	.0	8.00	.000	.0	0
5	125.0	125.0	.0	10.00	.000	.0	0
6	125.0	125.0	.0	30.00	.000	.0	0
7	130.0	130.0	.0	25.00	.000	.0	0

A horizontal earthquake loading coefficient
of .110 has been assigned

A vertical earthquake loading coefficient
of .000 has been assigned

A critical failure surface searching method, using a random technique for generating sliding BLOCK surfaces, has been specified.

300 trial surfaces will be generated and analyzed.

2 boxes specified for generation of central block base

Length of line segments for active and passive portions of sliding block is 20.0 ft

Box no.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Width (ft)
1	316.0	98.0	316.0	98.0	.0
2	75.0	100.4	315.9	97.9	.0

```
*************************************************************
**     Factor of safety calculation for surface #     4    **
**     failed to converge within FIFTY iterations          **
**                                                         **
**    The last calculated value of the FOS was   -2.069    **
**    This will be ignored for final summary of results    **
*************************************************************
```

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M. Gleason
95/10/16

The trial failure surface in question is
defined by the following 7 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	359.56	114.74
2	350.24	112.92
3	330.26	112.03
4	316.00	98.00
5	313.67	97.92
6	305.85	116.33
7	297.64	125.06

```
*************************************************************
**     Factor of safety calculation for surface #    18    **
**     failed to converge within FIFTY iterations          **
**                                                         **
**    The last calculated value of the FOS was   -1.888    **
**    This will be ignored for final summary of results    **
*************************************************************
```

The trial failure surface in question is
defined by the following 6 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	338.85	118.19
2	330.24	112.05
3	316.00	98.00
4	315.23	97.91
5	306.15	115.73
6	304.33	123.94

```
*************************************************************
**     Factor of safety calculation for surface #    34    **
**     failed to converge within FIFTY iterations          **
**                                                         **
**    The last calculated value of the FOS was   -2.331    **
**    This will be ignored for final summary of results    **
*************************************************************
```

The trial failure surface in question is
defined by the following 6 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	343.97	117.34
2	333.42	107.82
3	316.00	98.00
4	309.74	97.96
5	303.44	116.95
6	302.00	124.33

```
*************************************************************
**     Factor of safety calculation for surface #    68    **
**     failed to converge within FIFTY iterations          **
**                                                         **
**    The last calculated value of the FOS was   -2.219    **
**    This will be ignored for final summary of results    **
*************************************************************
```

(S) 30/77 95/10/16

The trial failure surface in question is
defined by the following 6 coordinate points

M. Gleason 95/10/16

Point No.	x-surf (ft)	y-surf (ft)
1	341.98	117.67
2	332.87	108.75
3	316.00	98.00
4	286.22	98.21
5	286.00	118.21
6	276.49	128.59

```
*************************************************************
**     Factor of safety calculation for surface #    88    **
**     failed to converge within FIFTY iterations          **
**                                                         **
**    The last calculated value of the FOS was   -1.691    **
**    This will be ignored for final summary of results    **
*************************************************************
```

The trial failure surface in question is
defined by the following 6 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	339.79	118.04
2	331.67	110.43
3	316.00	98.00
4	313.48	97.93
5	311.31	117.81
6	311.00	122.83

```
*************************************************************
**     Factor of safety calculation for surface #   121    **
**     failed to converge within FIFTY iterations          **
**                                                         **
**    The last calculated value of the FOS was   -1.652    **
**    This will be ignored for final summary of results    **
*************************************************************
```

The trial failure surface in question is
defined by the following 6 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	340.22	117.96
2	330.28	112.01

M. Gleason 95/10/16

95/10/16

3	316.00	98.00
4	290.13	98.17
5	287.10	117.94
6	278.77	128.20

```
*************************************************************
**     Factor of safety calculation for surface #   225    **
**     failed to converge within FIFTY iterations          **
**                                                         **
**    The last calculated value of the FOS was   -3.077    **
**    This will be ignored for final summary of results    **
*************************************************************
```

The trial failure surface in question is
defined by the following 6 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	345.32	117.11
2	330.75	111.51
3	316.00	98.00
4	311.72	97.94
5	299.52	113.79
6	299.52	124.75

```
*************************************************************
**     Factor of safety calculation for surface #   240    **
**     failed to converge within FIFTY iterations          **
**                                                         **
**    The last calculated value of the FOS was   -1.363    **
**    This will be ignored for final summary of results    **
*************************************************************
```

The trial failure surface in question is
defined by the following 6 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	346.09	116.98
2	331.80	110.26
3	316.00	98.00
4	312.14	97.94
5	309.20	117.72
6	304.02	124.00

```
*************************************************************
**     Factor of safety calculation for surface #   292    **
**     failed to converge within FIFTY iterations          **
**                                                         **
**    The last calculated value of the FOS was   -2.619    **
**    This will be ignored for final summary of results    **
*************************************************************
```

The trial failure surface in question is
defined by the following 6 coordinate points

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Point No.	x-surf (ft)	y-surf (ft)
1	340.46	117.92
2	331.39	110.77
3	316.00	98.00
4	309.92	97.96
5	300.50	115.61
6	297.19	125.14

Factors of safety have been calculated by the :

* * * * * SIMPLIFIED JANBU METHOD * * * * *

The 1 most critical of all the failure surfaces examined are displayed below - the most critical first

Failure surface No. 1 specified by 9 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	359.30	114.78
2	353.34	111.61
3	335.44	102.69
4	316.00	98.00
5	166.65	99.45
6	153.73	114.72
7	139.94	129.20
8	127.74	145.05
9	119.29	153.58

** Corrected JANBU FOS = .995 ** (Fo factor =1.043)

```
*********************************************************************
**                                                                 **
** Out of the    300 surfaces generated and analyzed by XSTABL,    **
**        9 surfaces were found to have MISLEADING FOS values.     **
**                                                                 **
*********************************************************************
```

The following is a summary of the TEN most critical surfaces

Problem Description : FINAL CONFIGURATION - PEAK STRENGTHS

Modified JANBU FOS	Correction Factor	Initial x-coord (ft)	Terminal x-coord (ft)	Available Strength (lb)

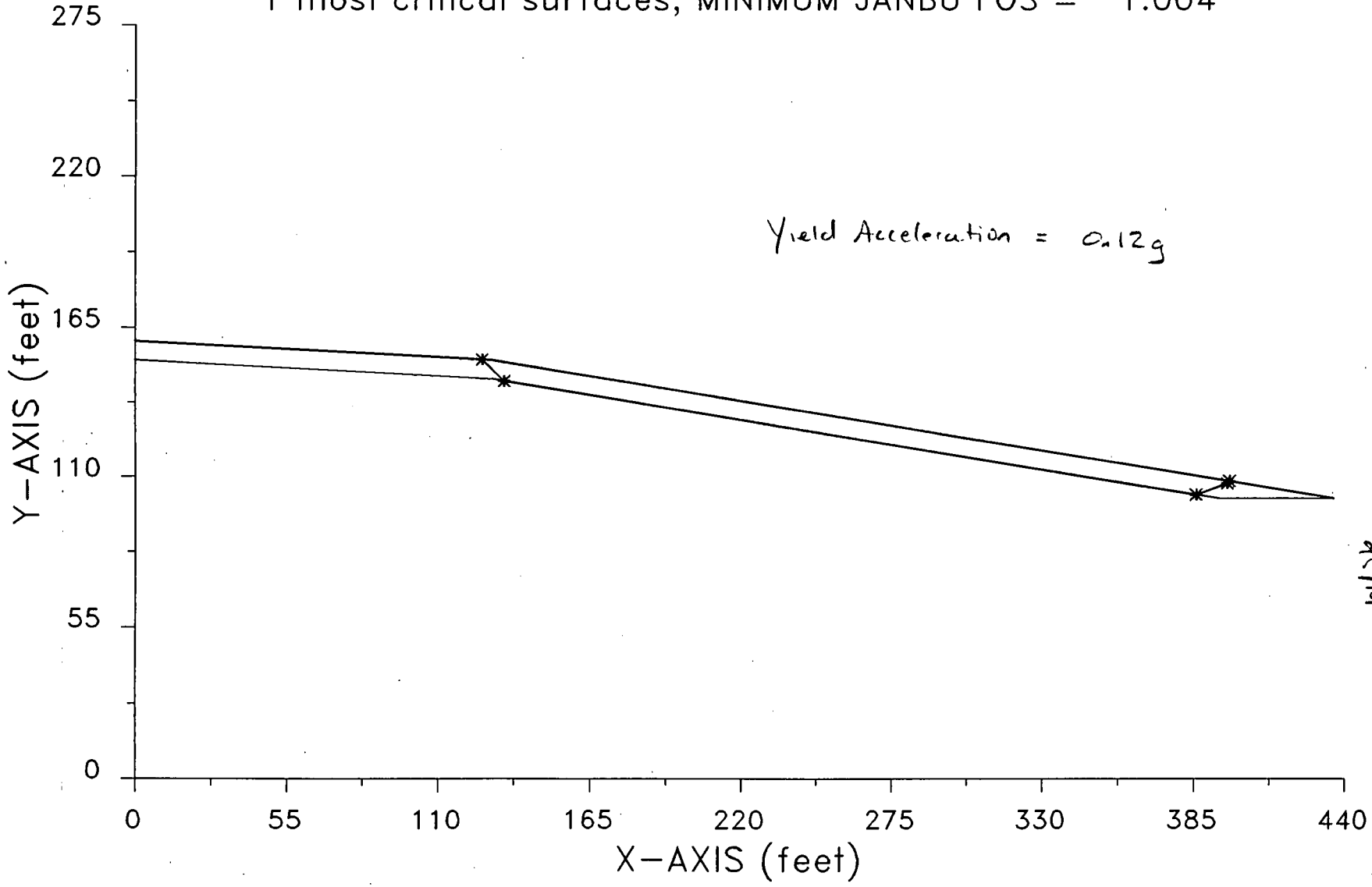
1.	.995	1.043	359.30	119.29	1.953E+05
2.	1.032	1.037	380.41	47.10	3.053E+05
3.	1.034	1.039	380.61	80.00	2.697E+05
4.	1.040	1.039	359.65	45.00	2.811E+05
5.	1.048	1.042	352.80	86.94	2.450E+05
6.	1.051	1.040	349.47	53.13	2.708E+05
7.	1.052	1.042	352.19	77.48	2.418E+05
8.	1.055	1.041	382.60	109.91	2.405E+05
9.	1.057	1.037	384.63	50.24	2.863E+05
10.	1.057	1.041	347.82	48.62	2.784E+05

* * * END OF FILE * * *

M. Gleason
95/10/16

FINAL COVER VENER STABILTY – STATIC

1 most critical surfaces, MINIMUM JANBU FOS = 1.004



M. Gleason
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*****************************************
*                X S T A B L            *
*                                       *
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*                using the              *
*             Method of Slices          *
*                                       *
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M. Gleason 95/10/16

Problem Description : FINAL COVER VENER STABILTY - STATIC

SEGMENT BOUNDARY COORDINATES
---

2 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	160.0	130.0	153.0	1
2	130.0	153.0	436.0	102.0	1

3 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	153.0	130.0	146.0	2
2	130.0	146.0	394.0	102.0	2
3	394.0	102.0	436.0	102.0	2

ISOTROPIC Soil Parameters
---

2 Soil unit(s) specified

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	125.0	125.0	.0	30.00	.000	.0	1
2	125.0	125.0	.0	15.00	.000	.0	1

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A horizontal earthquake loading coefficient of .120 has been assigned

A vertical earthquake loading coefficient of .000 has been assigned

M. Gleason
95/10/16

A critical failure surface searching method, using a random technique for generating sliding BLOCK surfaces, has been specified.

200 trial surfaces will be generated and analyzed.

2 boxes specified for generation of central block base

* * * * * DEFAULT SEGMENT LENGTH SELECTED BY XSTABL * * * * *

Length of line segments for active and passive portions of sliding block is 12.0 ft

Box no.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Width (ft)
1	300.0	117.6	394.0	102.0	.0
2	130.0	146.0	200.0	134.3	.0

Factors of safety have been calculated by the :

* * * * * SIMPLIFIED JANBU METHOD * * * * *

The 5 most critical of all the failure surfaces examined are displayed below - the most critical first

Failure surface No. 1 specified by 5 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	397.94	108.34
2	397.08	107.51
3	385.82	103.36
4	134.26	145.29
5	126.39	153.19

** Corrected JANBU FOS = 1.004 ** (Fo factor =1.007)

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Failure surface No. 2 specified by 5 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	400.81	107.87
2	399.02	106.88
3	387.65	103.05
4	147.72	143.04
5	139.31	151.45

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** Corrected JANBU FOS = 1.007 ** (Fo factor =1.008)

Failure surface No. 3 specified by 5 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	406.05	106.99
2	403.89	104.85
3	392.16	102.30
4	142.46	143.92
5	135.64	152.06

** Corrected JANBU FOS = 1.011 ** (Fo factor =1.008)

Failure surface No. 4 specified by 4 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	389.21	109.80
2	379.54	104.40
3	135.20	145.13
4	127.96	153.11

** Corrected JANBU FOS = 1.011 ** (Fo factor =1.008)

Failure surface No. 5 specified by 5 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	376.35	111.94
2	373.12	110.84
3	361.63	107.37
4	139.06	144.48
5	132.21	152.63

** Corrected JANBU FOS = 1.013 ** (Fo factor =1.008)

The following is a summary of the TEN most critical surfaces

Problem Description : FINAL COVER VENER STABILTY - STATIC

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	Modified JANBU FOS	Correction Factor	Initial x-coord (ft)	Terminal x-coord (ft)	Available Strength (lb)
1.	1.004	1.007	397.94	126.39	6.359E+04
2.	1.007	1.008	400.81	139.31	6.113E+04
3.	1.011	1.008	406.05	135.64	6.379E+04
4.	1.011	1.008	389.21	127.96	6.148E+04
5.	1.013	1.008	376.35	132.21	5.712E+04
6.	1.014	1.008	402.67	153.08	5.878E+04
7.	1.014	1.008	406.00	158.01	5.846E+04
8.	1.015	1.008	404.83	147.91	5.968E+04
9.	1.016	1.008	381.47	140.24	5.633E+04
10.	1.016	1.008	371.60	126.06	5.786E+04

* * * END OF FILE * * *

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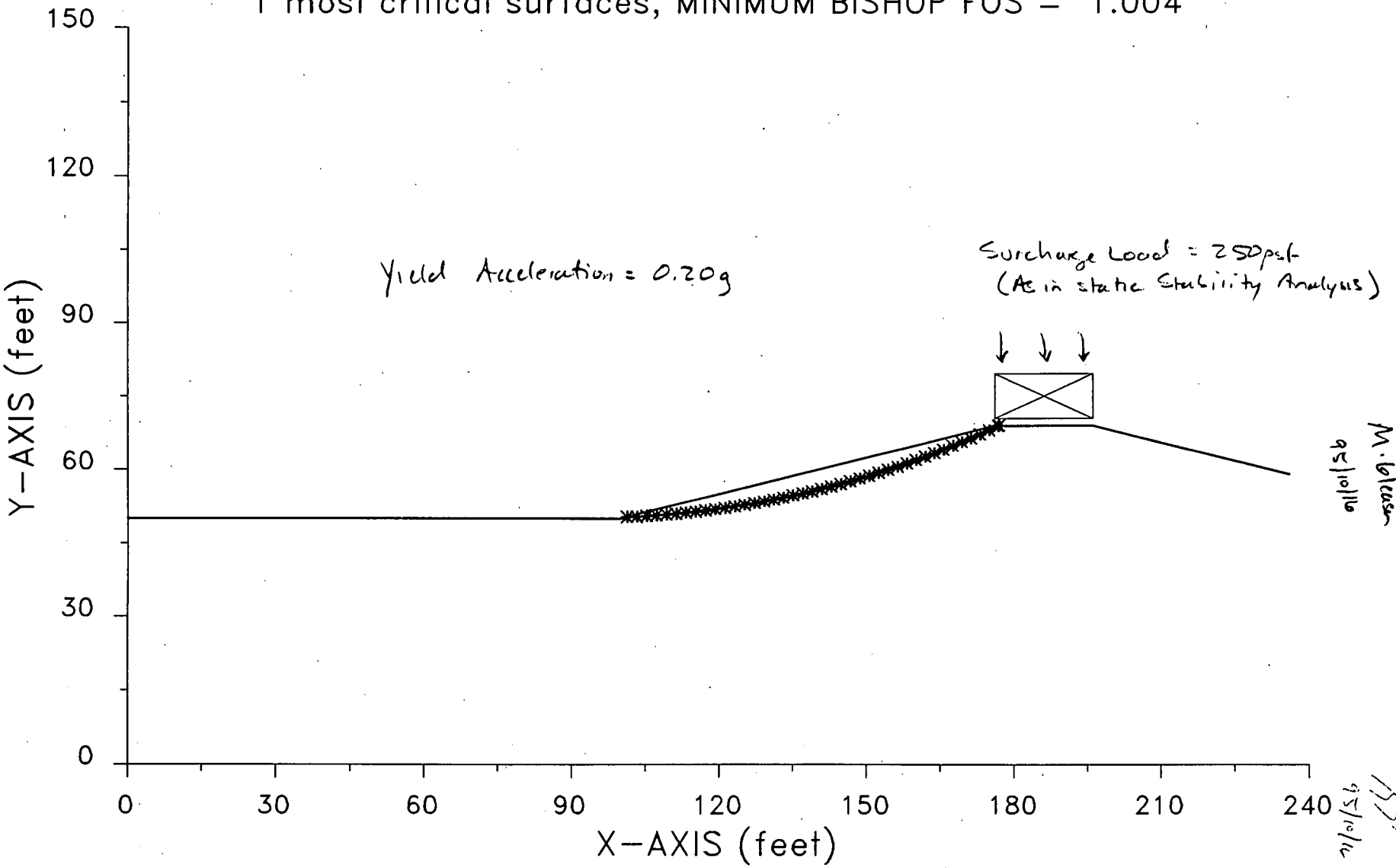
PERIMETER BERM STABILITY – LONG TERM

1 most critical surfaces, MINIMUM BISHOP FOS = 1.004



M. Wilson 9/5/10/16

9/5/10/16

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XSTABL File: BERMY 10-16-95 15:10

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*****************************************
*              X S T A B L              *
*                                       *
*        Slope Stability Analysis       *
*               using the               *
*            Method of Slices           *
*                                       *
*         Copyright (C) 1992 á 94       *
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*                                       *
*  Ver. 5.100                95 á 1305  *
*****************************************
```

Problem Description : PERIMETER BERM STABILITY - LONG TERM

SEGMENT BOUNDARY COORDINATES
---

4 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	50.0	100.0	50.0	1
2	100.0	50.0	176.0	69.0	1
3	176.0	69.0	196.0	69.0	1
4	196.0	69.0	236.0	59.0	1

ISOTROPIC Soil Parameters
---

1 Soil unit(s) specified

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	135.0	135.0	.0	25.00	.000	.0	0

A horizontal earthquake loading coefficient
of .200 has been assigned

A vertical earthquake loading coefficient
of .000 has been assigned

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BOUNDARY LOADS

1 load(s) specified

Load No.	x-left (ft)	x-right (ft)	Intensity (psf)	Direction (deg)
1	176.0	196.0	250.0	.0

NOTE - Intensity is specified as a uniformly distributed force acting on a HORIZONTALLY projected surface.

A critical failure surface searching method, using a random technique for generating CIRCULAR surfaces has been specified.

500 trial surfaces will be generated and analyzed.

10 Surfaces initiate from each of 50 points equally spaced along the ground surface between x = 80.0 ft
and x = 110.0 ft

Each surface terminates between x = 170.0 ft
and x = 200.0 ft

Unless further limitations were imposed, the minimum elevation at which a surface extends is y = .0 ft

* * * * * DEFAULT SEGMENT LENGTH SELECTED BY XSTABL * * * * *

2.0 ft line segments define each trial failure surface.

ANGULAR RESTRICTIONS :

The first segment of each failure surface will be inclined within the angular range defined by :

Lower angular limit := -45.0 degrees
Upper angular limit := (slope angle - 5.0) degrees

Factors of safety have been calculated by the :

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* * * * * SIMPLIFIED BISHOP METHOD * * * * *

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The most critical circular failure surface is specified by 41 coordinate points

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Point No.	x-surf (ft)	y-surf (ft)
1	101.43	50.36
2	103.43	50.45
3	105.42	50.57
4	107.42	50.70
5	109.41	50.86
6	111.40	51.04
7	113.39	51.24
8	115.38	51.45
9	117.37	51.69
10	119.35	51.95
11	121.33	52.23
12	123.31	52.53
13	125.28	52.84
14	127.26	53.18
15	129.22	53.54
16	131.19	53.92
17	133.15	54.32
18	135.10	54.74
19	137.05	55.18
20	139.00	55.64
21	140.94	56.12
22	142.88	56.61
23	144.81	57.13
24	146.74	57.67
25	148.66	58.23
26	150.57	58.80
27	152.48	59.40
28	154.38	60.02
29	156.28	60.65
30	158.17	61.31
31	160.05	61.98
32	161.93	62.67
33	163.80	63.39
34	165.66	64.12
35	167.51	64.87
36	169.36	65.64
37	171.20	66.43
38	173.03	67.23
39	174.85	68.06
40	176.66	68.90
41	176.87	69.00

**** Simplified BISHOP FOS = 1.004 ****

The following is a summary of the TEN most critical surfaces

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Problem Description : PERIMETER BERM STABILITY - LONG TERM

	FOS (BISHOP)	Circle Center x-coord (ft)	Circle Center y-coord (ft)	Radius (ft)	Initial x-coord (ft)	Terminal x-coord (ft)	Resisting Moment (ft-lb)
1.	1.004	93.08	246.11	195.93	101.43	176.87	2.421E+06
2.	1.034	102.00	187.83	138.54	87.96	171.18	2.241E+06
3.	1.036	110.51	174.67	125.32	97.76	177.89	2.844E+06
4.	1.041	108.96	179.22	130.30	92.24	178.46	3.160E+06
5.	1.042	106.44	169.18	120.17	91.02	170.82	2.224E+06
6.	1.044	42.28	506.06	459.10	105.10	182.83	4.439E+06
7.	1.047	108.68	189.38	140.57	90.41	181.26	3.818E+06
8.	1.055	107.72	189.19	140.76	86.73	180.99	3.973E+06
9.	1.056	107.07	204.43	155.69	87.35	183.86	4.554E+06
10.	1.058	90.20	307.73	257.87	100.20	187.69	5.554E+06

* * * END OF FILE * * *

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DEFORMATION ANALYSIS FILES

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FERMCO - OSDF
Seismic Deformation Analysis
Foundation

YSLIP- C Output File

TIME (s)			DEFORMATION (IN)
.000000	.000000	.000000	.000000
5.138869	.000000	.000000	.000000
5.150000	6.380257	.035510	.000052
5.175000	10.253719	.243434	.001345
5.200000	1.718517	.393087	.004653
5.225000	-19.223190	.174279	.007874
5.230072	-25.365296	.000000	.008115
5.230072	.000000	.000000	.008115
6.344942	.000000	.000000	.008115
6.350000	1.360990	.003442	.008117
6.375000	3.347796	.062302	.008400
6.400000	-3.431040	.061261	.009147
6.407003	-6.409766	.000000	.009273
6.407003	.000000	.000000	.009273
9.318106	.000000	.000000	.009273
9.325000	6.723750	.023176	.009294
9.350000	21.582260	.377001	.010959
9.375000	25.076653	.960238	.017468
9.400000	17.948883	1.498057	.029712
9.425000	2.325751	1.751490	.046024
9.450000	-18.899207	1.544322	.062679
9.475000	-42.300485	.779325	.074594
9.489553	-55.399725	.000000	.077114
9.489553	.000000	.000000	.077114
50.975000	.000000	.000000	.077114

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FERMCO - OSDF
Seismic Deformation Analysis
Final/Interim Impacted Materials

YSLIP_C Output File

TIME (s)			DEFORMATION (IN)
.000000	.000000	.000000	.000000
9.348826	.000000	.000000	.000000
9.350000	.637381	.000374	.000000
9.375000	3.829339	.056208	.000213
9.400000	-2.681472	.070556	.000970
9.407187	-6.784200	.000000	.001129
9.407187	.000000	.000000	.001129
50.975000	.000000	.000000	.001129

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FERMCO - OSDF
Seismic Deformation Analysis
Final Cover System

YSLIP_C OUTPUT FILE

TIME (s)			DEFORMATION (IN)
.000000	.000000	.000000	.000000
5.140645	.000000	.000000	.000000
5.150000	9.633136	.045061	.000055
5.175000	17.677656	.386446	.002014
5.200000	3.911492	.656310	.007428
5.225000	-27.310667	.363820	.013088
5.232683	-39.629547	.000000	.013824
5.232683	.000000	.000000	.013824
9.308584	.000000	.000000	.013824
9.325000	17.274693	.141787	.014129
9.350000	22.676986	.641183	.017872
9.375000	17.326034	1.141221	.026753
9.400000	2.898036	1.394022	.039526
9.425000	-19.474762	1.186813	.052685
9.450000	-46.603145	.360839	.060858
9.455978	-53.182988	.000000	.061364
9.455978	.000000	.000000	.061364
50.975000	.000000	.000000	.061364

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YSLIP-IN.XLS

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FERMCO - OSDF GE 3900-9.11
Seismic Deformation Analysis
Calculate theta equivalent to yield acceleration for input to YSLIP-C.

M. Gleason
20-Oct-95

$$a_{yield} = \frac{\tan\phi - \tan\theta}{1 + \tan\phi\tan\theta}$$

Case 1 Critical Interface on Final Cover

interface phi = 15 degrees 0.261799 radians

a-yield = 0.12 g

theta	(radians)	a-yield	
10	0.174533	0.087489	
9	0.15708	0.105104	
8	0.139626	0.122785	
8.2	0.143117	0.119243	
8.15	0.142244	0.120128	theta

PHI from XSTABL critical surface

a yield from XSTABL Analysis

Case 2 Interim/Final Impacted Materials
(Failure Surface Along the Liner System)

Interface phi = 8 degrees 0.139626 radians
a-yield = 0.11 g

theta	(radians)	a-yield	
10	0.174533	-0.03492	
8	0.139626	0	
6	0.10472	0.034921	
4	0.069813	0.069927	
2	0.034907	0.105104	
1.5	0.02618	0.113936	
1.6	0.027925	0.112168	
1.7	0.029671	0.110401	theta

Case 3 Foundation
(Failure Surface Within Subsurface Till)

phi = 25 degrees 0.436332 radians
a-yield = 0.10 g

theta	(radians)	a-yield	
10	0.174533	0.282968	
15	0.261799	0.19116	
20	0.349066	0.097357	
19	0.331613	0.11635	
19.5	0.340339	0.10687	
19.8	0.345575	0.101167	theta

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YSLIP_C INPUT FILE - FOUNDATION CONDITION

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TSS 95-10-20


```
25. 19.0 10000. 10000. 0.
0. 1 1
2040 255 16320 0.025 1
 -0.000009-0.000010-0.000160 0.000177 0.000097-0.000060 0.000210-0.000120
  0.000172-0.000120 0.000020 0.000005-0.000047-0.000070-0.000170-0.000200
 -0.000330-0.000340-0.000110-0.000160-0.000230-0.000320-0.000430-0.000550
 -0.000700-0.000860-0.001030-0.001210-0.001360-0.001480-0.001540-0.001530
 -0.001490-0.001430-0.001360-0.001260-0.001130-0.001020-0.000980-0.001050
 -0.001230-0.001490-0.001850-0.002330-0.002900-0.003510-0.004060-0.004440
 -0.004590-0.004440-0.004000-0.003320-0.002530-0.001730-0.001050-0.000640
  0.000690-0.001210-0.002040-0.002960-0.003770-0.004430-0.004890-0.004970
  0.004510-0.003500-0.002150-0.000000 0.000191 0.000460-0.000320-0.002230
  0.004840-0.007460-0.009500-0.010530-0.010440-0.009360-0.007460-0.004860
 -0.001950 0.000740 0.003120 0.005222 0.007681 0.008510 0.009860 0.010156
  0.011235 0.012369 0.013551 0.014537 0.015012 0.014033 0.014161 0.013116
  0.011760 0.010342 0.009234 0.008825 0.009307 0.010366 0.011339 0.011797
  0.011259 0.009199 0.005820 0.001716-0.002720-0.007240-0.011780-0.016340
 -0.020480-0.023640-0.025600-0.026210-0.025250-0.022600-0.019070-0.015530
 -0.013060-0.011860-0.011630-0.012020-0.012140-0.011140-0.009030-0.006000
 -0.002940-0.000330 0.000366-0.001640-0.006120-0.013100-0.020730-0.028280
 -0.034560-0.037950-0.037360-0.032150-0.021980-0.007100 0.010807 0.028743
  0.042949 0.052392 0.058412 0.061577 0.061026 0.056760 0.051113 0.047259
  0.046760 0.048777 0.051652 0.054767 0.058333 0.061752 0.063270 0.061474
  0.055751 0.045900 0.032747 0.017539 0.001129-0.014830-0.027290-0.034330
 -0.036560-0.035300-0.031780-0.026740-0.019310-0.011460-0.007210-0.006220
 -0.008370-0.013010-0.018740-0.023570-0.026770-0.028770-0.030520-0.032550
 -0.033860-0.033570-0.032510-0.032930-0.036110-0.040540-0.043550-0.043960
 -0.041910-0.037790-0.032020-0.025520-0.019700-0.015510-0.012540-0.009150
 -0.003510 0.006214 0.021202 0.041341 0.063658 0.083625 0.096932 0.108529
  0.092603 0.073156 0.045043 0.014503-0.011610-0.029940-0.041170-0.046530
 -0.045710-0.038910-0.028730-0.019290-0.013240-0.010130-0.008710-0.008830
 -0.010990-0.014860-0.019100-0.022670-0.024660-0.023460-0.017670-0.008120
  0.002491 0.012433 0.021633 0.028973 0.031526 0.027401 0.016222-0.001600
 -0.023960-0.047700-0.069830-0.087290-0.097690-0.099420-0.090940-0.071820
 -0.044040-0.012080 0.019474 0.047672 0.069649 0.086024 0.092271 0.094116
  0.087021 0.077946 0.064009 0.046241 0.026802 0.007611-0.013100-0.033670
 -0.051940-0.065390-0.073390-0.076920-0.077240-0.074490-0.068860-0.061970
 -0.054070-0.042700-0.026220-0.006290 0.013804 0.031400 0.046460 0.059807
  0.066585 0.066544 0.059563 0.048849 0.038022 0.029022 0.021439 0.015199
  0.011862 0.012105 0.015372 0.021730 0.031477 0.043306 0.055120 0.064116
  0.068399 0.067317 0.060159 0.046547 0.028455 0.010090-0.003930-0.010700
 -0.009910-0.003140 0.007792 0.020015 0.032847 0.040363 0.040276 0.031501
  0.016516-0.000160-0.014030-0.022930-0.027200-0.028900-0.029640-0.030070
 -0.030550-0.031200-0.031740-0.031560-0.029490-0.024130-0.015990-0.007520
 -0.000880 0.002915 0.003169-0.000190-0.006220-0.015030-0.028060-0.045230
 -0.063110-0.079590-0.089170-0.093900-0.090080-0.082200-0.066360-0.046710
 -0.027800-0.012040-0.001970 0.002271 0.000682-0.005040-0.011700-0.016700
 -0.018400-0.016250-0.010820-0.002590 0.007650 0.018171 0.027434 0.033077
  0.035751 0.032370 0.024094 0.011431-0.004550-0.020670-0.032350-0.035300
 -0.026040-0.007050 0.017967 0.046743 0.074600 0.097251 0.111049 0.114294
  0.107675 0.093167 0.073457 0.051726 0.030829 0.013533 0.002140-0.003000
 -0.006060-0.006340-0.003540 0.003460 0.011103 0.020045 0.031084 0.040046
  0.049047 0.055759 0.061306 0.064802 0.063550 0.055695 0.041340 0.023563
  0.005903-0.012120-0.032620-0.054710-0.074810-0.089550-0.097390-0.098280
 -0.093450-0.084030-0.070000-0.055070-0.041720-0.031250-0.026230-0.025000
 -0.026190-0.023100-0.015450-0.005160 0.004770 0.013227 0.020013 0.024284
  0.024787 0.021327 0.015116 0.008659 0.004707 0.003055 0.004303 0.008117
  0.011170 0.010747 0.006061-0.001980-0.012270-0.023960-0.034730-0.041010
 -0.041720-0.031770-0.013570 0.007645 0.027066 0.041031 0.050966 0.054050
  0.054044 0.049578 0.043071 0.039350 0.036500 0.035463 0.037564 0.042161
```



```
  0.045435 0.043720 0.036293 0.025401 0.013277 0.000169-0.013960-0.026470
  0.033020-0.032040-0.024790-0.012270 0.004945 0.024961 0.043403 0.055500
  0.058959 0.053922 0.041454 0.022364-0.001790-0.027270-0.049290-0.064820
 -0.073500-0.076200-0.073020-0.063660-0.050140-0.035500-0.021600-0.009020
  0.001652 0.009730 0.014407 0.013762 0.006663-0.005540-0.019930-0.033500
 -0.044500-0.052240-0.057860-0.062440-0.066030-0.068120-0.068190-0.065620
 -0.060320-0.055040-0.047650-0.038410-0.025710-0.011890 0.003359 0.016723
  0.030879 0.044520 0.056950 0.064437 0.065013 0.061404 0.058403 0.051650
  0.043066 0.030906 0.017579 0.002990-0.011880-0.027080-0.042170-0.055260
 -0.064080-0.067490-0.064000-0.055500-0.040720-0.022540-0.002540 0.015656
  0.026682 0.028575 0.023785 0.016230 0.008903 0.003880 0.003550 0.010155
  0.022939 0.037782 0.050354 0.057190 0.055080 0.046075 0.029650 0.010047
 -0.008950-0.024410-0.034880-0.039510-0.037960-0.030990-0.020340-0.008540
  0.002614 0.012844 0.022245 0.028975 0.029863 0.024072 0.013529 0.000567
 -0.013850-0.029510-0.045080-0.057550-0.063360-0.060550-0.049000-0.033450
 -0.014120 0.006375 0.026684 0.045340 0.060540 0.069971 0.072560 0.070159
  0.065770 0.060314 0.052020 0.038985 0.021509 0.002839-0.013150-0.025530
 -0.035940-0.045070-0.051270-0.052440-0.048710-0.043790-0.038090-0.037390
 -0.038210-0.039350-0.040670-0.042030-0.043000-0.042730-0.040130-0.035290
 -0.029960-0.026080-0.024650-0.024840-0.025040-0.024480-0.023270-0.021650
 -0.019280-0.015610-0.011270-0.008060-0.006940-0.006340-0.003450 0.003087
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M. Gleason
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M. Gleason
95/10/20

TSS
95-10-20

FERMCO - OSDF
GE3900-9.11
Layer 8 - Liner and Foundation Accleration
Synthetic - B2-SYN

MAX= 0.11429
MIN= -0.09942

ACCELERATION = Shear Stress / Normal Stress (σ_n) (-)

σ_n = 57 ft × 0.125 kcf = 7.125 ksf

Normal stress calculated at top of layer in question.
Top of Liner 57 ft below cover.

Time	Shear Stress		Accleration	
0	-0.00007		-0.00001	0.00001
0.025	-0.00007		-0.00001	0.00001
0.05	-0.00115		-0.00016	0.00016
0.075	0.00126	0.00018	-0.00018	
0.1	0.00069	0.00010	-0.00010	
0.125	-0.00049		-0.00007	0.00007
0.15	0.00150	0.00021	-0.00021	
0.175	-0.00083		-0.00012	0.00012
0.2	0.00123	0.00017	-0.00017	
0.225	-0.00084		-0.00012	0.00012
0.25	0.00015	0.00002	-0.00002	
0.275	0.00004	0.00000	0.00000	
0.3	-0.00033		-0.00005	0.00005
0.325	-0.00050		-0.00007	0.00007
0.35	-0.00120		-0.00017	0.00017
0.375	-0.00141		-0.00020	0.00020
0.4	-0.00236		-0.00033	0.00033
0.425	-0.00244		-0.00034	0.00034
0.45	-0.00077		-0.00011	0.00011
0.475	-0.00113		-0.00016	0.00016
0.5	-0.00164		-0.00023	0.00023
0.525	-0.00228		-0.00032	0.00032
0.55	-0.00305		-0.00043	0.00043
0.575	-0.00394		-0.00055	0.00055
0.6	-0.00496		-0.00070	0.00070
0.625	-0.00611		-0.00086	0.00086
0.65	-0.00735		-0.00103	0.00103
0.675	-0.00859		-0.00121	0.00121
0.7	-0.00971		-0.00136	0.00136
0.725	-0.01055		-0.00148	0.00148
0.75	-0.01096		-0.00154	0.00154
0.775	-0.01093		-0.00153	0.00153
0.8	-0.01062		-0.00149	0.00149
0.825	-0.01021		-0.00143	0.00143
0.85	-0.00969		-0.00136	0.00136 ← check
0.875	-0.00894		-0.00126	0.00126
0.9	-0.00803		-0.00113	0.00113
0.925	-0.00725		-0.00102	0.00102
0.95	-0.00701		-0.00098	0.00098
0.975	-0.00751		-0.00105	0.00105
1	-0.00873		-0.00123	0.00123
1.025	-0.01061		-0.00149	0.00149
1.05	-0.01318		-0.00185	0.00185
1.075	-0.01657		-0.00233	0.00233
1.1	-0.02068		-0.00290	0.00290
1.125	-0.02504		-0.00351	0.00351
1.15	-0.02893		-0.00406	0.00406
1.175	-0.03166		-0.00444	0.00444
1.2	-0.03269		-0.00459	0.00459
1.225	-0.03164		-0.00444	0.00444
1.25	-0.02849		-0.00400	0.00400

Acc. = -0.00969 / 7.125 = -0.00136 ✓

1.275	-0.02368		-0.00332	0.00332
1.3	-0.01804		-0.00253	0.00253
1.325	-0.01236		-0.00173	0.00173
1.35	-0.00747		-0.00105	0.00105
1.375	-0.00459		-0.00064	0.00064
1.4	-0.00491		-0.00069	0.00069
1.425	-0.00861		-0.00121	0.00121
1.45	-0.01455		-0.00204	0.00204
1.475	-0.02108		-0.00296	0.00296
1.5	-0.02689		-0.00377	0.00377
1.525	-0.03159		-0.00443	0.00443
1.55	-0.03482		-0.00489	0.00489
1.575	-0.03543		-0.00497	0.00497
1.6	-0.03217		-0.00451	0.00451
1.625	-0.02495		-0.00350	0.00350
1.65	-0.01532		-0.00215	0.00215
1.675	-0.00573		-0.00080	0.00080
1.7	0.00136	0.00019	-0.00019	
1.725	0.00333	0.00047	-0.00047	
1.75	-0.00225		-0.00032	0.00032
1.775	-0.01587		-0.00223	0.00223
1.8	-0.03448		-0.00484	0.00484
1.825	-0.05316		-0.00746	0.00746
1.85	-0.06769		-0.00950	0.00950
1.875	-0.07506		-0.01053	0.01053
1.9	-0.07436		-0.01044	0.01044
1.925	-0.06667		-0.00936	0.00936
1.95	-0.05313		-0.00746	0.00746
1.975	-0.03462		-0.00486	0.00486
2	-0.01388		-0.00195	0.00195
2.025	0.00533	0.00075	-0.00075	
2.05	0.02223	0.00312	-0.00312	
2.075	0.03721	0.00522	-0.00522	
2.1	0.05472	0.00768	-0.00768	
2.125	0.06069	0.00852	-0.00852	
2.15	0.06461	0.00907	-0.00907	
2.175	0.07236	0.01016	-0.01016	
2.2	0.08005	0.01123	-0.01123	
2.225	0.08813	0.01237	-0.01237	
2.25	0.09655	0.01355	-0.01355	
2.275	0.10358	0.01454	-0.01454	
2.3	0.10696	0.01501	-0.01501	
2.325	0.10569	0.01483	-0.01483	
2.35	0.10090	0.01416	-0.01416	
2.375	0.09345	0.01312	-0.01312	
2.4	0.08379	0.01176	-0.01176	
2.425	0.07369	0.01034	-0.01034	
2.45	0.06579	0.00923	-0.00923	
2.475	0.06288	0.00883	-0.00883	
2.5	0.06631	0.00931	-0.00931	
2.525	0.07386	0.01037	-0.01037	
2.55	0.08079	0.01134	-0.01134	
2.575	0.08405	0.01180	-0.01180	
2.6	0.08022	0.01126	-0.01126	
2.625	0.06555	0.00920	-0.00920	
2.65	0.04147	0.00582	-0.00582	
2.675	0.01223	0.00172	-0.00172	
2.7	-0.01936		-0.00272	0.00272
2.725	-0.05156		-0.00724	0.00724
2.75	-0.08391		-0.01178	0.01178

55/77

M. Gleason 95/10/20

JSS 95-10-20

2.775	-0.11641		-0.01634	0.01634
2.8	-0.14594		-0.02048	0.02048
2.825	-0.16847		-0.02364	0.02364
2.85	-0.18240		-0.02560	0.02560
2.875	-0.18673		-0.02621	0.02621
2.9	-0.17992		-0.02525	0.02525
2.925	-0.16160		-0.02268	0.02268
2.95	-0.13586		-0.01907	0.01907
2.975	-0.11068		-0.01553	0.01553
3	-0.09308		-0.01306	0.01306
3.025	-0.08453		-0.01186	0.01186
3.05	-0.08289		-0.01163	0.01163
3.075	-0.08563		-0.01202	0.01202
3.1	-0.08652		-0.01214	0.01214
3.125	-0.07934		-0.01114	0.01114
3.15	-0.06431		-0.00903	0.00903
3.175	-0.04332		-0.00608	0.00608
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3.625	0.37329	0.05239	-0.05239	
3.65	0.41619	0.05841	-0.05841	
3.675	0.43874	0.06158	-0.06158	
3.7	0.43481	0.06103	-0.06103	
3.725	0.40447	0.05677	-0.05677	
3.75	0.36418	0.05111	-0.05111	
3.775	0.33672	0.04726	-0.04726	
3.8	0.33322	0.04677	-0.04677	
3.825	0.34754	0.04878	-0.04878	
3.85	0.36802	0.05165	-0.05165	
3.875	0.39021	0.05477	-0.05477	
3.9	0.41562	0.05833	-0.05833	
3.925	0.43999	0.06175	-0.06175	
3.95	0.45080	0.06327	-0.06327	
3.975	0.43800	0.06147	-0.06147	
4	0.39723	0.05575	-0.05575	
4.025	0.32709	0.04591	-0.04591	
4.05	0.23333	0.03275	-0.03275	
4.075	0.12496	0.01754	-0.01754	
4.1	0.00804	0.00113	-0.00113	
4.125	-0.10563		-0.01483	0.01483
4.15	-0.19442		-0.02729	0.02729
4.175	-0.24462		-0.03433	0.03433
4.2	-0.26052		-0.03656	0.03656
4.225	-0.25154		-0.03530	0.03530
4.25	-0.22642		-0.03178	0.03178

4.275	-0.19056		-0.02674	0.02674
4.3	-0.13757		-0.01931	0.01931
4.325	-0.08166		-0.01146	0.01146
4.35	-0.05139		-0.00721	0.00721
4.375	-0.04429		-0.00622	0.00622
4.4	-0.05963		-0.00837	0.00837
4.425	-0.09266		-0.01301	0.01301
4.45	-0.13351		-0.01874	0.01874
4.475	-0.16791		-0.02357	0.02357
4.5	-0.19076		-0.02677	0.02677
4.525	-0.20496		-0.02877	0.02877
4.55	-0.21740		-0.03052	0.03052
4.575	-0.23190		-0.03255	0.03255
4.6	-0.24128		-0.03386	0.03386
4.625	-0.23922		-0.03357	0.03357
4.65	-0.23167		-0.03251	0.03251
4.675	-0.23461		-0.03293	0.03293
4.7	-0.25731		-0.03611	0.03611
4.725	-0.28885		-0.04054	0.04054
4.75	-0.31031		-0.04355	0.04355
4.775	-0.31318		-0.04396	0.04396
4.8	-0.29858		-0.04191	0.04191
4.825	-0.26927		-0.03779	0.03779
4.85	-0.22815		-0.03202	0.03202
4.875	-0.18184		-0.02552	0.02552
4.9	-0.14035		-0.01970	0.01970
4.925	-0.11052		-0.01551	0.01551
4.95	-0.08935		-0.01254	0.01254
4.975	-0.06518		-0.00915	0.00915
5	-0.02502		-0.00351	0.00351
5.025	0.04427	0.00621	-0.00621	
5.05	0.15163	0.02128	-0.02128	
5.075	0.29456	0.04134	-0.04134	
5.1	0.45356	0.06366	-0.06366	
5.125	0.59583	0.08363	-0.08363	
5.15	0.69064	0.09693	-0.09693	
5.175	0.71627	0.10053	-0.10053	
5.2	0.65979	0.09260	-0.09260	
5.225	0.52124	0.07316	-0.07316	
5.25	0.32093	0.04504	-0.04504	
5.275	0.10334	0.01450	-0.01450	
5.3	-0.08269		-0.01161	0.01161
5.325	-0.21334		-0.02994	0.02994
5.35	-0.29334		-0.04117	0.04117
5.375	-0.33149		-0.04653	0.04653
5.4	-0.32569		-0.04571	0.04571
5.425	-0.27722		-0.03891	0.03891
5.45	-0.20467		-0.02873	0.02873
5.475	-0.13748		-0.01929	0.01929
5.5	-0.09433		-0.01324	0.01324
5.525	-0.07221		-0.01013	0.01013
5.55	-0.06207		-0.00871	0.00871
5.575	-0.06289		-0.00883	0.00883
5.6	-0.07833		-0.01099	0.01099
5.625	-0.10590		-0.01486	0.01486
5.65	-0.13606		-0.01910	0.01910
5.675	-0.16155		-0.02267	0.02267
5.7	-0.17571		-0.02466	0.02466
5.725	-0.16718		-0.02346	0.02346
5.75	-0.12589		-0.01767	0.01767

5.775	-0.05786	-0.00812	0.00812
5.8	0.01775 0.00249	-0.00249	
5.825	0.00859 0.01243	-0.01243	
5.85	0.15414 0.02163	-0.02163	
5.875	0.28643 0.02897	-0.02897	
5.9	0.22462 0.03153	-0.03153	
5.925	0.19523 0.02740	-0.02740	
5.95	0.11558 0.01622	-0.01622	
5.975	-0.01142	-0.00160	0.00160
6	-0.17070	-0.02396	0.02396
[illegible]325	-0.33987	-0.04770	0.04770
[illegible]5	-0.49754	-0.06983	0.06983
[illegible]875	-0.62191	-0.08729	0.08729
[illegible].1	-0.69607	-0.09769	0.09769
6.125	-0.70835	-0.09942	0.09942
6.15	-0.64796	-0.09094	0.09094
6.175	-0.51175	-0.07182	0.07182
6.2	-0.31380	-0.04404	0.04404
6.225	-0.08608	-0.01208	0.01208
6.25	0.13875 0.01947	-0.01947	
6.275	0.33967 0.04767	-0.04767	
6.3	0.49625 0.06965	-0.06965	
6.325	0.61292 0.08602	-0.08602	
6.35	0.65743 0.09227	-0.09227	
6.375	0.67058 0.09412	-0.09412	
6.4	0.62572 0.08782	-0.08782	
6.425	0.55537 0.07795	-0.07795	
6.45	0.45607 0.06401	-0.06401	
6.475	0.32947 0.04624	-0.04624	
6.5	0.19096 0.02680	-0.02680	
6.525	0.05423 0.00761	-0.00761	
6.55	-0.09333	-0.01310	0.01310
6.575	-0.23986	-0.03367	0.03367
6.6	-0.37009	-0.05194	0.05194
6.625	-0.46592	-0.06539	0.06539
6.65	-0.52289	-0.07339	0.07339
6.675	-0.54806	-0.07692	0.07692
6.7	-0.55034	-0.07724	0.07724
6.725	-0.53075	-0.07449	0.07449
6.75	-0.49863	-0.06886	0.06886
6.775	-0.44152	-0.06197	0.06197
6.8	-0.38526	-0.05407	0.05407
6.825	-0.30424	-0.04270	0.04270
6.85	-0.18682	-0.02622	0.02622
6.875	-0.04483	-0.00629	0.00629
6.9	0.09835 0.01380	-0.01380	
6.925	0.22430 0.03148	-0.03148	
6.95	0.33103 0.04646	-0.04646	
6.975	0.42043 0.05901	-0.05901	
7	0.47442 0.06658	-0.06658	
7.025	0.47412 0.06654	-0.06654	
7.05	0.42439 0.05956	-0.05956	
7.075	0.34805 0.04885	-0.04885	
7.1	0.27091 0.03802	-0.03802	
7.125	0.20678 0.02902	-0.02902	
7.15	0.15275 0.02144	-0.02144	
7.175	0.10830 0.01520	-0.01520	
7.2	0.08452 0.01186	-0.01186	
7.225	0.08625 0.01210	-0.01210	
7.25	0.10952 0.01537	-0.01537	

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[illegible]275	0.15483 0.02173	-0.02173	
[illegible]3	0.22428 0.03148	-0.03148	
7.325	0.30912 0.04339	-0.04339	
7.35	0.39273 0.05512	-0.05512	
7.375	0.45683 0.06412	-0.06412	
7.4	0.48734 0.06840	-0.06840	
7.425	0.47963 0.06732	-0.06732	
7.45	0.42864 0.06016	-0.06016	
7.475	0.33165 0.04655	-0.04655	
7.5	0.20274 0.02845	-0.02845	
7.525	0.07189 0.01009	-0.01009	
7.55	-0.02800	-0.00393	0.00393
7.575	-0.07623	-0.01070	0.01070
7.6	-0.07059	-0.00991	0.00991
7.625	-0.02240	-0.00314	0.00314
7.65	0.05552 0.00779	-0.00779	
7.675	0.14031 0.02002	-0.02002	
7.7	0.23404 0.03285	-0.03285	
7.725	0.28759 0.04036	-0.04036	
7.75	0.28697 0.04028	-0.04028	
7.775	0.22501 0.03158	-0.03158	
7.8	0.11760 0.01652	-0.01652	
7.825	-0.00115	-0.00016	0.00016
7.85	-0.09996	-0.01403	0.01403
7.875	-0.16340	-0.02293	0.02293
7.9	-0.19379	-0.02720	0.02720
7.925	-0.20589	-0.02890	0.02890
7.95	-0.21115	-0.02964	0.02964
7.975	-0.21426	-0.03007	0.03007
8	-0.21765	-0.03055	0.03055
8.025	-0.22228	-0.03120	0.03120
8.05	-0.22611	-0.03174	0.03174
8.075	-0.22487	-0.03156	0.03156
8.1	-0.21011	-0.02949	0.02949
8.125	-0.17192	-0.02413	0.02413
8.15	-0.11394	-0.01599	0.01599
8.175	-0.05355	-0.00752	0.00752
8.2	-0.00628	-0.00088	0.00088
8.225	0.02077 0.00292	-0.00292	
8.25	0.02258 0.00317	-0.00317	
8.275	-0.00133	-0.00019	0.00019
8.3	-0.04432	-0.00622	0.00622
8.325	-0.10710	-0.01503	0.01503
8.35	-0.19994	-0.02806	0.02806
8.375	-0.32223	-0.04523	0.04523
8.4	-0.44966	-0.06311	0.06311
8.425	-0.56708	-0.07959	0.07959
8.45	-0.63531	-0.08917	0.08917
8.475	-0.66903	-0.09390	0.09390
8.5	-0.64185	-0.09008	0.09008
[illegible]525	-0.58624	-0.08228	0.08228
[illegible]5	-0.47203	-0.06636	0.06636
[illegible]575	-0.33279	-0.04671	0.04671
8.6	-0.19806	-0.02780	0.02780
8.625	-0.08582	-0.01204	0.01204
8.65	-0.01401	-0.00197	0.00197
8.675	0.01618 0.00227	-0.00227	
8.7	0.00486 0.00068	-0.00068	
8.725	-0.03598	-0.00504	0.00504
8.75	-0.08395	-0.01178	0.01178

8.775	-0.11958	-0.01678	0.01678
8.8	-0.13107	-0.01840	0.01840
8.825	-0.11581	-0.01625	0.01625
8.85	-0.07709	-0.01082	0.01082
8.875	-0.01848	-0.00259	0.00259
8.9	0.05451 0.00765	-0.00765	
8.925	0.12947 0.01817	-0.01817	
8.95	0.19547 0.02743	-0.02743	
8.975	0.24137 0.03388	-0.03388	
9	0.25473 0.03575	-0.03575	
9.025	0.23869 0.03238	-0.03238	
9.05	0.17167 0.02409	-0.02409	
9.075	0.08145 0.01143	-0.01143	
9.1	-0.03241	-0.00455	0.00455
9.125	-0.14727	-0.02067	0.02067
9.15	-0.23047	-0.03235	0.03235
9.175	-0.25158	-0.03530	0.03530
9.2	-0.19125	-0.02684	0.02684
9.225	-0.05598	-0.00785	0.00785
9.25	0.12802 0.01797	-0.01797	
9.275	0.33304 0.04674	-0.04674	
9.3	0.53158 0.07461	-0.07461	
9.325	0.69292 0.09725	-0.09725	
9.35	0.79123 0.11105	-0.11105	
9.375	0.81434 0.11429	-0.11429	
9.4	0.76718 0.10767	-0.10767	
9.425	0.66382 0.09317	-0.09317	
9.45	0.52338 0.07346	-0.07346	
9.475	0.36855 0.05173	-0.05173	
9.5	0.21966 0.03083	-0.03083	
9.525	0.09642 0.01353	-0.01353	
9.55	0.01530 0.00215	-0.00215	
9.575	-0.02709	-0.00380	0.00380
9.6	-0.04321	-0.00606	0.00606
9.625	-0.04514	-0.00634	0.00634
9.65	-0.02526	-0.00354	0.00354
9.675	0.02471 0.00347	-0.00347	
9.7	0.07968 0.01118	-0.01118	
9.725	0.14852 0.02084	-0.02084	
9.75	0.22147 0.03108	-0.03108	
9.775	0.29103 0.04085	-0.04085	
9.8	0.34946 0.04905	-0.04905	
9.825	0.39728 0.05576	-0.05576	
9.85	0.43738 0.06139	-0.06139	
9.875	0.46172 0.06480	-0.06480	
9.9	0.45288 0.06355	-0.06355	
9.925	0.39603 0.05570	-0.05570	
9.95	0.29455 0.04134	-0.04134	
9.975	0.16788 0.02356	-0.02356	
10	0.04206 0.00590	-0.00590	
10.025	-0.08633	-0.01212	0.01212
10.05	-0.23239	-0.03262	0.03262
10.075	-0.38978	-0.05471	0.05471
10.1	-0.53380	-0.07481	0.07481
10.125	-0.63804	-0.08955	0.08955
10.15	-0.69389	-0.09739	0.09739
10.175	-0.70023	-0.09828	0.09828
10.2	-0.66580	-0.09345	0.09345
10.225	-0.59875	-0.08403	0.08403
10.25	-0.50502	-0.07088	0.07088

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10.275	-0.39806	-0.05587	0.05587
10.3	-0.29725	-0.04172	0.04172
10.325	-0.22263	-0.03125	0.03125
10.35	-0.18687	-0.02623	0.02623
10.375	-0.18381	-0.02580	0.02580
10.4	-0.18659	-0.02619	0.02619
10.425	-0.16517	-0.02318	0.02318
10.45	-0.11009	-0.01545	0.01545
10.475	-0.03674	-0.00516	0.00516
10.5	0.03399 0.00477	-0.00477	
10.525	0.09424 0.01323	-0.01323	
10.55	0.14259 0.02001	-0.02001	
10.575	0.17303 0.02428	-0.02428	
10.6	0.17661 0.02479	-0.02479	
10.625	0.15196 0.02133	-0.02133	
10.65	0.10770 0.01512	-0.01512	
10.675	0.06170 0.00866	-0.00866	
10.7	0.03411 0.00479	-0.00479	
10.725	0.02177 0.00306	-0.00306	
10.75	0.03123 0.00438	-0.00438	
10.775	0.05784 0.00812	-0.00812	
10.8	0.07959 0.01117	-0.01117	
10.825	0.07657 0.01075	-0.01075	
10.85	0.04319 0.00606	-0.00606	
10.875	-0.01351	-0.00190	0.00190
10.9	-0.08739	-0.01227	0.01227
10.925	-0.17074	-0.02396	0.02396
10.95	-0.24746	-0.03473	0.03473
10.975	-0.29792	-0.04181	0.04181
11	-0.29729	-0.04172	0.04172
11.025	-0.22637	-0.03177	0.03177
11.05	-0.09668	-0.01357	0.01357
11.075	0.05447 0.00765	-0.00765	
11.1	0.19284 0.02707	-0.02707	
11.125	0.29805 0.04183	-0.04183	
11.15	0.36314 0.05097	-0.05097	
11.175	0.39081 0.05485	-0.05485	
11.2	0.38507 0.05404	-0.05404	
11.225	0.35325 0.04958	-0.04958	
11.25	0.31258 0.04387	-0.04387	
11.275	0.28037 0.03935	-0.03935	
11.3	0.26007 0.03650	-0.03650	
11.325	0.25268 0.03546	-0.03546	
11.35	0.26764 0.03756	-0.03756	
11.375	0.30040 0.04216	-0.04216	
11.4	0.32373 0.04544	-0.04544	
11.425	0.31151 0.04372	-0.04372	
11.45	0.25859 0.03629	-0.03629	
11.475	0.18098 0.02540	-0.02540	
11.5	0.09460 0.01328	-0.01328	
11.525	0.00121 0.00017	-0.00017	
11.55	-0.09944	-0.01396	0.01396
11.575	-0.18859	-0.02647	0.02647
11.6	-0.23527	-0.03302	0.03302
11.625	-0.22838	-0.03204	0.03204
11.65	-0.17661	-0.02479	0.02479
11.675	-0.08742	-0.01227	0.01227
11.7	0.03523 0.00494	-0.00494	
11.725	0.17785 0.02496	-0.02496	
11.75	0.30925 0.04340	-0.04340	

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11.775	0.39544 0.05550	-0.05550	
11.8	0.42888 0.05896	-0.05896	
11.825	0.38419 0.05392	-0.05392	
11.85	0.29536 0.04145	-0.04145	
11.875	0.15934 0.02236	-0.02236	
11.9	-0.01277	-0.00179	0.00179
11.925	-0.19433	-0.02727	0.02727
11.95	-0.35121	-0.04929	0.04929
11.975	-0.46187	-0.06482	0.06482
12	-0.52366	-0.07350	0.07350
.825	-0.54294	-0.07620	0.07620
05	-0.52027	-0.07302	0.07302
..075	-0.45357	-0.06366	0.06366
12.1	-0.35723	-0.05014	0.05014
12.125	-0.25297	-0.03550	0.03550
12.15	-0.15387	-0.02160	0.02160
12.175	-0.06428	-0.00902	0.00902
12.2	0.01177 0.00165	-0.00165	
12.225	0.06933 0.00973	-0.00973	
12.25	0.10265 0.01441	-0.01441	
12.275	0.09805 0.01376	-0.01376	
12.3	0.04747 0.00666	-0.00666	
12.325	-0.03947	-0.00554	0.00554
12.35	-0.14204	-0.01993	0.01993
12.375	-0.23928	-0.03358	0.03358
12.4	-0.31709	-0.04450	0.04450
12.425	-0.37223	-0.05224	0.05224
12.45	-0.41227	-0.05786	0.05786
12.475	-0.44485	-0.06244	0.06244
12.5	-0.47049	-0.06603	0.06603
12.525	-0.48538	-0.06812	0.06812
12.55	-0.48587	-0.06819	0.06819
12.575	-0.46756	-0.06562	0.06562
12.6	-0.42979	-0.06032	0.06032
12.625	-0.39214	-0.05504	0.05504
12.65	-0.33951	-0.04765	0.04765
12.675	-0.27367	-0.03841	0.03841
12.7	-0.18318	-0.02571	0.02571
12.725	-0.08474	-0.01189	0.01189
12.75	0.02394 0.00336	-0.00336	
12.775	0.11915 0.01672	-0.01672	
12.8	0.22801 0.03888	-0.03888	
12.825	0.31726 0.04453	-0.04453	
12.85	0.40577 0.05695	-0.05695	
12.875	0.45911 0.06444	-0.06444	
12.9	0.46322 0.06501	-0.06501	
12.925	0.43807 0.06148	-0.06148	
12.95	0.41612 0.05840	-0.05840	
12.975	0.36807 0.05166	-0.05166	
13	0.30684 0.04307	-0.04307	
13.025	0.22021 0.03091	-0.03091	
13.05	0.12525 0.01758	-0.01758	
13.075	0.02136 0.00300	-0.00300	
13.1	-0.08465	-0.01188	0.01188
13.125	-0.19294	-0.02708	0.02708
13.15	-0.30045	-0.04217	0.04217
13.175	-0.39373	-0.05526	0.05526
13.2	-0.45657	-0.06408	0.06408
13.225	-0.48084	-0.06749	0.06749
13.25	-0.46173	-0.06480	0.06480

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.275	-0.39542	-0.05550	0.05550
.3	-0.29018	-0.04072	0.04072
13.325	-0.16063	-0.02254	0.02254
13.35	-0.01810	-0.00254	0.00254
13.375	0.11155 0.01566	-0.01566	
13.4	0.19011 0.02668	-0.02668	
13.425	0.20359 0.02857	-0.02857	
13.45	0.16947 0.02378	-0.02378	
13.475	0.11564 0.01623	-0.01623	
13.5	0.06343 0.00890	-0.00890	
13.525	0.02765 0.00388	-0.00388	
13.55	0.02535 0.00356	-0.00356	
13.575	0.07235 0.01015	-0.01015	
13.6	0.16344 0.02294	-0.02294	
13.625	0.26920 0.03778	-0.03778	
13.65	0.35877 0.05035	-0.05035	
13.675	0.40748 0.05719	-0.05719	
13.7	0.39815 0.05588	-0.05588	
13.725	0.32828 0.04607	-0.04607	
13.75	0.21126 0.02965	-0.02965	
13.775	0.07159 0.01005	-0.01005	
13.8	-0.06374	-0.00895	0.00895
13.825	-0.17392	-0.02441	0.02441
13.85	-0.24852	-0.03488	0.03488
13.875	-0.28150	-0.03951	0.03951
13.9	-0.27048	-0.03796	0.03796
13.925	-0.22083	-0.03099	0.03099
13.95	-0.14493	-0.02034	0.02034
13.975	-0.06081	-0.00854	0.00854
14	0.01863 0.00261	-0.00261	
14.025	0.09152 0.01284	-0.01284	
14.05	0.15850 0.02225	-0.02225	
14.075	0.20645 0.02898	-0.02898	
14.1	0.21277 0.02986	-0.02986	
14.125	0.17151 0.02407	-0.02407	
14.15	0.09639 0.01353	-0.01353	
14.175	0.00404 0.00057	-0.00057	
14.2	-0.09869	-0.01385	0.01385
14.225	-0.21025	-0.02951	0.02951
14.25	-0.32118	-0.04508	0.04508
14.275	-0.41001	-0.05755	0.05755
14.3	-0.45145	-0.06336	0.06336
14.325	-0.43144	-0.06055	0.06055
14.35	-0.35479	-0.04980	0.04980
14.375	-0.23831	-0.03345	0.03345
14.4	-0.10060	-0.01412	0.01412
14.425	0.04542 0.00637	-0.00637	
14.45	0.19013 0.02668	-0.02668	
14.475	0.32310 0.04535	-0.04535	
4.5	0.43141 0.06055	-0.06055	
525	0.49855 0.06997	-0.06997	
55	0.51699 0.07256	-0.07256	
..575	0.49989 0.07016	-0.07016	
14.6	0.46867 0.06578	-0.06578	
14.625	0.42974 0.06031	-0.06031	
14.65	0.37064 0.05202	-0.05202	
14.675	0.27777 0.03899	-0.03899	
14.7	0.15325 0.02151	-0.02151	
14.725	0.02023 0.00284	-0.00284	
14.75	-0.09371	-0.01315	0.01315

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14.775	-0.18188	-0.02553	0.02553
14.8	-0.25607	-0.03594	0.03594
14.825	-0.32114	-0.04507	0.04507
14.85	-0.36532	-0.05127	0.05127
14.875	-0.37360	-0.05244	0.05244
14.9	-0.34709	-0.04871	0.04871
14.925	-0.31197	-0.04379	0.04379
14.95	-0.27706	-0.03889	0.03889
14.975	-0.26639	-0.03739	0.03739
15	-0.27227	-0.03821	0.03821
15.025	-0.28037	-0.03935	0.03935
15.05	-0.28976	-0.04067	0.04067
15.075	-0.29946	-0.04203	0.04203
15.1	-0.30637	-0.04300	0.04300
15.125	-0.30445	-0.04273	0.04273
15.15	-0.28592	-0.04013	0.04013
15.175	-0.25145	-0.03529	0.03529
15.2	-0.21345	-0.02996	0.02996
15.225	-0.18583	-0.02608	0.02608
15.25	-0.17562	-0.02465	0.02465
15.275	-0.17699	-0.02484	0.02484
15.3	-0.17841	-0.02504	0.02504
15.325	-0.17444	-0.02448	0.02448
15.35	-0.16580	-0.02327	0.02327
15.375	-0.15429	-0.02165	0.02165
15.4	-0.13740	-0.01928	0.01928
15.425	-0.11124	-0.01561	0.01561
15.45	-0.08033	-0.01127	0.01127
15.475	-0.05744	-0.00806	0.00806
15.5	-0.04947	-0.00694	0.00694
15.525	-0.04519	-0.00634	0.00634
15.55	-0.02460	-0.00345	0.00345
15.575	0.02200 0.00309	-0.00309	
15.6	0.09367 0.01315	-0.01315	
15.625	0.18657 0.02619	-0.02619	
15.65	0.29895 0.04196	-0.04196	
15.675	0.42063 0.05904	-0.05904	
15.7	0.52348 0.07346	-0.07346	
15.725	0.58164 0.08163	-0.08163	
15.75	0.58968 0.08276	-0.08276	
15.775	0.55580 0.07801	-0.07801	
15.8	0.48823 0.06852	-0.06852	
15.825	0.39163 0.05496	-0.05496	
15.85	0.27791 0.03900	-0.03900	
15.875	0.17519 0.02459	-0.02459	
15.9	0.11501 0.01625	-0.01625	
15.925	0.11618 0.01631	-0.01631	
15.95	0.16362 0.02296	-0.02296	
15.975	0.23691 0.03325	-0.03325	
16	0.32004 0.04492	-0.04492	
16.025	0.41525 0.05828	-0.05828	
16.05	0.51255 0.07194	-0.07194	
16.075	0.57266 0.08037	-0.08037	
16.1	0.60434 0.08482	-0.08482	
16.125	0.58684 0.08236	-0.08236	
16.15	0.54317 0.07623	-0.07623	
16.175	0.50277 0.07056	-0.07056	
16.2	0.47769 0.06704	-0.06704	
16.225	0.45821 0.06431	-0.06431	
16.25	0.43836 0.06152	-0.06152	

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16.275	0.42159 0.05917	-0.05917	
16.3	0.40662 0.05707	-0.05707	
16.325	0.39267 0.05511	-0.05511	
16.35	0.38335 0.05380	-0.05380	
16.375	0.37168 0.05217	-0.05217	
16.4	0.34377 0.04825	-0.04825	
16.425	0.29232 0.04103	-0.04103	
16.45	0.21921 0.03077	-0.03077	
16.475	0.13045 0.01831	-0.01831	
16.5	0.03454 0.00485	-0.00485	
16.525	-0.05906	-0.00829	0.00829
16.55	-0.14361	-0.02016	0.02016
16.575	-0.20498	-0.02877	0.02877
16.6	-0.21827	-0.03063	0.03063
16.625	-0.16542	-0.02322	0.02322
16.65	-0.05998	-0.00842	0.00842
16.675	0.05814 0.00816	-0.00816	
16.7	0.15314 0.02149	-0.02149	
16.725	0.21074 0.02958	-0.02958	
16.75	0.23266 0.03265	-0.03265	
16.775	0.21679 0.03043	-0.03043	
16.8	0.15669 0.02199	-0.02199	
16.825	0.05836 0.00819	-0.00819	
16.85	-0.05240	-0.00735	0.00735
16.875	-0.14650	-0.02056	0.02056
16.9	-0.21386	-0.03002	0.03002
16.925	-0.25190	-0.03535	0.03535
16.95	-0.24953	-0.03502	0.03502
16.975	-0.20881	-0.02818	0.02818
17	-0.09988	-0.01402	0.01402
17.025	0.03159 0.00443	-0.00443	
17.05	0.16815 0.02360	-0.02360	
17.075	0.28691 0.04027	-0.04027	
17.1	0.36479 0.05120	-0.05120	
17.125	0.37494 0.05262	-0.05262	
17.15	0.34805 0.04773	-0.04773	
17.175	0.24882 0.03492	-0.03492	
17.2	0.12167 0.01708	-0.01708	
17.225	-0.03417	-0.00480	0.00480
17.25	-0.19638	-0.02756	0.02756
17.275	-0.34004	-0.04773	0.04773
17.3	-0.44742	-0.06280	0.06280
17.325	-0.52198	-0.07325	0.07325
17.35	-0.57717	-0.08101	0.08101
17.375	-0.61322	-0.08607	0.08607
17.4	-0.61024	-0.08565	0.08565
17.425	-0.55733	-0.07822	0.07822
17.45	-0.46869	-0.06578	0.06578
17.475	-0.36636	-0.05142	0.05142
17.5	-0.26393	-0.03704	0.03704
17.525	-0.16456	-0.02310	0.02310
17.55	-0.07482	-0.01050	0.01050
17.575	-0.01371	-0.00192	0.00192
17.6	0.00086 0.00012	-0.00012	
17.625	-0.03556	-0.00499	0.00499
17.65	-0.11704	-0.01643	0.01643
17.675	-0.22872	-0.03210	0.03210
17.7	-0.34631	-0.04861	0.04861
17.725	-0.44513	-0.06247	0.06247
17.75	-0.51555	-0.07236	0.07236

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17.775	-0.55801		-0.07832	0.07832
17.8	-0.57016		-0.08002	0.08002
17.825	-0.54697		-0.07677	0.07677
17.85	-0.49105		-0.06892	0.06892
17.875	-0.41833		-0.05871	0.05871
17.9	-0.34547		-0.04849	0.04849
17.925	-0.28213		-0.03960	0.03960
17.95	-0.23099		-0.03242	0.03242
17.975	-0.19748		-0.02772	0.02772
18	-0.19139		-0.02686	0.02686
[illegible].025	-0.20834		-0.02924	0.02924
[illegible]05	-0.23005		-0.03229	0.03229
[illegible].075	-0.24402		-0.03425	0.03425
18.1	-0.25038		-0.03513	0.03513
18.125	-0.25140		-0.03528	0.03528
18.15	-0.24546		-0.03445	0.03445
18.175	-0.22523		-0.03161	0.03161
18.2	-0.18967		-0.02662	0.02662
18.225	-0.15551		-0.02183	0.02183
18.25	-0.13496		-0.01894	0.01894
18.275	-0.12559		-0.01763	0.01763
18.3	-0.12710		-0.01784	0.01784
18.325	-0.13793		-0.01936	0.01936
18.35	-0.15072		-0.02115	0.02115
18.375	-0.15782		-0.02215	0.02215
18.4	-0.15267		-0.02143	0.02143
18.425	-0.13517		-0.01897	0.01897
18.45	-0.11284		-0.01584	0.01584
18.475	-0.08588		-0.01194	0.01194
18.5	-0.03804		-0.00534	0.00534
18.525	0.03466	0.00487	-0.00487	
18.55	0.12364	0.01735	-0.01735	
18.575	0.21746	0.03052	-0.03052	
18.6	0.38884	0.04335	-0.04335	
18.625	0.39200	0.05502	-0.05502	
18.65	0.46186	0.06482	-0.06482	
18.675	0.51463	0.07223	-0.07223	
18.7	0.54969	0.07715	-0.07715	
18.725	0.56470	0.07926	-0.07926	
18.75	0.55511	0.07791	-0.07791	
18.775	0.52551	0.07376	-0.07376	
18.8	0.48986	0.06864	-0.06864	
18.825	0.45658	0.06408	-0.06408	
18.85	0.42781	0.06004	-0.06004	
18.875	0.39311	0.05517	-0.05517	
18.9	0.34391	0.04827	-0.04827	
18.925	0.27925	0.03919	-0.03919	
18.95	0.20112	0.02823	-0.02823	
18.975	0.10778	0.01513	-0.01513	
19	0.00107	0.00015	-0.00015	
19.025	-0.10662		-0.01496	0.01496
19.05	-0.19783		-0.02777	0.02777
19.075	-0.25712		-0.03609	0.03609
19.1	-0.27483		-0.03857	0.03857
19.125	-0.25949		-0.03642	0.03642
19.15	-0.19910		-0.02794	0.02794
19.175	-0.09766		-0.01371	0.01371
19.2	0.03382	0.00475	-0.00475	
19.225	0.18159	0.02549	-0.02549	
19.25	0.33358	0.04682	-0.04682	

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[illegible]275	0.45460	0.06380	-0.06380	
[illegible].3	0.55812	0.07833	-0.07833	
19.325	0.60592	0.08504	-0.08504	
19.35	0.61316	0.08606	-0.08606	
19.375	0.57445	0.08062	-0.08062	
19.4	0.49526	0.06951	-0.06951	
19.425	0.39214	0.05504	-0.05504	
19.45	0.28378	0.03983	-0.03983	
19.475	0.17781	0.02496	-0.02496	
19.5	0.07552	0.01060	-0.01060	
19.525	-0.02024		-0.00284	0.00284
19.55	-0.10391		-0.01458	0.01458
19.575	-0.17203		-0.02414	0.02414
19.6	-0.22722		-0.03189	0.03189
19.625	-0.27196		-0.03817	0.03817
19.65	-0.30193		-0.04238	0.04238
19.675	-0.31147		-0.04372	0.04372
19.7	-0.30220		-0.04241	0.04241
19.725	-0.28278		-0.03969	0.03969
19.75	-0.26495		-0.03719	0.03719
19.775	-0.25775		-0.03617	0.03617
19.8	-0.25898		-0.03635	0.03635
19.825	-0.25751		-0.03614	0.03614
19.85	-0.24305		-0.03411	0.03411
19.875	-0.20940		-0.02939	0.02939
19.9	-0.15832		-0.02222	0.02222
19.925	-0.09772		-0.01371	0.01371
19.95	-0.03767		-0.00529	0.00529
19.975	0.00902	0.00127	-0.00127	
20	0.03553	0.00499	-0.00499	
20.025	0.04040	0.00567	-0.00567	
20.05	0.02150	0.00302	-0.00302	
20.075	-0.02076		-0.00291	0.00291
20.1	-0.08103		-0.01137	0.01137
20.125	-0.14427		-0.02025	0.02025
20.15	-0.19596		-0.02750	0.02750
20.175	-0.23405		-0.03285	0.03285
20.2	-0.26593		-0.03732	0.03732
20.225	-0.30016		-0.04213	0.04213
20.25	-0.33923		-0.04761	0.04761
20.275	-0.37918		-0.05322	0.05322
20.3	-0.41451		-0.05818	0.05818
20.325	-0.44682		-0.06271	0.06271
20.35	-0.47746		-0.06701	0.06701
20.375	-0.49646		-0.06968	0.06968
20.4	-0.49865		-0.06886	0.06886
20.425	-0.45683		-0.06412	0.06412
20.45	-0.40538		-0.05690	0.05690
20.475	-0.34988		-0.04911	0.04911
[illegible]0.5	-0.29508		-0.04140	0.04140
[illegible]525	-0.23901		-0.03355	0.03355
[illegible]55	-0.18054		-0.02534	0.02534
[illegible].575	-0.11831		-0.01660	0.01660
20.6	-0.05122		-0.00719	0.00719
20.625	0.01770	0.00248	-0.00248	
[illegible]0.65	0.08025	0.01126	-0.01126	
20.675	0.12969	0.01820	-0.01820	
20.7	0.16612	0.02331	-0.02331	
20.725	0.19181	0.02692	-0.02692	
20.75	0.20743	0.02911	-0.02911	

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20.775	0.21503	0.03018	-0.03018	
20.8	0.22191	0.03114	-0.03114	
20.825	0.23422	0.03287	-0.03287	
20.85	0.24623	0.03456	-0.03456	
20.875	0.24585	0.03451	-0.03451	
20.9	0.22853	0.03207	-0.03207	
20.925	0.20089	0.02819	-0.02819	
20.95	0.16752	0.02351	-0.02351	
20.975	0.12619	0.01771	-0.01771	
21	0.07652	0.01074	-0.01074	
21.025	0.02616	0.00367	-0.00367	
21.05	-0.01082		-0.00152	0.00152
21.075	-0.02526		-0.00354	0.00354
21.1	-0.01701		-0.00239	0.00239
21.125	0.01193	0.00167	-0.00167	
21.15	0.06050	0.00849	-0.00849	
21.175	0.12461	0.01749	-0.01749	
21.2	0.19416	0.02725	-0.02725	
21.225	0.25413	0.03567	-0.03567	
21.25	0.29183	0.04096	-0.04096	
21.275	0.30330	0.04257	-0.04257	
21.3	0.28337	0.03977	-0.03977	
21.325	0.24176	0.03393	-0.03393	
21.35	0.18460	0.02592	-0.02592	
21.375	0.12505	0.01755	-0.01755	
21.4	0.07767	0.01090	-0.01090	
21.425	0.04948	0.00694	-0.00694	
21.45	0.04095	0.00575	-0.00575	
21.475	0.05098	0.00716	-0.00716	
21.5	0.08220	0.01154	-0.01154	
21.525	0.13766	0.01932	-0.01932	
21.55	0.20661	0.02900	-0.02900	
21.575	0.26817	0.03764	-0.03764	
21.6	0.30499	0.04281	-0.04281	
21.625	0.30778	0.04320	-0.04320	
21.65	0.27619	0.03876	-0.03876	
21.675	0.21521	0.03020	-0.03020	
21.7	0.12975	0.01821	-0.01821	
21.725	0.02559	0.00359	-0.00359	
21.75	-0.08553		-0.01200	0.01200
21.775	-0.18715		-0.02627	0.02627
21.8	-0.26030		-0.03653	0.03653
21.825	-0.28926		-0.04060	0.04060
21.85	-0.27817		-0.03792	0.03792
21.875	-0.20977		-0.02944	0.02944
21.9	-0.11705		-0.01643	0.01643
21.925	-0.00105		-0.00015	0.00015
21.95	0.12536	0.01759	-0.01759	
21.975	0.24993	0.03508	-0.03508	
22	0.35942	0.05044	-0.05044	
22.025	0.43454	0.06099	-0.06099	
22.05	0.45978	0.06453	-0.06453	
22.075	0.43201	0.06063	-0.06063	
22.1	0.36238	0.05085	-0.05085	
22.125	0.27253	0.03825	-0.03825	
22.15	0.18478	0.02593	-0.02593	
22.175	0.11188	0.01570	-0.01570	
22.2	0.05968	0.00836	-0.00836	
22.225	0.03399	0.00477	-0.00477	
22.25	0.03615	0.00507	-0.00507	

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22.275	0.05574	0.00782	-0.00782	
22.3	0.07643	0.01073	-0.01073	
22.325	0.08612	0.01209	-0.01209	
22.35	0.08086	0.01135	-0.01135	
22.375	0.05452	0.00765	-0.00765	
22.4	0.00963	0.00135	-0.00135	
22.425	-0.05114		-0.00718	0.00718
22.45	-0.11997		-0.01684	0.01684
22.475	-0.16148		-0.02266	0.02266
22.5	-0.19644		-0.02757	0.02757
22.525	-0.22239		-0.03121	0.03121
22.55	-0.24287		-0.03409	0.03409
22.575	-0.24457		-0.03433	0.03433
22.6	-0.21615		-0.03034	0.03034
22.625	-0.16048		-0.02251	0.02251
22.65	-0.09233		-0.01296	0.01296
22.675	-0.02930		-0.00411	0.00411
22.7	0.02119	0.00297	-0.00297	
22.725	0.06094	0.00855	-0.00855	
22.75	0.09175	0.01288	-0.01288	
22.775	0.11058	0.01552	-0.01552	
22.8	0.11195	0.01571	-0.01571	
22.825	0.09382	0.01317	-0.01317	
22.85	0.06464	0.00907	-0.00907	
22.875	0.03856	0.00541	-0.00541	
22.9	0.02171	0.00305	-0.00305	
22.925	0.01084	0.00152	-0.00152	
22.95	0.00209	0.00029	-0.00029	
22.975	-0.00566		-0.00079	0.00079
23	-0.01546		-0.00217	0.00217
23.025	-0.03533		-0.00496	0.00496
23.05	-0.07427		-0.01042	0.01042
23.075	-0.13577		-0.01906	0.01906
23.1	-0.21821		-0.03063	0.03063
23.125	-0.31697		-0.04449	0.04449
23.15	-0.42179		-0.05920	0.05920
23.175	-0.51706		-0.07260	0.07260
23.2	-0.58997		-0.08280	0.08280
23.225	-0.62764		-0.08809	0.08809
23.25	-0.62831		-0.08818	0.08818
23.275	-0.59581		-0.08362	0.08362
23.3	-0.53440		-0.07500	0.07500
23.325	-0.44770		-0.06283	0.06283
23.35	-0.34380		-0.04825	0.04825
23.375	-0.23146		-0.03249	0.03249
23.4	-0.11614		-0.01630	0.01630
23.425	-0.00311		-0.00044	0.00044
23.45	0.10109	0.01419	-0.01419	
23.475	0.19090	0.02679	-0.02679	
23.5	0.24912	0.03496	-0.03496	
23.525	0.26465	0.03714	-0.03714	
23.55	0.24852	0.03488	-0.03488	
23.575	0.19083	0.02678	-0.02678	
23.6	0.10598	0.01487	-0.01487	
23.625	0.00849	0.00119	-0.00119	
23.65	-0.08338		-0.01170	0.01170
23.675	-0.15225		-0.02137	0.02137
23.7	-0.18897		-0.02652	0.02652
23.725	-0.19521		-0.02740	0.02740
23.75	-0.17759		-0.02492	0.02492

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23.775	-0.14314		-0.02009	0.02009
23.8	-0.10861		-0.01412	0.01412
23.825	-0.06805		-0.00843	0.00843
23.85	-0.02914		-0.00409	0.00409
23.875	-0.01071		-0.00150	0.00150
23.9	-0.00193		-0.00027	0.00027
23.925	0.00205	0.00029	-0.00029	
23.95	0.00253	0.00036	-0.00036	
23.975	-0.00067		-0.00009	0.00009
24	-0.00405		-0.00057	0.00057
.025	0.00224	0.00031	-0.00031	
.05	0.02801	0.00393	-0.00393	
.075	0.07172	0.01007	-0.01007	
24.1	0.12557	0.01762	-0.01762	
24.125	0.19050	0.02674	-0.02674	
24.15	0.27131	0.03808	-0.03808	
24.175	0.36042	0.05059	-0.05059	
24.2	0.44014	0.06177	-0.06177	
24.225	0.49741	0.06981	-0.06981	
24.25	0.52762	0.07405	-0.07405	
24.275	0.53261	0.07475	-0.07475	
24.3	0.51900	0.07284	-0.07284	
24.325	0.49079	0.06888	-0.06888	
24.35	0.44849	0.06295	-0.06295	
24.375	0.39540	0.05551	-0.05551	
24.4	0.33797	0.04743	-0.04743	
24.425	0.28150	0.03951	-0.03951	
24.45	0.22991	0.03227	-0.03227	
24.475	0.18427	0.02586	-0.02586	
24.5	0.14266	0.02002	-0.02002	
24.525	0.10423	0.01463	-0.01463	
24.55	0.07143	0.01003	-0.01003	
24.575	0.04802	0.00674	-0.00674	
24.6	0.03774	0.00530	-0.00530	
24.625	0.04164	0.00584	-0.00584	
24.65	0.05621	0.00789	-0.00789	
24.675	0.07722	0.01084	-0.01084	
24.7	0.10224	0.01435	-0.01435	
24.725	0.12895	0.01810	-0.01810	
24.75	0.15439	0.02167	-0.02167	
24.775	0.17721	0.02487	-0.02487	
24.8	0.19468	0.02732	-0.02732	
24.825	0.19910	0.02794	-0.02794	
24.85	0.18298	0.02568	-0.02568	
24.875	0.14376	0.02018	-0.02018	
24.9	0.08431	0.01183	-0.01183	
24.925	0.01224	0.00172	-0.00172	
24.95	-0.06233		-0.00875	0.00875
24.975	-0.13213		-0.01854	0.01854
25	-0.19408		-0.02724	0.02724
25.025	-0.24568		-0.03448	0.03448
25.05	-0.28510		-0.04001	0.04001
25.075	-0.31436		-0.04412	0.04412
25.1	-0.34083		-0.04784	0.04784
25.125	-0.37121		-0.05210	0.05210
25.15	-0.40586		-0.05696	0.05696
25.175	-0.44149		-0.06196	0.06196
25.2	-0.47888		-0.06597	0.06597
25.225	-0.49618		-0.06964	0.06964
25.25	-0.49363		-0.06928	0.06928

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.275	-0.48343		-0.06785	0.06785
.3	-0.44972		-0.06312	0.06312
25.325	-0.41703		-0.05853	0.05853
25.35	-0.37324		-0.05238	0.05238
25.375	-0.33358		-0.04682	0.04682
25.4	-0.28935		-0.04061	0.04061
25.425	-0.26030		-0.03655	0.03655
25.45	-0.22933		-0.03219	0.03219
25.475	-0.21393		-0.03003	0.03003
25.5	-0.20099		-0.02821	0.02821
25.525	-0.20733		-0.02910	0.02910
25.55	-0.22130		-0.03106	0.03106
25.575	-0.25524		-0.03582	0.03582
25.6	-0.28635		-0.04019	0.04019
25.625	-0.31246		-0.04385	0.04385
25.65	-0.33385		-0.04686	0.04686
25.675	-0.32095		-0.04505	0.04505
25.7	-0.32096		-0.04505	0.04505
25.725	-0.28266		-0.03967	0.03967
25.75	-0.25876		-0.03632	0.03632
25.775	-0.21467		-0.03013	0.03013
25.8	-0.17458		-0.02450	0.02450
25.825	-0.12765		-0.01792	0.01792
25.85	-0.08355		-0.01173	0.01173
25.875	-0.03441		-0.00483	0.00483
25.9	0.02007	0.00282	-0.00282	
25.925	0.08425	0.01182	-0.01182	
25.95	0.15955	0.02239	-0.02239	
25.975	0.23166	0.03251	-0.03251	
26	0.29757	0.04176	-0.04176	
26.025	0.33937	0.04763	-0.04763	
26.05	0.37184	0.05219	-0.05219	
26.075	0.38955	0.05467	-0.05467	
26.1	0.38894	0.05459	-0.05459	
26.125	0.36493	0.05122	-0.05122	
26.15	0.32435	0.04552	-0.04552	
26.175	0.28064	0.03939	-0.03939	
26.2	0.24203	0.03397	-0.03397	
26.225	0.21031	0.02952	-0.02952	
26.25	0.18644	0.02617	-0.02617	
26.275	0.17311	0.02430	-0.02430	
26.3	0.17254	0.02422	-0.02422	
26.325	0.18169	0.02550	-0.02550	
26.35	0.19451	0.02730	-0.02730	
26.375	0.20704	0.02906	-0.02906	
26.4	0.21758	0.03054	-0.03054	
26.425	0.22596	0.03171	-0.03171	
26.45	0.23276	0.03267	-0.03267	
26.475	0.23897	0.03354	-0.03354	
26.5	0.24456	0.03432	-0.03432	
.525	0.24864	0.03490	-0.03490	
.55	0.25058	0.03517	-0.03517	
.575	0.25212	0.03539	-0.03539	
26.6	0.25721	0.03610	-0.03610	
26.625	0.26698	0.03747	-0.03747	
26.65	0.27834	0.03907	-0.03907	
26.675	0.28927	0.04060	-0.04060	
26.7	0.30309	0.04254	-0.04254	
26.725	0.32216	0.04522	-0.04522	
26.75	0.34086	0.04784	-0.04784	

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26.775	0.34886	0.04885	-0.04885	
26.8	0.33432	0.04692	-0.04692	
26.825	0.29467	0.04136	-0.04136	
26.85	0.23911	0.03230	-0.03230	
26.875	0.14829	0.02081	-0.02081	
26.9	0.05986	0.00840	-0.00840	
26.925	-0.02494		-0.00350	0.00350
26.95	-0.09704		-0.01362	0.01362
26.975	-0.14791		-0.02076	0.02076
27	-0.17105		-0.02401	0.02401
27.025	-0.16556		-0.02324	0.02324
27.05	-0.13763		-0.01932	0.01932
27.075	-0.09699		-0.01361	0.01361
27.1	-0.05199		-0.00730	0.00730
27.125	-0.01031		-0.00145	0.00145
27.15	0.01986	0.00267	-0.00267	
27.175	0.02087	0.00405	-0.00405	
27.2	0.01894	0.00266	-0.00266	
27.225	-0.00502		-0.00070	0.00070
27.25	-0.03772		-0.00529	0.00529
27.275	-0.07357		-0.01033	0.01033
27.3	-0.10383		-0.01457	0.01457
27.325	-0.11938		-0.01676	0.01676
27.35	-0.11449		-0.01607	0.01607
27.375	-0.08813		-0.01237	0.01237
27.4	-0.04663		-0.00654	0.00654
27.425	-0.00112		-0.00016	0.00016
27.45	0.04153	0.00583	-0.00583	
27.475	0.07512	0.01054	-0.01054	
27.5	0.09021	0.01266	-0.01266	
27.525	0.08092	0.01136	-0.01136	
27.55	0.04954	0.00681	-0.00681	
27.575	0.00046	0.00006	-0.00006	
27.6	-0.05299		-0.00744	0.00744
27.625	-0.10439		-0.01465	0.01465
27.65	-0.15072		-0.02115	0.02115
27.675	-0.18834		-0.02643	0.02643
27.7	-0.21271		-0.02985	0.02985
27.725	-0.21419		-0.03006	0.03006
27.75	-0.20315		-0.02851	0.02851
27.775	-0.18429		-0.02586	0.02586
27.8	-0.16357		-0.02296	0.02296
27.825	-0.14208		-0.02005	0.02005
27.85	-0.12110		-0.01701	0.01701
27.875	-0.09855		-0.01383	0.01383
27.9	-0.07670		-0.01077	0.01077
27.925	-0.05802		-0.00826	0.00826
27.95	-0.04470		-0.00627	0.00627
27.975	-0.03150		-0.00442	0.00442
28	-0.01767		-0.00248	0.00248
28.025	-0.00260		-0.00036	0.00036
28.05	0.01252	0.00176	-0.00176	
28.075	0.02488	0.00349	-0.00349	
28.1	0.03167	0.00444	-0.00444	
28.125	0.03166	0.00444	-0.00444	
28.15	0.02529	0.00355	-0.00355	
28.175	0.01598	0.00223	-0.00223	
28.2	0.00697	0.00098	-0.00098	
28.225	-0.00265		-0.00037	0.00037
28.25	-0.01532		-0.00215	0.00215

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28.275	-0.02994		-0.00420	0.00420
28.3	-0.04182		-0.00587	0.00587
28.325	-0.04745		-0.00666	0.00666
28.35	-0.04913		-0.00690	0.00690
28.375	-0.05145		-0.00722	0.00722
28.4	-0.05410		-0.00759	0.00759
28.425	-0.05247		-0.00736	0.00736
28.45	-0.04583		-0.00643	0.00643
28.475	-0.03913		-0.00549	0.00549
28.5	-0.03555		-0.00499	0.00499
28.525	-0.03403		-0.00478	0.00478
28.55	-0.03383		-0.00475	0.00475
28.575	-0.03506		-0.00492	0.00492
28.6	-0.03601		-0.00505	0.00505
28.625	-0.03399		-0.00477	0.00477
28.65	-0.02725		-0.00383	0.00383
28.675	-0.01663		-0.00233	0.00233
28.7	-0.00467		-0.00066	0.00066
28.725	0.00848	0.00119	-0.00119	
28.75	0.02305	0.00324	-0.00324	
28.775	0.03817	0.00536	-0.00536	
28.8	0.04994	0.00701	-0.00701	
28.825	0.06087	0.00854	-0.00854	
28.85	0.08807	0.01124	-0.01124	
28.875	0.08960	0.01258	-0.01258	
28.9	0.09313	0.01307	-0.01307	
28.925	0.08612	0.01209	-0.01209	
28.95	0.07062	0.00991	-0.00991	
28.975	0.04734	0.00664	-0.00664	
29	0.01460	0.00205	-0.00205	
29.025	-0.02917		-0.00409	0.00409
29.05	-0.07801		-0.01106	0.01106
29.075	-0.12172		-0.01708	0.01708
29.1	-0.14869		-0.02087	0.02087
29.125	-0.15844		-0.02224	0.02224
29.15	-0.15270		-0.02143	0.02143
29.175	-0.13177		-0.01849	0.01849
29.2	-0.09515		-0.01335	0.01335
29.225	-0.04655		-0.00653	0.00653
29.25	0.00488	0.00068	-0.00068	
29.275	0.04884	0.00686	-0.00686	
29.3	0.07810	0.01097	-0.01097	
29.325	0.08996	0.01263	-0.01263	
29.35	0.08440	0.01185	-0.01185	
29.375	0.06326	0.00888	-0.00888	
29.4	0.03018	0.00424	-0.00424	
29.425	-0.00860		-0.00121	0.00121
29.45	-0.04709		-0.00661	0.00661
29.475	-0.08213		-0.01153	0.01153
29.5	-0.11264		-0.01581	0.01581
29.525	-0.13638		-0.01914	0.01914
29.55	-0.14796		-0.02077	0.02077
29.575	-0.14478		-0.02032	0.02032
29.6	-0.13077		-0.01835	0.01835
29.625	-0.10988		-0.01541	0.01541
29.65	-0.08197		-0.01150	0.01150
29.675	-0.04852		-0.00681	0.00681
29.7	-0.01519		-0.00213	0.00213
29.725	0.00998	0.00139	-0.00139	
29.75	0.02099	0.00295	-0.00295	

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29.775	0.01077	0.00263	-0.00263	
29.8	0.00653	0.00092	-0.00092	
29.825	-0.01488		-0.00209	0.00209
29.85	-0.04382		-0.00615	0.00615
29.875	-0.07491		-0.01051	0.01051
29.9	-0.10285		-0.01444	0.01444
29.925	-0.11452		-0.01607	0.01607
29.95	-0.11096		-0.01557	0.01557
29.975	-0.09406		-0.01320	0.01320
30	-0.05985		-0.00840	0.00840
.025	-0.00872		-0.00122	0.00122
.05	0.05166	0.00725	-0.00725	
.075	0.11047	0.01550	-0.01550	
0.1	0.15873	0.02228	-0.02228	
30.125	0.18900	0.02653	-0.02653	
30.15	0.19561	0.02745	-0.02745	
30.175	0.17669	0.02480	-0.02480	
30.2	0.13458	0.01889	-0.01889	
30.225	0.07761	0.01089	-0.01089	
30.25	0.01782	0.00250	-0.00250	
30.275	-0.03738		-0.00523	0.00523
30.3	-0.08733		-0.01226	0.01226
30.325	-0.13315		-0.01869	0.01869
30.35	-0.17156		-0.02408	0.02408
30.375	-0.19798		-0.02778	0.02778
30.4	-0.21116		-0.02964	0.02964
30.425	-0.21571		-0.03027	0.03027
30.45	-0.21705		-0.03046	0.03046
30.475	-0.21397		-0.03003	0.03003
30.5	-0.20062		-0.02816	0.02816
30.525	-0.17679		-0.02481	0.02481
30.55	-0.14763		-0.02072	0.02072
30.575	-0.11737		-0.01647	0.01647
30.6	-0.08816		-0.01237	0.01237
30.625	-0.06264		-0.00879	0.00879
30.65	-0.04356		-0.00611	0.00611
30.675	-0.03206		-0.00450	0.00450
30.7	-0.02725		-0.00383	0.00383
30.725	-0.02536		-0.00356	0.00356
30.75	-0.02385		-0.00335	0.00335
30.775	-0.02261		-0.00317	0.00317
30.8	-0.01911		-0.00268	0.00268
30.825	-0.00976		-0.00137	0.00137
30.85	0.00438	0.00061	-0.00061	
30.875	0.01720	0.00241	-0.00241	
30.9	0.02378	0.00334	-0.00334	
30.925	0.02518	0.00353	-0.00353	
30.95	0.02543	0.00357	-0.00357	
30.975	0.02481	0.00348	-0.00348	
31	0.02014	0.00283	-0.00283	
31.025	0.01238	0.00174	-0.00174	
31.05	0.00825	0.00116	-0.00116	
31.075	0.01124	0.00158	-0.00158	
31.1	0.01773	0.00249	-0.00249	
31.125	0.02323	0.00326	-0.00326	
31.15	0.02902	0.00407	-0.00407	
31.175	0.04044	0.00568	-0.00568	
31.2	0.05925	0.00832	-0.00832	
31.225	0.08191	0.01150	-0.01150	
31.25	0.10456	0.01468	-0.01468	

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.275	0.12732	0.01787	-0.01787	
.3	0.15062	0.02114	-0.02114	
31.325	0.17239	0.02420	-0.02420	
31.35	0.18926	0.02656	-0.02656	
31.375	0.19915	0.02795	-0.02795	
31.4	0.20419	0.02866	-0.02866	
31.425	0.20862	0.02928	-0.02928	
31.45	0.21448	0.03010	-0.03010	
31.475	0.22085	0.03100	-0.03100	
31.5	0.22570	0.03168	-0.03168	
31.525	0.22700	0.03186	-0.03186	
31.55	0.22451	0.03151	-0.03151	
31.575	0.21933	0.03078	-0.03078	
31.6	0.21124	0.02965	-0.02965	
31.625	0.19961	0.02802	-0.02802	
31.65	0.18511	0.02598	-0.02598	
31.675	0.16989	0.02384	-0.02384	
31.7	0.15601	0.02190	-0.02190	
31.725	0.14389	0.02020	-0.02020	
31.75	0.13395	0.01880	-0.01880	
31.775	0.12783	0.01794	-0.01794	
31.8	0.12687	0.01781	-0.01781	
31.825	0.12965	0.01820	-0.01820	
31.85	0.13319	0.01869	-0.01869	
31.875	0.13689	0.01921	-0.01921	
31.9	0.13971	0.01961	-0.01961	
31.925	0.14973	0.02101	-0.02101	
31.95	0.15005	0.02106	-0.02106	
31.975	0.15677	0.02200	-0.02200	
32	0.14732	0.02068	-0.02068	
32.025	0.13395	0.01880	-0.01880	
32.05	0.11871	0.01666	-0.01666	
32.075	0.08661	0.01216	-0.01216	
32.1	0.05712	0.00802	-0.00802	
32.125	0.02199	0.00309	-0.00309	
32.15	-0.00512		-0.00072	0.00072
32.175	-0.03119		-0.00438	0.00438
32.2	-0.04842		-0.00680	0.00680
32.225	-0.05542		-0.00778	0.00778
32.25	-0.05340		-0.00749	0.00749
32.275	-0.04622		-0.00649	0.00649
32.3	-0.03841		-0.00539	0.00539
32.325	-0.03323		-0.00466	0.00466
32.35	-0.03293		-0.00462	0.00462
32.375	-0.03912		-0.00549	0.00549
32.4	-0.05038		-0.00707	0.00707
32.425	-0.06287		-0.00882	0.00882
32.45	-0.07524		-0.01056	0.01056
32.475	-0.08805		-0.01236	0.01236
32.5	-0.10015		-0.01406	0.01406
.525	-0.11095		-0.01557	0.01557
.55	-0.12241		-0.01718	0.01718
.575	-0.13753		-0.01930	0.01930
32.6	-0.15891		-0.02230	0.02230
32.625	-0.18741		-0.02630	0.02630
32.65	-0.22011		-0.03089	0.03089
32.675	-0.24975		-0.03505	0.03505
32.7	-0.26820		-0.03764	0.03764
32.725	-0.27100		-0.03804	0.03804
32.75	-0.25877		-0.03632	0.03632

32.775	-0.23480		-0.03295	0.03295
32.8	-0.20243		-0.02841	0.02841
32.825	-0.16467		-0.02311	0.02311
32.85	-0.12721		-0.01785	0.01785
32.875	-0.09957		-0.01397	0.01397
32.9	-0.09038		-0.01268	0.01268
32.925	-0.10229		-0.01436	0.01436
32.95	-0.12966		-0.01820	0.01820
32.975	-0.16363		-0.02297	0.02297
33	-0.19784		-0.02777	0.02777
33.025	-0.22758		-0.03193	0.03193
33.05	-0.24643		-0.03459	0.03459
33.075	-0.24748		-0.03472	0.03472
33.1	-0.22623		-0.03175	0.03175
33.125	-0.18607		-0.02612	0.02612
33.15	-0.13648		-0.01916	0.01916
33.175	-0.08634		-0.01212	0.01212
33.2	-0.03976		-0.00558	0.00558
33.225	0.00177	0.00025	-0.00025	
33.25	0.03456	0.00485	-0.00485	
33.275	0.05539	0.00777	-0.00777	
33.3	0.06563	0.00921	-0.00921	
33.325	0.06862	0.00963	-0.00963	
33.35	0.06653	0.00934	-0.00934	
33.375	0.05949	0.00835	-0.00835	
33.4	0.04797	0.00673	-0.00673	
33.425	0.03392	0.00476	-0.00476	
33.45	0.01965	0.00276	-0.00276	
33.475	0.00695	0.00098	-0.00098	
33.5	-0.00224		-0.00031	0.00031
33.525	-0.00444		-0.00062	0.00062
33.55	0.00283	0.00040	-0.00040	
33.575	0.01780	0.00250	-0.00250	
33.6	0.03555	0.00499	-0.00499	
33.625	0.05242	0.00736	-0.00736	
33.65	0.06881	0.00966	-0.00966	
33.675	0.08589	0.01205	-0.01205	
33.7	0.10257	0.01440	-0.01440	
33.725	0.11743	0.01648	-0.01648	
33.75	0.13025	0.01828	-0.01828	
33.775	0.14168	0.01989	-0.01989	
33.8	0.15179	0.02130	-0.02130	
33.825	0.15898	0.02230	-0.02230	
33.85	0.16188	0.02260	-0.02260	
33.875	0.15719	0.02206	-0.02206	
33.9	0.14675	0.02060	-0.02060	
33.925	0.12931	0.01815	-0.01815	
33.95	0.10618	0.01490	-0.01490	
33.975	0.08158	0.01144	-0.01144	
34	0.05818	0.00815	-0.00815	
34.025	0.04618	0.00647	-0.00647	
34.05	0.04305	0.00604	-0.00604	
34.075	0.04356	0.00611	-0.00611	
34.1	0.04737	0.00665	-0.00665	
34.125	0.05107	0.00717	-0.00717	
34.15	0.05596	0.00785	-0.00785	
34.175	0.05195	0.00729	-0.00729	
34.2	0.03735	0.00524	-0.00524	
34.225	0.01417	0.00199	-0.00199	
34.25	-0.01032		-0.00145	0.00145

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34.275	-0.03208		-0.00450	0.00450
34.3	-0.05029		-0.00706	0.00706
34.325	-0.06304		-0.00885	0.00885
34.35	-0.06687		-0.00938	0.00938
34.375	-0.06015		-0.00844	0.00844
34.4	-0.04552		-0.00639	0.00639
34.425	-0.02847		-0.00400	0.00400
34.45	-0.01339		-0.00188	0.00188
34.475	-0.00233		-0.00033	0.00033
34.5	0.00412	0.00058	-0.00058	
34.525	0.00741	0.00104	-0.00104	
34.55	0.00978	0.00137	-0.00137	
34.575	0.01228	0.00172	-0.00172	
34.6	0.01615	0.00227	-0.00227	
34.625	0.02447	0.00343	-0.00343	
34.65	0.03897	0.00547	-0.00547	
34.675	0.05614	0.00788	-0.00788	
34.7	0.06958	0.00977	-0.00977	
34.725	0.07537	0.01058	-0.01058	
34.75	0.07317	0.01027	-0.01027	
34.775	0.06298	0.00884	-0.00884	
34.8	0.04291	0.00602	-0.00602	
34.825	0.01149	0.00161	-0.00161	
34.85	-0.02813		-0.00395	0.00395
34.875	-0.06926		-0.00972	0.00972
34.9	-0.10718		-0.01503	0.01503
34.925	-0.13963		-0.01960	0.01960
34.95	-0.16385		-0.02300	0.02300
34.975	-0.17496		-0.02456	0.02456
35	-0.17019		-0.02389	0.02389
35.025	-0.15223		-0.02137	0.02137
35.05	-0.12720		-0.01785	0.01785
35.075	-0.10157		-0.01426	0.01426
35.1	-0.07948		-0.01116	0.01116
35.125	-0.06264		-0.00879	0.00879
35.15	-0.05224		-0.00733	0.00733
35.175	-0.04891		-0.00686	0.00686
35.2	-0.04943		-0.00694	0.00694
35.225	-0.04869		-0.00683	0.00683
35.25	-0.04627		-0.00649	0.00649
35.275	-0.03587		-0.00503	0.00503
35.3	-0.01979		-0.00278	0.00278
35.325	-0.00249		-0.00035	0.00035
35.35	0.01394	0.00196	-0.00196	
35.375	0.02610	0.00366	-0.00366	
35.4	0.03241	0.00455	-0.00455	
35.425	0.03233	0.00454	-0.00454	
35.45	0.02709	0.00380	-0.00380	
35.475	0.02011	0.00282	-0.00282	
35.5	0.01434	0.00201	-0.00201	
35.525	0.01056	0.00148	-0.00148	
35.55	0.00793	0.00111	-0.00111	
35.575	0.00599	0.00084	-0.00084	
35.6	0.00586	0.00082	-0.00082	
35.625	0.00812	0.00114	-0.00114	
35.65	0.01131	0.00159	-0.00159	
35.675	0.01382	0.00194	-0.00194	
35.7	0.01609	0.00226	-0.00226	
35.725	0.02039	0.00286	-0.00286	
35.75	0.02806	0.00394	-0.00394	

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35.775	0.03785	0.00531	-0.00531
35.8	0.04742	0.00665	-0.00665
35.825	0.05601	0.00786	-0.00786
35.85	0.06398	0.00898	-0.00898
35.875	0.07069	0.00992	-0.00992
35.9	0.07399	0.01038	-0.01038
35.925	0.07226	0.01014	-0.01014
35.95	0.06633	0.00931	-0.00931
35.975	0.05835	0.00819	-0.00819
36	0.05014	0.00704	-0.00704
.025	0.04326	0.00607	-0.00607
05	0.04004	0.00562	-0.00562
.075	0.04171	0.00585	-0.00585
.1	0.04727	0.00663	-0.00663
36.125	0.05516	0.00774	-0.00774
36.15	0.06407	0.00910	-0.00910
36.175	0.07629	0.01071	-0.01071
36.2	0.08645	0.01213	-0.01213
36.225	0.08915	0.01251	-0.01251
36.25	0.08027	0.01127	-0.01127
36.275	0.06142	0.00862	-0.00862
36.3	0.03692	0.00518	-0.00518
36.325	0.01611	0.00226	-0.00226
36.35	-0.00549	-0.00077	0.00077
36.375	-0.02397	-0.00336	0.00336
36.4	-0.03792	-0.00532	0.00532
36.425	-0.04393	-0.00617	0.00617
36.45	-0.04012	-0.00563	0.00563
36.475	-0.02797	-0.00392	0.00392
36.5	-0.01186	-0.00166	0.00166
36.525	0.00198	0.00027	-0.00027
36.55	0.00977	0.00137	-0.00137
36.575	0.01325	0.00186	-0.00186
36.6	0.01506	0.00211	-0.00211
36.625	0.01593	0.00224	-0.00224
36.65	0.01477	0.00207	-0.00207
36.675	0.01145	0.00161	-0.00161
36.7	0.00754	0.00106	-0.00106
36.725	0.00430	0.00060	-0.00060
36.75	0.00088	0.00012	-0.00012
36.775	-0.00531	-0.00075	0.00075
36.8	-0.01542	-0.00216	0.00216
36.825	-0.02768	-0.00388	0.00388
36.85	-0.03998	-0.00560	0.00560
36.875	-0.05098	-0.00714	0.00714
36.9	-0.05938	-0.00833	0.00833
36.925	-0.06337	-0.00889	0.00889
36.95	-0.06137	-0.00861	0.00861
36.975	-0.05314	-0.00746	0.00746
37	-0.04010	-0.00563	0.00563
37.025	-0.02507	-0.00352	0.00352
37.05	-0.01151	-0.00162	0.00162
37.075	-0.00281	-0.00039	0.00039
37.1	-0.00102	-0.00014	0.00014
37.125	-0.00594	-0.00083	0.00083
37.15	-0.01512	-0.00212	0.00212
37.175	-0.02475	-0.00347	0.00347
37.2	-0.03152	-0.00442	0.00442
37.225	-0.03399	-0.00477	0.00477
37.25	-0.03194	-0.00448	0.00448

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.275	-0.02592	-0.00364	0.00364
.3	-0.01702	-0.00239	0.00239
37.325	-0.00622	-0.00087	0.00087
37.35	0.00482	0.00068	-0.00068
37.375	0.01334	0.00187	-0.00187
37.4	0.01754	0.00246	-0.00246
37.425	0.01812	0.00254	-0.00254
37.45	0.01663	0.00233	-0.00233
37.475	0.01327	0.00186	-0.00186
37.5	0.00792	0.00111	-0.00111
37.525	0.00164	0.00023	-0.00023
37.55	-0.00432	-0.00061	0.00061
37.575	-0.00908	-0.00127	0.00127
37.6	-0.01165	-0.00163	0.00163
37.625	-0.01045	-0.00147	0.00147
37.65	-0.00369	-0.00052	0.00052
37.675	0.00921	0.00129	-0.00129
37.7	0.02678	0.00375	-0.00375
37.725	0.04666	0.00655	-0.00655
37.75	0.06811	0.00956	-0.00956
37.775	0.08971	0.01259	-0.01259
37.8	0.10899	0.01530	-0.01530
37.825	0.12325	0.01730	-0.01730
37.85	0.13077	0.01835	-0.01835
37.875	0.13225	0.01856	-0.01856
37.9	0.12874	0.01807	-0.01807
37.925	0.12005	0.01685	-0.01685
37.95	0.10680	0.01499	-0.01499
37.975	0.09181	0.01289	-0.01289
38	0.07811	0.01096	-0.01096
38.025	0.06662	0.00935	-0.00935
38.05	0.05716	0.00802	-0.00802
38.075	0.04967	0.00697	-0.00697
38.1	0.04274	0.00600	-0.00600
38.125	0.03320	0.00466	-0.00466
38.15	0.01911	0.00268	-0.00268
38.175	0.00145	0.00020	-0.00020
38.2	-0.02004	-0.00281	0.00281
38.225	-0.03381	-0.00474	0.00474
38.25	-0.05211	-0.00731	0.00731
38.275	-0.05823	-0.00817	0.00817
38.3	-0.06124	-0.00859	0.00859
38.325	-0.05504	-0.00772	0.00772
38.35	-0.03648	-0.00512	0.00512
38.375	-0.02394	-0.00336	0.00336
38.4	-0.00320	-0.00045	0.00045
38.425	0.01355	0.00190	-0.00190
38.45	0.02441	0.00343	-0.00343
38.475	0.03341	0.00469	-0.00469
38.5	0.03550	0.00498	-0.00498
.525	0.02841	0.00399	-0.00399
55	0.01434	0.00201	-0.00201
.575	0.00262	0.00037	-0.00037
38.6	-0.01983	-0.00278	0.00278
38.625	-0.03807	-0.00534	0.00534
38.65	-0.06132	-0.00861	0.00861
38.675	-0.07825	-0.01098	0.01098
38.7	-0.08947	-0.01256	0.01256
38.725	-0.09567	-0.01343	0.01343
38.75	-0.09825	-0.01379	0.01379

38.775	-0.09801	-0.01376	0.01376
38.8	-0.09502	-0.01334	0.01334
38.825	-0.09033	-0.01268	0.01268
38.85	-0.08611	-0.01209	0.01209
38.875	-0.08342	-0.01171	0.01171
38.9	-0.08189	-0.01148	0.01148
38.925	-0.08126	-0.01141	0.01141
38.95	-0.08210	-0.01152	0.01152
38.975	-0.08388	-0.01177	0.01177
39	-0.08545	-0.01199	0.01199
39.025	-0.08511	-0.01195	0.01195
39.05	-0.08068	-0.01132	0.01132
39.075	-0.07063	-0.00991	0.00991
39.1	-0.05514	-0.00774	0.00774
39.125	-0.03514	-0.00493	0.00493
39.15	-0.01248	-0.00175	0.00175
39.175	0.00933	0.00131	-0.00131
39.2	0.02763	0.00388	-0.00388
39.225	0.04164	0.00584	-0.00584
39.25	0.05078	0.00712	-0.00712
39.275	0.05426	0.00762	-0.00762
39.3	0.05381	0.00744	-0.00744
39.325	0.04852	0.00681	-0.00681
39.35	0.04273	0.00600	-0.00600
39.375	0.03759	0.00528	-0.00528
39.4	0.03353	0.00471	-0.00471
39.425	0.03020	0.00424	-0.00424
39.45	0.02831	0.00397	-0.00397
39.475	0.02883	0.00405	-0.00405
39.5	0.03147	0.00442	-0.00442
39.525	0.03494	0.00490	-0.00490
39.55	0.03739	0.00525	-0.00525
39.575	0.03713	0.00521	-0.00521
39.6	0.03334	0.00468	-0.00468
39.625	0.02529	0.00355	-0.00355
39.65	0.01277	0.00179	-0.00179
39.675	-0.00201	-0.00028	0.00028
39.7	-0.01558	-0.00219	0.00219
39.725	-0.02568	-0.00360	0.00360
39.75	-0.03096	-0.00435	0.00435
39.775	-0.03099	-0.00435	0.00435
39.8	-0.02625	-0.00368	0.00368
39.825	-0.01706	-0.00239	0.00239
39.85	-0.00434	-0.00061	0.00061
39.875	0.00933	0.00131	-0.00131
39.9	0.02129	0.00299	-0.00299
39.925	0.02986	0.00419	-0.00419
39.95	0.03302	0.00463	-0.00463
39.975	0.02838	0.00398	-0.00398
40	0.01525	0.00214	-0.00214
40.025	-0.00475	-0.00067	0.00067
40.05	-0.02860	-0.00401	0.00401
40.075	-0.05316	-0.00746	0.00746
40.1	-0.07538	-0.01058	0.01058
40.125	-0.09289	-0.01304	0.01304
40.15	-0.10453	-0.01467	0.01467
40.175	-0.10979	-0.01541	0.01541
40.2	-0.10806	-0.01517	0.01517
40.225	-0.09933	-0.01394	0.01394
40.25	-0.08617	-0.01209	0.01209

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40.275	-0.07214	-0.01013	0.01013
40.3	-0.05888	-0.00826	0.00826
40.325	-0.04636	-0.00651	0.00651
40.35	-0.03463	-0.00486	0.00486
40.375	-0.02502	-0.00351	0.00351
40.4	-0.01933	-0.00271	0.00271
40.425	-0.01800	-0.00253	0.00253
40.45	-0.01923	-0.00270	0.00270
40.475	-0.02116	-0.00297	0.00297
40.5	-0.02436	-0.00342	0.00342
40.525	-0.02559	-0.00359	0.00359
40.55	-0.02338	-0.00328	0.00328
40.575	-0.02230	-0.00313	0.00313
40.6	-0.02186	-0.00307	0.00307
40.625	-0.02273	-0.00319	0.00319
40.65	-0.02539	-0.00356	0.00356
40.675	-0.02824	-0.00396	0.00396
40.7	-0.03004	-0.00422	0.00422
40.725	-0.03132	-0.00440	0.00440
40.75	-0.03225	-0.00453	0.00453
40.775	-0.03101	-0.00435	0.00435
40.8	-0.02618	-0.00367	0.00367
40.825	-0.01916	-0.00269	0.00269
40.85	-0.01250	-0.00175	0.00175
40.875	-0.00742	-0.00104	0.00104
40.9	-0.00346	-0.00049	0.00049
40.925	-0.00035	-0.00005	0.00005
40.95	0.00102	0.00026	-0.00026
40.975	0.00397	0.00056	-0.00056
41	0.00744	0.00104	-0.00104
41.025	0.01341	0.00188	-0.00188
41.05	0.02166	0.00304	-0.00304
41.075	0.03002	0.00421	-0.00421
41.1	0.03616	0.00508	-0.00508
41.125	0.03886	0.00545	-0.00545
41.15	0.03803	0.00534	-0.00534
41.175	0.03459	0.00485	-0.00485
41.2	0.03033	0.00426	-0.00426
41.225	0.02685	0.00377	-0.00377
41.25	0.02534	0.00356	-0.00356
41.275	0.02723	0.00382	-0.00382
41.3	0.03294	0.00462	-0.00462
41.325	0.04095	0.00575	-0.00575
41.35	0.04917	0.00690	-0.00690
41.375	0.05580	0.00783	-0.00783
41.4	0.05899	0.00828	-0.00828
41.425	0.05758	0.00808	-0.00808
41.45	0.05173	0.00726	-0.00726
41.475	0.04218	0.00592	-0.00592
41.5	0.02977	0.00418	-0.00418
41.525	0.01550	0.00218	-0.00218
41.55	0.00019	0.00003	-0.00003
41.575	-0.01394	-0.00196	0.00196
41.6	-0.02531	-0.00355	0.00355
41.625	-0.03114	-0.00437	0.00437
41.65	-0.03003	-0.00421	0.00421
41.675	-0.02480	-0.00348	0.00348
41.7	-0.01807	-0.00254	0.00254
41.725	-0.00997	-0.00140	0.00140
41.75	-0.00196	-0.00028	0.00028

000873

41.775	0.00461	0.00065	-0.00065	
41.8	0.00807	0.00113	-0.00113	
41.825	0.00710	0.00100	-0.00100	
41.85	0.00169	0.00024	-0.00024	
41.875	-0.00651		-0.00091	0.00091
41.9	-0.01501		-0.00211	0.00211
41.925	-0.02179		-0.00306	0.00306
41.95	-0.02564		-0.00360	0.00360
41.975	-0.02607		-0.00366	0.00366
42	-0.02293		-0.00322	0.00322
.025	-0.01585		-0.00222	0.00222
05	-0.00494		-0.00069	0.00069
..075	0.00857	0.00120	-0.00120	
42.1	0.02232	0.00313	-0.00313	
42.125	0.03333	0.00468	-0.00468	
42.15	0.03926	0.00551	-0.00551	
42.175	0.03994	0.00561	-0.00561	
42.2	0.03657	0.00513	-0.00513	
42.225	0.02972	0.00417	-0.00417	
42.25	0.02016	0.00283	-0.00283	
42.275	0.01012	0.00142	-0.00142	
42.3	0.00214	0.00030	-0.00030	
42.325	-0.00296		-0.00042	0.00042
42.35	-0.00615		-0.00086	0.00086
42.375	-0.00837		-0.00117	0.00117
42.4	-0.00958		-0.00134	0.00134
42.425	-0.00865		-0.00121	0.00121
42.45	-0.00452		-0.00063	0.00063
42.475	0.00234	0.00033	-0.00033	
42.5	0.01100	0.00154	-0.00154	
42.525	0.02138	0.00300	-0.00300	
42.55	0.03145	0.00441	-0.00441	
42.575	0.04296	0.00603	-0.00603	
42.6	0.05145	0.00722	-0.00722	
42.625	0.05682	0.00797	-0.00797	
42.65	0.05872	0.00824	-0.00824	
42.675	0.06113	0.00858	-0.00858	
42.7	0.06324	0.00888	-0.00888	
42.725	0.06741	0.00946	-0.00946	
42.75	0.07434	0.01043	-0.01043	
42.775	0.08339	0.01170	-0.01170	
42.8	0.09467	0.01329	-0.01329	
42.825	0.10305	0.01446	-0.01446	
42.85	0.10858	0.01524	-0.01524	
42.875	0.10945	0.01536	-0.01536	
42.9	0.10561	0.01482	-0.01482	
42.925	0.09701	0.01362	-0.01362	
42.95	0.08450	0.01186	-0.01186	
42.975	0.07015	0.00985	-0.00985	
43	0.05631	0.00790	-0.00790	
43.025	0.04488	0.00619	-0.00619	
43.05	0.03351	0.00470	-0.00470	
43.075	0.02448	0.00344	-0.00344	
43.1	0.01638	0.00230	-0.00230	
43.125	0.00847	0.00119	-0.00119	
43.15	0.00062	0.00009	-0.00009	
43.175	-0.00701		-0.00098	0.00098
43.2	-0.01394		-0.00196	0.00196
43.225	-0.01917		-0.00269	0.00269
43.25	-0.02198		-0.00308	0.00308

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275	-0.02189		-0.00307	0.00307
.3	-0.01814		-0.00255	0.00255
43.325	-0.01023		-0.00144	0.00144
43.35	0.00163	0.00023	-0.00023	
43.375	0.01566	0.00220	-0.00220	
43.4	0.02865	0.00402	-0.00402	
43.425	0.03768	0.00529	-0.00529	
43.45	0.04098	0.00575	-0.00575	
43.475	0.03807	0.00534	-0.00534	
43.5	0.02968	0.00417	-0.00417	
43.525	0.01743	0.00245	-0.00245	
43.55	0.00311	0.00044	-0.00044	
43.575	-0.01140		-0.00160	0.00160
43.6	-0.02444		-0.00343	0.00343
43.625	-0.03492		-0.00490	0.00490
43.65	-0.04173		-0.00586	0.00586
43.675	-0.04430		-0.00622	0.00622
43.7	-0.04334		-0.00608	0.00608
43.725	-0.04004		-0.00562	0.00562
43.75	-0.03515		-0.00493	0.00493
43.775	-0.02937		-0.00412	0.00412
43.8	-0.02425		-0.00340	0.00340
43.825	-0.02164		-0.00304	0.00304
43.85	-0.02252		-0.00316	0.00316
43.875	-0.02640		-0.00370	0.00370
43.9	-0.03228		-0.00453	0.00453
43.925	-0.03926		-0.00551	0.00551
43.95	-0.04581		-0.00643	0.00643
43.975	-0.05009		-0.00703	0.00703
44	-0.05117		-0.00718	0.00718
44.025	-0.04973		-0.00698	0.00698
44.05	-0.04676		-0.00656	0.00656
44.075	-0.04248		-0.00596	0.00596
44.1	-0.03740		-0.00525	0.00525
44.125	-0.03253		-0.00457	0.00457
44.15	-0.02831		-0.00397	0.00397
44.175	-0.02476		-0.00347	0.00347
44.2	-0.02197		-0.00308	0.00308
44.225	-0.01980		-0.00278	0.00278
44.25	-0.01833		-0.00257	0.00257
44.275	-0.01805		-0.00253	0.00253
44.3	-0.01929		-0.00271	0.00271
44.325	-0.02227		-0.00313	0.00313
44.35	-0.02739		-0.00384	0.00384
44.375	-0.03442		-0.00483	0.00483
44.4	-0.04213		-0.00591	0.00591
44.425	-0.04850		-0.00681	0.00681
44.45	-0.05186		-0.00728	0.00728
44.475	-0.05218		-0.00732	0.00732
.5	-0.05060		-0.00711	0.00711
525	-0.04826		-0.00677	0.00677
55	-0.04486		-0.00630	0.00630
..575	-0.04032		-0.00566	0.00566
44.6	-0.03540		-0.00497	0.00497
44.625	-0.03119		-0.00438	0.00438
44.65	-0.02792		-0.00392	0.00392
44.675	-0.02584		-0.00351	0.00351
44.7	-0.01882		-0.00264	0.00264
44.725	-0.01797		-0.00252	0.00252
44.75	-0.01465		-0.00206	0.00206

44.775	-0.00934		-0.00131	0.00131
44.8	-0.00314		-0.00044	0.00044
44.825	0.00282	0.00040	-0.00040	
44.85	0.01018	0.00143	-0.00143	
44.875	0.01891	0.00265	-0.00265	
44.9	0.02451	0.00344	-0.00344	
44.925	0.03307	0.00464	-0.00464	
44.95	0.03787	0.00532	-0.00532	
44.975	0.04199	0.00589	-0.00589	
45	0.04284	0.00601	-0.00601	
45.025	0.03947	0.00554	-0.00554	
45.05	0.03185	0.00447	-0.00447	
45.075	0.02119	0.00297	-0.00297	
45.1	0.00950	0.00133	-0.00133	
45.125	-0.00106		-0.00015	0.00015
45.15	-0.00858		-0.00120	0.00120
45.175	-0.01199		-0.00168	0.00168
45.2	-0.01094		-0.00154	0.00154
45.225	-0.00551		-0.00077	0.00077
45.25	0.00333	0.00047	-0.00047	
45.275	0.01333	0.00187	-0.00187	
45.3	0.02238	0.00314	-0.00314	
45.325	0.02958	0.00415	-0.00415	
45.35	0.03447	0.00484	-0.00484	
45.375	0.03646	0.00512	-0.00512	
45.4	0.03553	0.00499	-0.00499	
45.425	0.03256	0.00457	-0.00457	
45.45	0.02885	0.00405	-0.00405	
45.475	0.02532	0.00355	-0.00355	
45.5	0.02205	0.00309	-0.00309	
45.525	0.01921	0.00270	-0.00270	
45.55	0.01742	0.00245	-0.00245	
45.575	0.01692	0.00237	-0.00237	
45.6	0.01738	0.00244	-0.00244	
45.625	0.01807	0.00254	-0.00254	
45.65	0.01790	0.00252	-0.00252	
45.675	0.01668	0.00234	-0.00234	
45.7	0.01446	0.00203	-0.00203	
45.725	0.01150	0.00161	-0.00161	
45.75	0.00787	0.00110	-0.00110	
45.775	0.00403	0.00057	-0.00057	
45.8	0.00054	0.00008	-0.00008	
45.825	-0.00220		-0.00031	0.00031
45.85	-0.00380		-0.00053	0.00053
45.875	-0.00438		-0.00061	0.00061
45.9	-0.00472		-0.00066	0.00066
45.925	-0.00538		-0.00075	0.00075
45.95	-0.00613		-0.00086	0.00086
45.975	-0.00668		-0.00093	0.00093
46	-0.00715		-0.00100	0.00100
46.025	-0.00835		-0.00117	0.00117
46.05	-0.01047		-0.00147	0.00147
46.075	-0.01379		-0.00194	0.00194
46.1	-0.01862		-0.00261	0.00261
46.125	-0.02452		-0.00344	0.00344
46.15	-0.03045		-0.00427	0.00427
46.175	-0.03547		-0.00498	0.00498
46.2	-0.03923		-0.00551	0.00551
46.225	-0.04205		-0.00590	0.00590
46.25	-0.04446		-0.00624	0.00624

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46.275	-0.04679		-0.00657	0.00657
46.3	-0.04909		-0.00689	0.00689
46.325	-0.05155		-0.00724	0.00724
46.35	-0.05420		-0.00761	0.00761
46.375	-0.05624		-0.00789	0.00789
46.4	-0.05615		-0.00788	0.00788
46.425	-0.05295		-0.00743	0.00743
46.45	-0.04697		-0.00659	0.00659
46.475	-0.03916		-0.00550	0.00550
46.5	-0.03052		-0.00428	0.00428
46.525	-0.02232		-0.00313	0.00313
46.55	-0.01588		-0.00223	0.00223
46.575	-0.01184		-0.00166	0.00166
46.6	-0.01009		-0.00142	0.00142
46.625	-0.00993		-0.00139	0.00139
46.65	-0.01086		-0.00141	0.00141
46.675	-0.00952		-0.00134	0.00134
46.7	-0.00796		-0.00112	0.00112
46.725	-0.00520		-0.00073	0.00073
46.75	-0.00131		-0.00018	0.00018
46.775	0.00333	0.00047	-0.00047	
46.8	0.00807	0.00113	-0.00113	
46.825	0.01219	0.00171	-0.00171	
46.85	0.01498	0.00210	-0.00210	
46.875	0.01591	0.00223	-0.00223	
46.9	0.01279	0.00180	-0.00180	
46.925	0.01331	0.00187	-0.00187	
46.95	0.01080	0.00152	-0.00152	
46.975	0.00682	0.00096	-0.00096	
47	0.00397	0.00056	-0.00056	
47.025	0.00157	0.00022	-0.00022	
47.05	0.00039	0.00005	-0.00005	
47.075	0.00042	0.00006	-0.00006	
47.1	0.00146	0.00021	-0.00021	
47.125	0.00334	0.00047	-0.00047	
47.15	0.00629	0.00088	-0.00088	
47.175	0.01083	0.00152	-0.00152	
47.2	0.01657	0.00233	-0.00233	
47.225	0.02280	0.00320	-0.00320	
47.25	0.02969	0.00417	-0.00417	
47.275	0.03732	0.00524	-0.00524	
47.3	0.04489	0.00630	-0.00630	
47.325	0.05147	0.00722	-0.00722	
47.35	0.05606	0.00787	-0.00787	
47.375	0.05783	0.00812	-0.00812	
47.4	0.05711	0.00802	-0.00802	
47.425	0.05429	0.00762	-0.00762	
47.45	0.04904	0.00688	-0.00688	
47.475	0.04178	0.00586	-0.00586	
47.5	0.03384	0.00475	-0.00475	
47.525	0.02642	0.00371	-0.00371	
47.55	0.02079	0.00292	-0.00292	
47.575	0.01806	0.00254	-0.00254	
47.6	0.01841	0.00258	-0.00258	
47.625	0.02136	0.00300	-0.00300	
47.65	0.02617	0.00367	-0.00367	
47.675	0.03147	0.00442	-0.00442	
47.7	0.03570	0.00501	-0.00501	
47.725	0.03802	0.00534	-0.00534	
47.75	0.03835	0.00538	-0.00538	

47.775	0.03696	0.00519	-0.00519	
47.8	0.03396	0.00477	-0.00477	
47.825	0.02955	0.00415	-0.00415	
47.85	0.02486	0.00338	-0.00338	
47.875	0.01794	0.00252	-0.00252	
47.9	0.01188	0.00166	-0.00166	
47.925	0.00631	0.00089	-0.00089	
47.95	0.00277	0.00039	-0.00039	
47.975	0.00068	0.00000	-0.00000	
48	0.00138	0.00019	-0.00019	
.025	0.00388	0.00054	-0.00054	
05	0.00685	0.00096	-0.00096	
..075	0.01208	0.00170	-0.00170	
48.1	0.01538	0.00216	-0.00216	
48.125	0.01752	0.00246	-0.00246	
48.15	0.01667	0.00234	-0.00234	
48.175	0.01269	0.00178	-0.00178	
48.2	0.00657	0.00092	-0.00092	
48.225	-0.00093		-0.00013	0.00013
48.25	-0.00924		-0.00130	0.00130
48.275	-0.01767		-0.00248	0.00248
48.3	-0.02559		-0.00359	0.00359
48.325	-0.03225		-0.00453	0.00453
48.35	-0.03676		-0.00516	0.00516
48.375	-0.03868		-0.00543	0.00543
48.4	-0.03788		-0.00532	0.00532
48.425	-0.03451		-0.00484	0.00484
48.45	-0.02954		-0.00415	0.00415
48.475	-0.02404		-0.00337	0.00337
48.5	-0.01852		-0.00260	0.00260
48.525	-0.01364		-0.00191	0.00191
48.55	-0.01039		-0.00146	0.00146
48.575	-0.00959		-0.00135	0.00135
48.6	-0.01150		-0.00161	0.00161
48.625	-0.01537		-0.00216	0.00216
48.65	-0.01983		-0.00278	0.00278
48.675	-0.02394		-0.00336	0.00336
48.7	-0.02729		-0.00383	0.00383
48.725	-0.02971		-0.00417	0.00417
48.75	-0.03120		-0.00438	0.00438
48.775	-0.03154		-0.00443	0.00443
48.8	-0.03079		-0.00432	0.00432
48.825	-0.02954		-0.00415	0.00415
48.85	-0.02842		-0.00399	0.00399
48.875	-0.02784		-0.00391	0.00391
48.9	-0.02785		-0.00391	0.00391
48.925	-0.02798		-0.00393	0.00393
48.95	-0.02734		-0.00384	0.00384
48.975	-0.02517		-0.00353	0.00353
49	-0.02130		-0.00299	0.00299
49.025	-0.01636		-0.00230	0.00230
49.05	-0.01096		-0.00154	0.00154
49.075	-0.00631		-0.00089	0.00089
49.1	-0.00371		-0.00052	0.00052
49.125	-0.00156		-0.00022	0.00022
49.15	0.00066	0.00009	-0.00009	
49.175	0.00049	0.00007	-0.00007	
49.2	-0.00001		0.00000	0.00000
49.225	-0.00008		-0.00001	0.00001
49.25	0.00108	0.00015	-0.00015	

275	0.00355	0.00050	-0.00050	
..3	0.00674	0.00095	-0.00095	
49.325	0.01035	0.00145	-0.00145	
49.35	0.01406	0.00197	-0.00197	
49.375	0.01700	0.00239	-0.00239	
49.4	0.01828	0.00257	-0.00257	
49.425	0.01771	0.00249	-0.00249	
49.45	0.01561	0.00219	-0.00219	
49.475	0.01283	0.00180	-0.00180	
49.5	0.01054	0.00148	-0.00148	
49.525	0.00951	0.00133	-0.00133	
49.55	0.01010	0.00142	-0.00142	
49.575	0.01284	0.00180	-0.00180	
49.6	0.01806	0.00253	-0.00253	
49.625	0.02514	0.00353	-0.00353	
49.65	0.03278	0.00460	-0.00460	
49.675	0.04003	0.00562	-0.00562	
49.7	0.04638	0.00651	-0.00651	
49.725	0.05132	0.00720	-0.00720	
49.75	0.05436	0.00763	-0.00763	
49.775	0.05493	0.00771	-0.00771	
49.8	0.05239	0.00735	-0.00735	
49.825	0.04676	0.00656	-0.00656	
49.85	0.03868	0.00543	-0.00543	
49.875	0.02849	0.00400	-0.00400	
49.9	0.01648	0.00231	-0.00231	
49.925	0.00367	0.00052	-0.00052	
49.95	-0.00843		-0.00118	0.00118
49.975	-0.01843		-0.00259	0.00259
50	-0.02560		-0.00359	0.00359
50.025	-0.02986		-0.00419	0.00419
50.05	-0.03166		-0.00444	0.00444
50.075	-0.03188		-0.00447	0.00447
50.1	-0.03158		-0.00443	0.00443
50.125	-0.03138		-0.00440	0.00440
50.15	-0.03118		-0.00438	0.00438
50.175	-0.03072		-0.00431	0.00431
50.2	-0.02963		-0.00416	0.00416
50.225	-0.02751		-0.00386	0.00386
50.25	-0.02393		-0.00336	0.00336
50.275	-0.01886		-0.00265	0.00265
50.3	-0.01320		-0.00185	0.00185
50.325	-0.00833		-0.00117	0.00117
50.35	-0.00523		-0.00073	0.00073
50.375	-0.00419		-0.00059	0.00059
50.4	-0.00481		-0.00068	0.00068
50.425	-0.00669		-0.00094	0.00094
50.45	-0.00976		-0.00137	0.00137
50.475	-0.01357		-0.00190	0.00190
0.5	-0.01735		-0.00244	0.00244
525	-0.02054		-0.00288	0.00288
55	-0.02306		-0.00324	0.00324
.575	-0.02507		-0.00352	0.00352
50.6	-0.02681		-0.00376	0.00376
50.625	-0.02830		-0.00397	0.00397
0.65	-0.02937		-0.00412	0.00412
50.675	-0.02995		-0.00420	0.00420
50.7	-0.03008		-0.00422	0.00422
50.725	-0.02974		-0.00417	0.00417
50.75	-0.02886		-0.00405	0.00405

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50.775	-0.02737		-0.00384	0.00384
50.8	-0.02222		-0.00312	0.00312
50.825	-0.01929		-0.00271	0.00271
50.85	-0.01582		-0.00222	0.00222
50.875	-0.01161		-0.00163	0.00163
50.9	-0.00734		-0.00103	0.00103
50.925	-0.00267		-0.00038	0.00038
50.95	0.00138	0.00019	-0.00019	
50.975	0.00525	0.00074	-0.00074	
51	0.00631	0.00089	-0.00089	
51.025	0.01204	0.00169	-0.00169	
51.05	0.01027	0.00144	-0.00144	
51.075	0.01310	0.00184	-0.00184	
51.1	0.00948	0.00133	-0.00133	
51.125	0.01306	0.00183	-0.00183	
51.15	0.01099	0.00154	-0.00154	
51.175	0.01211	0.00170	-0.00170	

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FERMCO - OSDF
GE3900-9.11
Layer 2 - Cover Acceleration
Synthetic - B2-SYN
MAX= 0.14264
MIN= -0.13084

Acceleration = $\frac{\text{Shear Stress}}{\text{Normal Stress } (\sigma_n)}$

$\sigma_n = 3ft \times 0.125 kcf$
$= 0.375 ksf$

Normal stress calculated at top of layer in question

Time	Shear Stress	Accleration	(-)
0	0.000043	0.00011	-0.00011
.925	0.000024	0.00006	-0.00006
.15	0.000042	0.00011	-0.00011
.075	0.000022	0.00006	-0.00006
.1	0.00004 0.00011	-0.00011	
0.125	0.000021	0.00006	-0.00006
0.15	0.000039	0.00010	-0.00010
0.175	0.000019	0.00005	-0.00005
0.2	0.000037	0.00010	-0.00010
0.225	0.000016	0.00004	-0.00004
0.25	0.000034	0.00009	-0.00009
0.275	0.000013	0.00003	-0.00003
0.3	0.00003 0.00000	-0.00000	
0.325	0.000009	0.00002	-0.00002
0.35	0.000025	0.00007	-0.00007
0.375	0.000002	0.00001	-0.00001
0.4	0.000016	0.00004	-0.00004
0.425	-0.00001	-0.00003	0.00003
0.45	-0.000001	0.00000 0.00000	
0.475	-0.000035	-0.00009	0.00009
0.5	-0.000042	-0.00011	0.00011
0.525	-0.0001 -0.00027	0.00027	
0.55	-0.000129	-0.00034	0.00034 ← check
0.575	-0.000202	-0.00054	0.00054
0.6	-0.00024	-0.00064	0.00064
0.625	-0.000316	-0.00084	0.00084
0.65	-0.000357	-0.00095	0.00095
0.675	-0.000445	-0.00119	0.00119
0.7	-0.000504	-0.00134	0.00134
0.725	-0.000598	-0.00159	0.00159
0.75	-0.000628	-0.00167	0.00167
0.775	-0.000654	-0.00174	0.00174
0.8	-0.000593	-0.00158	0.00158
0.825	-0.00052	-0.00139	0.00139
0.85	-0.000403	-0.00107	0.00107
0.875	-0.000388	-0.00103	0.00103
0.9	-0.000402	-0.00107	0.00107
0.925	-0.000434	-0.00116	0.00116
0.95	-0.000349	-0.00093	0.00093
0.975	-0.000272	-0.00073	0.00073
1	-0.000234	-0.00062	0.00062
1.025	-0.000379	-0.00101	0.00101
1.05	-0.000601	-0.00160	0.00160
1.075	-0.000885	-0.00236	0.00236
1.1	-0.001094	-0.00292	0.00292
1.125	-0.001307	-0.00349	0.00349
1.15	-0.00151	-0.00403	0.00403
1.175	-0.001785	-0.00476	0.00476
1.2	-0.001953	-0.00521	0.00521
1.225	-0.001983	-0.00529	0.00529
1.25	-0.001767	-0.00471	0.00471

$Acc = \frac{-0.000129}{0.375}$
$= -0.00034$ ✓

.275	-0.001394	-0.00372	0.00372
.3	-0.000845	-0.00225	0.00225
1.325	-0.000323	-0.00086	0.00086
1.35	0.000088	0.00023	-0.00023
1.375	0.000203	0.00054	-0.00054
1.4	0.000187	0.00050	-0.00050
1.425	0.00006 0.00016	-0.00016	
1.45	-0.000274	-0.00073	0.00073
1.475	-0.000988	-0.00263	0.00263
1.5	-0.001754	-0.00468	0.00468
1.525	-0.002243	-0.00598	0.00598
1.55	-0.002245	-0.00599	0.00599
1.575	-0.001989	-0.00530	0.00530
1.6	-0.001674	-0.00446	0.00446
1.625	-0.001513	-0.00403	0.00403
1.65	-0.001148	-0.00306	0.00306
1.675	-0.000401	-0.00107	0.00107
1.7	0.000621	0.00166	-0.00166
1.725	0.001369	0.00365	-0.00365
1.75	0.001485	0.00396	-0.00396
1.775	0.00078 0.00208	-0.00208	
1.8	-0.000706	-0.00188	0.00188
1.825	-0.002959	-0.00789	0.00789
1.85	-0.005191	-0.01384	0.01384
1.875	-0.006278	-0.01674	0.01674
1.9	-0.005624	-0.01500	0.01500
1.925	-0.004007	-0.01069	0.01069
1.95	-0.002101	-0.00560	0.00560
1.975	-0.000486	-0.00130	0.00130
2	0.000334	0.00089	-0.00089
2.025	0.000613	0.00163	-0.00163
2.05	0.001435	0.00383	-0.00383
2.075	0.002683	0.00715	-0.00715
2.1	0.003425	0.00913	-0.00913
2.125	0.003836	0.01023	-0.01023
2.15	0.004584	0.01222	-0.01222
2.175	0.004603	0.01227	-0.01227
2.2	0.004053	0.01081	-0.01081
2.225	0.004137	0.01103	-0.01103
2.25	0.004797	0.01279	-0.01279
2.275	0.005575	0.01487	-0.01487
2.3	0.006479	0.01728	-0.01728
2.325	0.006972	0.01859	-0.01859
2.35	0.0067 0.01787	-0.01787	
2.375	0.005304	0.01414	-0.01414
2.4	0.003555	0.00948	-0.00948
2.425	0.002734	0.00729	-0.00729
2.45	0.0027 0.00720	-0.00720	
2.475	0.002528	0.00674	-0.00674
2.5	0.002616	0.00698	-0.00698
.525	0.003894	0.00825	-0.00825
.5	0.003877	0.01034	-0.01034
.575	0.004814	0.01284	-0.01284
2.6	0.005485	0.01463	-0.01463
2.625	0.004944	0.01318	-0.01318
2.65	0.003405	0.00908	-0.00908
2.675	0.00111 0.00296	-0.00296	
2.7	-0.002268	-0.00605	0.00605
2.725	-0.005314	-0.01417	0.01417
2.75	-0.006396	-0.01706	0.01706

2.775	-0.006697	-0.01786	0.01786
2.8	-0.007339	-0.01957	0.01957
2.825	-0.00868	-0.02315	0.02315
2.85	-0.010735	-0.02863	0.02863
2.875	-0.012381	-0.03302	0.03302
2.9	-0.012181	-0.03248	0.03248
2.925	-0.010452	-0.02787	0.02787
2.95	-0.007728	-0.02061	0.02061
2.975	-0.004647	-0.01239	0.01239
3	-0.001823	-0.00486	0.00486
3.025	-0.000539	-0.00144	0.00144
3.05	-0.001775	-0.00473	0.00473
3.075	-0.004601	-0.01227	0.01227
3.1	-0.006577	-0.01754	0.01754
3.125	-0.006613	-0.01763	0.01763
3.15	-0.005477	-0.01461	0.01461
3.175	-0.003186	-0.00828	0.00828
3.2	0.000802	0.00214	-0.00214
3.225	0.003247	0.00866	-0.00866
3.25	0.003004	0.00801	-0.00801
3.275	0.002197	0.00586	-0.00586
3.3	0.000714	0.00190	-0.00190
3.325	-0.002574	-0.00686	0.00686
3.35	-0.007129	-0.01901	0.01901
3.375	-0.012532	-0.03342	0.03342
3.4	-0.015967	-0.04258	0.04258
3.425	-0.016577	-0.04421	0.04421
3.45	-0.016732	-0.04462	0.04462
3.475	-0.015467	-0.04125	0.04125
3.5	-0.010731	-0.02862	0.02862
3.525	-0.004092	-0.01091	0.01091
3.55	0.003433	0.00915	-0.00915
3.575	0.012526	0.03340	-0.03340
3.6	0.022842	0.06091	-0.06091
3.625	0.031215	0.08324	-0.08324
3.65	0.033129	0.08834	-0.08834
3.675	0.027232	0.07262	-0.07262
3.7	0.019939	0.05317	-0.05317
3.725	0.018171	0.04846	-0.04846
3.75	0.019987	0.05330	-0.05330
3.775	0.019275	0.05140	-0.05140
3.8	0.01572 0.04192	-0.04192	
3.825	0.01361 0.03629	-0.03629	
3.85	0.015453	0.04121	-0.04121
3.875	0.019692	0.05251	-0.05251
3.9	0.02367 0.06312	-0.06312	
3.925	0.02559 0.06824	-0.06824	
3.95	0.025364	0.06764	-0.06764
3.975	0.024221	0.06459	-0.06459
4	0.02268 0.06048	-0.06048	
4.025	0.019022	0.05073	-0.05073
4.05	0.013208	0.03522	-0.03522
4.075	0.00635 0.01693	-0.01693	
4.1	-0.001981	-0.00528	0.00528
4.125	-0.010517	-0.02805	0.02805
4.15	-0.016392	-0.04371	0.04371
4.175	-0.020617	-0.05498	0.05498
4.2	-0.023035	-0.06143	0.06143
4.225	-0.01986	-0.05296	0.05296
4.25	-0.011775	-0.03140	0.03140

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4.275	-0.006054	-0.01614	0.01614
4.3	-0.004912	-0.01310	0.01310
4.325	-0.005255	-0.01401	0.01401
4.35	-0.004697	-0.01253	0.01253
4.375	-0.001397	-0.00373	0.00373
4.4	0.001749	0.00466	-0.00466
4.425	0.000043	0.00011	-0.00011
4.45	-0.005326	-0.01420	0.01420
4.475	-0.011188	-0.02983	0.02983
4.5	-0.01647	-0.04392	0.04392
4.525	-0.018869	-0.05032	0.05032
4.55	-0.014915	-0.03977	0.03977
4.575	-0.008473	-0.02259	0.02259
4.6	-0.006215	-0.01657	0.01657
4.625	-0.009626	-0.02567	0.02567
4.65	-0.015476	-0.04127	0.04127
4.675	-0.018055	-0.04815	0.04815
4.7	-0.015122	-0.04033	0.04033
4.725	-0.01077	-0.02872	0.02872
4.75	-0.01023	-0.02728	0.02728
4.775	-0.015605	-0.04161	0.04161
4.8	-0.0214 -0.05707	0.05707	
4.825	-0.021114	-0.05630	0.05630
4.85	-0.015678	-0.04181	0.04181
4.875	-0.008461	-0.02256	0.02256
4.9	-0.001156	-0.00308	0.00308
4.925	0.003326	0.00887	-0.00887
4.95	0.002618	0.00698	-0.00698
4.975	-0.002473	-0.00659	0.00659
5	-0.006936	-0.01850	0.01850
5.025	-0.006052	-0.01614	0.01614
5.05	0.001174	0.00313	-0.00313
5.075	0.012494	0.03332	-0.03332
5.1	0.025889	0.06904	-0.06904
5.125	0.039851	0.10414	-0.10414
5.15	0.048634	0.12969	-0.12969
5.175	0.051629	0.13768	-0.13768
5.2	0.046504	0.12401	-0.12401
5.225	0.034881	0.09302	-0.09302
5.25	0.019959	0.05322	-0.05322
5.275	0.002578	0.00687	-0.00687
5.3	-0.015352	-0.04094	0.04094
5.325	-0.029436	-0.07850	0.07850
5.35	-0.03356	-0.08949	0.08949
5.375	-0.025847	-0.06893	0.06893
5.4	-0.014324	-0.03820	0.03820
5.425	-0.009807	-0.02402	0.02402
5.45	-0.009986	-0.02663	0.02663
5.475	-0.009921	-0.02646	0.02646
5.5	-0.005425	-0.01447	0.01447
5.525	-0.000292	-0.00078	0.00078
5.55	0.00156 0.00416	-0.00416	
5.575	-0.000238	-0.00063	0.00063
5.6	-0.003032	-0.00809	0.00809
5.625	-0.005618	-0.01498	0.01498
5.65	-0.008427	-0.02247	0.02247
5.675	-0.010809	-0.02882	0.02882
5.7	-0.011625	-0.03100	0.03100
5.725	-0.010633	-0.02835	0.02835
5.75	-0.009235	-0.02463	0.02463

5.775	-0.007622	-0.02033	0.02033
5.8	-0.002543	-0.00678	0.00678
5.825	0.006819	0.01818 -0.01818	
5.85	0.015184	0.04049 -0.04049	
5.875	0.016981	0.04528 -0.04528	
5.9	0.014549	0.03880 -0.03880	
5.925	0.013404	0.03574 -0.03574	
5.95	0.012886	0.03223 -0.03223	
5.975	0.004675	0.01247 -0.01247	
6	-0.006643	-0.01771	0.01771
6.025	-0.017831	-0.04755	0.04755
6.05	-0.030918	-0.08245	0.08245
6.075	-0.043518	-0.11605	0.11605
6.1	-0.048581	-0.12955	0.12955
6.125	-0.046245	-0.12332	0.12332
6.15	-0.039798	-0.10613	0.10613
6.175	-0.030996	-0.08266	0.08266
6.2	-0.019838	-0.05290	0.05290
6.225	-0.005049	-0.01346	0.01346
6.25	0.012284	0.03276 -0.03276	
6.275	0.028972	0.07726 -0.07726	
6.3	0.040670	0.10847 -0.10847	
6.325	0.044195	0.11785 -0.11785	
6.35	0.042793	0.11411 -0.11411	
6.375	0.039109	0.10429 -0.10429	
6.4	0.033384	0.08902 -0.08902	
6.425	0.02809 0.07491	-0.07491	
6.45	0.023884	0.06369 -0.06369	
6.475	0.018956	0.05055 -0.05055	
6.5	0.012572	0.03353 -0.03353	
6.525	0.002834	0.00756 -0.00756	
6.55	-0.009607	-0.02562	0.02562
6.575	-0.01932	-0.05152	0.05152
6.6	-0.024131	-0.06435	0.06435
6.625	-0.028975	-0.07727	0.07727
6.65	-0.034671	-0.09246	0.09246
6.675	-0.035916	-0.09578	0.09578
6.7	-0.031441	-0.08384	0.08384
6.725	-0.026601	-0.07094	0.07094
6.75	-0.024097	-0.06426	0.06426
6.775	-0.022236	-0.05930	0.05930
6.8	-0.019025	-0.05073	0.05073
6.825	-0.014845	-0.03959	0.03959
6.85	-0.012268	-0.03271	0.03271
6.875	-0.008595	-0.02292	0.02292
6.9	0.003062	0.00817 -0.00817	
6.925	0.019674	0.05246 -0.05246	
6.95	0.031095	0.08292 -0.08292	
6.975	0.033574	0.08953 -0.08953	
7	0.030265	0.08071 -0.08071	
7.025	0.026268	0.07005 -0.07005	
7.05	0.025508	0.06802 -0.06802	
7.075	0.023303	0.06214 -0.06214	
7.1	0.0157 0.04187	-0.04187	
7.125	0.007148	0.01906 -0.01906	
7.15	0.001549	0.00413 -0.00413	
7.175	0.000192	0.00051 -0.00051	
7.2	0.002784	0.00742 -0.00742	
7.225	0.004894	0.01305 -0.01305	
7.25	0.005011	0.01336 -0.01336	

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7.275	0.006646	0.01772 -0.01772	
7.3	0.009877	0.02634 -0.02634	
7.325	0.012788	0.03410 -0.03410	
7.35	0.018059	0.04816 -0.04816	
7.375	0.027306	0.07282 -0.07282	
7.4	0.034998	0.09333 -0.09333	
7.425	0.035262	0.09403 -0.09403	
7.45	0.029165	0.07777 -0.07777	
7.475	0.019632	0.05235 -0.05235	
7.5	0.009596	0.02559 -0.02559	
7.525	-0.000156	-0.00042	0.00042
7.55	-0.00981	-0.02616	0.02616
7.575	-0.015988	-0.04263	0.04263
7.6	-0.015707	-0.04189	0.04189
7.625	-0.009146	-0.02439	0.02439
7.65	0.00169 0.00451	-0.00451	
7.675	0.012168	0.03245 -0.03245	
7.7	0.018375	0.04900 -0.04900	
7.725	0.020503	0.05467 -0.05467	
7.75	0.020623	0.05499 -0.05499	
7.775	0.018097	0.04826 -0.04826	
7.8	0.01169 0.03117	-0.03117	
7.825	0.000788	0.00210 -0.00210	
7.85	-0.01264	-0.03371	0.03371
7.875	-0.023249	-0.06200	0.06200
7.9	-0.025059	-0.06682	0.06682
7.925	-0.017652	-0.04707	0.04707
7.95	-0.007307	-0.01949	0.01949
7.975	-0.001216	-0.00324	0.00324
8	-0.003542	-0.00945	0.00945
8.025	-0.011932	-0.03182	0.03182
8.05	-0.019197	-0.05119	0.05119
8.075	-0.021107	-0.05629	0.05629
8.1	-0.017135	-0.04569	0.04569
8.125	-0.009860	-0.02631	0.02631
8.15	-0.00357	-0.00952	0.00952
8.175	-0.000305	-0.00081	0.00081
8.2	0.002275	0.00607 -0.00607	
8.225	0.00442 0.01179	-0.01179	
8.25	0.003755	0.01001 -0.01001	
8.275	0.000972	0.00259 -0.00259	
8.3	-0.001286	-0.00343	0.00343
8.325	-0.00454	-0.01211	0.01211
8.35	-0.010386	-0.02770	0.02770
8.375	-0.015605	-0.04161	0.04161
8.4	-0.020239	-0.05397	0.05397
8.425	-0.030856	-0.08015	0.08015
8.45	-0.042969	-0.11458	0.11458
8.475	-0.049066	-0.13084	0.13084
8.5	-0.044547	-0.11879	0.11879
8.525	-0.034748	-0.09266	0.09266
8.55	-0.024191	-0.06451	0.06451
8.575	-0.013633	-0.03635	0.03635
8.6	-0.00421	-0.01123	0.01123
8.625	0.002414	0.00644 -0.00644	
8.65	0.006579	0.01754 -0.01754	
8.675	0.008599	0.02293 -0.02293	
8.7	0.007371	0.01966 -0.01966	
8.725	0.002362	0.00630 -0.00630	
8.75	-0.003528	-0.00941	0.00941

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8.775	-0.00953	-0.02541	0.02541
8.8	-0.014004	-0.03734	0.03734
8.825	-0.01275	-0.03400	0.03400
8.85	-0.006243	-0.01665	0.01665
8.875	0.001606	0.00428 -0.00428	
8.9	0.007666	0.02044 -0.02044	
8.925	0.010833	0.02889 -0.02889	
8.95	0.012862	0.03430 -0.03430	
8.975	0.015195	0.04052 -0.04052	
9	0.016639	0.04437 -0.04437	
9.025	0.017362	0.04630 -0.04630	
9.05	0.016701	0.04454 -0.04454	
9.075	0.010693	0.02851 -0.02851	
9.1	0.000515	0.00137 -0.00137	
9.125	-0.009499	-0.02533	0.02533
9.15	-0.017788	-0.04743	0.04743
9.175	-0.024187	-0.06450	0.06450
9.2	-0.024637	-0.06570	0.06570
9.225	-0.014893	-0.03971	0.03971
9.25	0.002763	0.00737 -0.00737	
9.275	0.023424	0.06246 -0.06246	
9.3	0.041685	0.11116 -0.11116	
9.325	0.051479	0.13728 -0.13728	
9.35	0.05349 0.14264	-0.14264	
9.375	0.051498	0.13733 -0.13733	
9.4	0.046127	0.12301 -0.12301	
9.425	0.037798	0.10079 -0.10079	
9.45	0.027699	0.07386 -0.07386	
9.475	0.017455	0.04655 -0.04655	
9.5	0.007603	0.02027 -0.02027	
9.525	-0.002282	-0.00609	0.00609
9.55	-0.008832	-0.02355	0.02355
9.575	-0.010588	-0.02823	0.02823
9.6	-0.008552	-0.02281	0.02281
9.625	-0.002615	-0.00697	0.00697
9.65	0.003531	0.00942 -0.00942	
9.675	0.003633	0.00969 -0.00969	
9.7	-0.000033	-0.00009	0.00009
9.725	0.001373	0.00366 -0.00366	
9.75	0.00887 0.02365	-0.02365	
9.775	0.016213	0.04323 -0.04323	
9.8	0.022102	0.05894 -0.05894	
9.825	0.027174	0.07246 -0.07246	
9.85	0.027981	0.07440 -0.07440	
9.875	0.022809	0.06082 -0.06082	
9.9	0.018891	0.05038 -0.05038	
9.925	0.021861	0.05616 -0.05616	
9.95	0.022849	0.06093 -0.06093	
9.975	0.01624 0.04331	-0.04331	
10	0.002519	0.00672 -0.00672	
10.025	-0.013162	-0.03510	0.03510
10.05	-0.024701	-0.06587	0.06587
10.075	-0.026938	-0.07183	0.07183
10.1	-0.026294	-0.07012	0.07012
10.125	-0.032916	-0.08778	0.08778
10.15	-0.04332	-0.11552	0.11552
10.175	-0.04904	-0.13077	0.13077
10.2	-0.046927	-0.12514	0.12514
10.225	-0.038649	-0.10306	0.10306
10.25	-0.026086	-0.06956	0.06956

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10.275	-0.013574	-0.03620	0.03620
10.3	-0.006768	-0.01805	0.01805
10.325	-0.005045	-0.01345	0.01345
10.35	-0.004853	-0.01294	0.01294
10.375	-0.005568	-0.01485	0.01485
10.4	-0.007865	-0.02097	0.02097
10.425	-0.011871	-0.03166	0.03166
10.45	-0.014149	-0.03773	0.03773
10.475	-0.010028	-0.02674	0.02674
10.5	0.001293	0.00345 -0.00345	
10.525	0.014229	0.03794 -0.03794	
10.55	0.020547	0.05479 -0.05479	
10.575	0.017271	0.04606 -0.04606	
10.6	0.010435	0.02783 -0.02783	
10.625	0.0058 0.01547	-0.01547	
10.65	0.003571	0.00952 -0.00952	
10.675	0.002281	0.00608 -0.00608	
10.7	0.001277	0.00341 -0.00341	
10.725	0.000201	0.00054 -0.00054	
10.75	-0.001523	-0.00406	0.00406
10.775	-0.00179	-0.00477	0.00477
10.8	0.002104	0.00561 -0.00561	
10.825	0.007734	0.02062 -0.02062	
10.85	0.011514	0.03070 -0.03070	
10.875	0.009149	0.02440 -0.02440	
10.9	-0.000821	-0.00219	0.00219
10.925	-0.012945	-0.03452	0.03452
10.95	-0.020668	-0.05511	0.05511
10.975	-0.023288	-0.06210	0.06210
11	-0.022634	-0.06036	0.06036
11.025	-0.018279	-0.04874	0.04874
11.05	-0.010782	-0.02875	0.02875
11.075	-0.000357	-0.00095	0.00095
11.1	0.015004	0.04001 -0.04001	
11.125	0.029926	0.07980 -0.07980	
11.15	0.034872	0.09299 -0.09299	
11.175	0.0299 0.07973	-0.07973	
11.2	0.021506	0.05735 -0.05735	
11.225	0.014116	0.03764 -0.03764	
11.25	0.010595	0.02825 -0.02825	
11.275	0.010782	0.02875 -0.02875	
11.3	0.012452	0.03321 -0.03321	
11.325	0.01411 0.03763	-0.03763	
11.35	0.015073	0.04019 -0.04019	
11.375	0.013834	0.03689 -0.03689	
11.4	0.011977	0.03194 -0.03194	
11.425	0.015466	0.04124 -0.04124	
11.45	0.022382	0.05947 -0.05947	
11.475	0.020845	0.05559 -0.05559	
11.5	0.008615	0.02297 -0.02297	
11.525	-0.006137	-0.01637	0.01637
11.55	-0.015228	-0.04061	0.04061
11.575	-0.017509	-0.04669	0.04669
11.6	-0.017387	-0.04637	0.04637
11.625	-0.017356	-0.04628	0.04628
11.65	-0.015351	-0.04094	0.04094
11.675	-0.008639	-0.02304	0.02304
11.7	0.000488	0.00130 -0.00130	
11.725	0.007991	0.02131 -0.02131	
11.75	0.016528	0.04407 -0.04407	

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11.775	0.027475	0.07327	-0.07327
11.8	0.03543	0.09448	-0.09448
11.825	0.033959	0.09856	-0.09856
11.85	0.022387	0.05970	-0.05970
11.875	0.007066	0.01884	-0.01884
11.9	-0.006488	-0.01730	0.01730
11.925	-0.017159	-0.04576	0.04576
11.95	-0.025319	-0.06752	0.06752
11.975	-0.032401	-0.08640	0.08640
12	-0.037055	-0.09881	0.09881
12.025	-0.03647	-0.09725	0.09725
12.05	-0.031539	-0.08410	0.08410
12.075	-0.025737	-0.06863	0.06863
12.1	-0.020560	-0.05485	0.05485
12.125	-0.014432	-0.03849	0.03849
12.15	-0.004934	-0.01316	0.01316
12.175	0.002899	0.00773	-0.00773
12.2	0.00499	0.01331	-0.01331
12.225	0.005488	0.01463	-0.01463
12.25	0.006977	0.01861	-0.01861
12.275	0.007584	0.02022	-0.02022
12.3	0.006415	0.01711	-0.01711
12.325	0.004457	0.01189	-0.01189
12.35	-0.001624	-0.00433	0.00433
12.375	-0.014681	-0.03915	0.03915
12.4	-0.027206	-0.07276	0.07276
12.425	-0.03178	-0.08475	0.08475
12.45	-0.028798	-0.07679	0.07679
12.475	-0.022812	-0.06083	0.06083
12.5	-0.017637	-0.04703	0.04703
12.525	-0.017624	-0.04700	0.04700
12.55	-0.024091	-0.06424	0.06424
12.575	-0.031453	-0.08387	0.08387
12.6	-0.032228	-0.08594	0.08594
12.625	-0.02554	-0.06811	0.06811
12.65	-0.015051	-0.04014	0.04014
12.675	-0.005344	-0.01425	0.01425
12.7	-0.002348	-0.00626	0.00626
12.725	-0.004684	-0.01249	0.01249
12.75	-0.003002	-0.00801	0.00801
12.775	0.005189	0.01384	-0.01384
12.8	0.014409	0.03842	-0.03842
12.825	0.021447	0.05719	-0.05719
12.85	0.027487	0.07330	-0.07330
12.875	0.030952	0.08254	-0.08254
12.9	0.030805	0.08215	-0.08215
12.925	0.029438	0.07850	-0.07850
12.95	0.023986	0.06396	-0.06396
12.975	0.013963	0.03723	-0.03723
13	0.010039	0.02677	-0.02677
13.025	0.012893	0.03438	-0.03438
13.05	0.011648	0.03106	-0.03106
13.075	0.003994	0.01065	-0.01065
13.1	-0.004849	-0.01293	0.01293
13.125	-0.013482	-0.03595	0.03595
13.15	-0.021664	-0.05777	0.05777
13.175	-0.026735	-0.07129	0.07129
13.2	-0.027705	-0.07388	0.07388
13.225	-0.028268	-0.07538	0.07538
13.25	-0.029111	-0.07763	0.07763

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13.275	-0.026166	-0.06978	0.06978
13.3	-0.01932	-0.05152	0.05152
13.325	-0.010851	-0.02894	0.02894
13.35	0.000611	0.00163	-0.00163
13.375	0.012802	0.03414	-0.03414
13.4	0.020425	0.05447	-0.05447
13.425	0.024205	0.06455	-0.06455
13.45	0.023188	0.06183	-0.06183
13.475	0.011478	0.03061	-0.03061
13.5	-0.004952	-0.01321	0.01321
13.525	-0.01296	-0.03456	0.03456
13.55	-0.009336	-0.02490	0.02490
13.575	-0.006638	-0.00170	0.00170
13.6	0.007759	0.02069	-0.02069
13.625	0.016559	0.04416	-0.04416
13.65	0.026163	0.06977	-0.06977
13.675	0.03159	0.08424	-0.08424
13.7	0.029676	0.07914	-0.07914
13.725	0.024037	0.06410	-0.06410
13.75	0.016396	0.04372	-0.04372
13.775	0.003933	0.01049	-0.01049
13.8	-0.010308	-0.02749	0.02749
13.825	-0.02004	-0.05344	0.05344
13.85	-0.023204	-0.06188	0.06188
13.875	-0.02179	-0.05811	0.05811
13.9	-0.017503	-0.04667	0.04667
13.925	-0.012115	-0.03231	0.03231
13.95	-0.007204	-0.01942	0.01942
13.975	-0.00287	-0.00765	0.00765
14	0.002212	0.00590	-0.00590
14.025	0.007872	0.02099	-0.02099
14.05	0.01161	0.03096	-0.03096
14.075	0.012406	0.03308	-0.03308
14.1	0.013562	0.03617	-0.03617
14.125	0.015824	0.04220	-0.04220
14.15	0.014291	0.03811	-0.03811
14.175	0.004099	0.01093	-0.01093
14.2	-0.009501	-0.02534	0.02534
14.225	-0.018222	-0.04859	0.04859
14.25	-0.02165	-0.05773	0.05773
14.275	-0.023739	-0.06330	0.06330
14.3	-0.026269	-0.07005	0.07005
14.325	-0.028393	-0.07571	0.07571
14.35	-0.027593	-0.07358	0.07358
14.375	-0.020917	-0.05578	0.05578
14.4	-0.007082	-0.01889	0.01889
14.425	0.009117	0.02431	-0.02431
14.45	0.02083	0.05555	-0.05555
14.475	0.025807	0.06882	-0.06882
14.5	0.027043	0.07211	-0.07211
14.525	0.028007	0.07469	-0.07469
14.55	0.029701	0.07942	-0.07942
14.575	0.031611	0.08430	-0.08430
14.6	0.030112	0.08030	-0.08030
14.625	0.022771	0.06072	-0.06072
14.65	0.014776	0.03940	-0.03940
14.675	0.011922	0.03179	-0.03179
14.7	0.011471	0.03059	-0.03059
14.725	0.006201	0.01654	-0.01654
14.75	-0.005372	-0.01433	0.01433

14.775	-0.018587	-0.04957	0.04957
14.8	-0.02671	-0.07123	0.07123
14.825	-0.025649	-0.06840	0.06840
14.85	-0.01920	-0.05141	0.05141
14.875	-0.016374	-0.04366	0.04366
14.9	-0.018811	-0.05016	0.05016
14.925	-0.020985	-0.05596	0.055[illegible]
14.95	-0.018191	-0.04851	0.048[illegible]
14.975	-0.011726	-0.03127	0.03127
15	-0.007254	-0.01934	0.01934
15.025	-0.008633	-0.02302	0.02302
15.05	-0.014008	-0.03735	0.03735
15.075	-0.019131	-0.05102	0.05102
15.1	-0.021051	-0.05614	0.05614
15.125	-0.019480	-0.05197	0.05197
15.15	-0.015565	-0.04151	0.04151
15.175	-0.011427	-0.03047	0.03047
15.2	-0.008841	-0.02358	0.02358
15.225	-0.006872	-0.01833	0.01833
15.25	-0.004626	-0.01234	0.01234
15.275	-0.004670	-0.01247	0.01247
15.3	-0.007495	-0.01999	0.01999
15.325	-0.010971	-0.02926	0.02926
15.35	-0.012112	-0.03230	0.03230
15.375	-0.00929	-0.02477	0.02477
15.4	-0.005025	-0.01340	0.01340
15.425	-0.002096	-0.00559	0.00559
15.45	-0.001013	-0.00270	0.00270
15.475	-0.001076	-0.00287	0.00287
15.5	-0.000042	-0.00011	0.00011
15.525	0.001555	0.00415	-0.00415
15.55	0.0009	0.00240	-0.00240
15.575	-0.001516	-0.00404	0.00404
15.6	-0.000836	-0.00223	0.00223
15.625	0.006418	0.01711	-0.01711
15.65	0.01701	0.04536	-0.04536
15.675	0.026341	0.07024	-0.07024
15.7	0.034039	0.09077	-0.09077
15.725	0.0403	0.10747	-0.10747
15.75	0.043414	0.11577	-0.11577
15.775	0.03076	0.10336	-0.10336
15.8	0.027573	0.07353	-0.07353
15.825	0.017401	0.04662	-0.04662
15.85	0.011573	0.03086	-0.03086
15.875	0.007231	0.01928	-0.01928
15.9	0.002418	0.00645	-0.00645
15.925	-0.002054	-0.00548	0.00548
15.95	-0.0017	-0.00453	0.00453
15.975	0.006084	0.01622	-0.01622
16	0.019134	0.05102	-0.05102
16.025	0.030806	0.08215	-0.08215
16.05	0.034459	0.09189	-0.09189
16.075	0.033265	0.08871	-0.08871
16.1	0.034365	0.09164	-0.09164
16.125	0.035671	0.09512	-0.09512
16.15	0.032689	0.08717	-0.08717
16.175	0.026816	0.07151	-0.07151
16.2	0.020241	0.05398	-0.05398
16.225	0.015211	0.04056	-0.04056
16.25	0.01672	0.04459	-0.04459

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16.275	0.023297	0.06213	-0.06213
16.3	0.026177	0.06981	-0.06981
16.325	0.02292	0.06112	-0.06112
16.35	0.019003	0.05067	-0.05067
16.375	0.015465	0.04124	-0.04124
16.4	0.012114	0.03230	-0.03230
16.425	0.013219	0.03525	-0.03525
16.45	0.016589	0.04402	-0.04402
16.475	0.013352	0.03561	-0.03561
16.5	0.003003	0.00801	-0.00801
16.525	-0.008395	-0.02239	0.02239
16.55	-0.016322	-0.04353	0.04353
16.575	-0.020459	-0.05456	0.05456
16.6	-0.019989	-0.05309	0.05309
16.625	-0.015761	-0.04203	0.04203
16.65	-0.010325	-0.02753	0.02753
16.675	-0.001715	-0.00457	0.00457
16.7	0.012299	0.03280	-0.03280
16.725	0.024926	0.06647	-0.06647
16.75	0.026088	0.06957	-0.06957
16.775	0.016589	0.04424	-0.04424
16.8	0.005574	0.01486	-0.01486
16.825	-0.001355	-0.00361	0.00361
16.85	-0.005875	-0.01567	0.01567
16.875	-0.011361	-0.03030	0.03030
16.9	-0.016584	-0.04422	0.04422
16.925	-0.019177	-0.05114	0.05114
16.95	-0.018296	-0.04879	0.04879
16.975	-0.016251	-0.04334	0.04334
17	-0.013139	-0.03504	0.03504
17.025	-0.004729	-0.01261	0.01261
17.05	0.008602	0.02294	-0.02294
17.075	0.021578	0.05754	-0.05754
17.1	0.030198	0.08053	-0.08053
17.125	0.032159	0.08576	-0.08576
17.15	0.026351	0.07027	-0.07027
17.175	0.014606	0.03895	-0.03895
17.2	0.001975	0.00527	-0.00527
17.225	-0.008028	-0.02141	0.02141
17.25	-0.015046	-0.04012	0.04012
17.275	-0.02148	-0.05728	0.05728
17.3	-0.029113	-0.07763	0.07763
17.325	-0.036085	-0.09623	0.09623
17.35	-0.038493	-0.10265	0.10265
17.375	-0.035544	-0.09478	0.09478
17.4	-0.031927	-0.08514	0.08514
17.425	-0.032133	-0.08569	0.08569
17.45	-0.032648	-0.08706	0.08706
17.475	-0.02594	-0.06917	0.06917
17.5	-0.012562	-0.03350	0.03350
17.525	-0.001731	-0.00462	0.00462
17.55	0.00317	0.00845	-0.00845
17.575	0.004617	0.01231	-0.01231
17.6	0.004466	0.01191	-0.01191
17.625	0.002768	0.00738	-0.00738
17.65	-0.001838	-0.00490	0.00490
17.675	-0.009433	-0.02515	0.02515
17.7	-0.018316	-0.04884	0.04884
17.725	-0.028534	-0.07609	0.07609
17.75	-0.037444	-0.09985	0.09985

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17.775	-0.039902	-0.10641	0.10641
17.8	-0.034646	-0.09239	0.09239
17.825	-0.027576	-0.07354	0.07354
17.85	-0.024104	-0.06428	0.06428
17.875	-0.022024	-0.05873	0.05873
17.9	-0.01776	-0.04736	0.04736
17.925	-0.012295	-0.03279	0.03279
17.95	-0.008548	-0.02279	0.02279
17.975	-0.006501	-0.01734	0.01734
18	-0.005003	-0.01355	0.01355
18.025	-0.005501	-0.01467	0.01467
18.05	-0.008563	-0.02283	0.02283
18.075	-0.014604	-0.03894	0.03894
18.1	-0.019345	-0.05159	0.05159
18.125	-0.0176 -0.04693	0.04693	
18.15	-0.011842	-0.03158	0.03158
18.175	-0.007923	-0.02113	0.02113
18.2	-0.006931	-0.01848	0.01848
18.225	-0.007174	-0.01913	0.01913
18.25	-0.006299	-0.01680	0.01680
18.275	-0.003449	-0.00920	0.00920
18.3	-0.00262	-0.00699	0.00699
18.325	-0.004901	-0.01307	0.01307
18.35	-0.005743	-0.01531	0.01531
18.375	-0.007029	-0.01874	0.01874
18.4	-0.010123	-0.02699	0.02699
18.425	-0.010309	-0.02749	0.02749
18.45	-0.00649	-0.01731	0.01731
18.475	-0.001210	-0.00325	0.00325
18.5	0.002805	0.00748 -0.00748	
18.525	0.003347	0.00893 -0.00893	
18.55	0.003485	0.00929 -0.00929	
18.575	0.008592	0.02291 -0.02291	
18.6	0.018296	0.04879 -0.04879	
18.625	0.026986	0.07196 -0.07196	
18.65	0.032032	0.08542 -0.08542	
18.675	0.034097	0.09093 -0.09093	
18.7	0.033155	0.08841 -0.08841	
18.725	0.029992	0.07998 -0.07998	
18.75	0.027816	0.07418 -0.07418	
18.775	0.028466	0.07591 -0.07591	
18.8	0.029263	0.07803 -0.07803	
18.825	0.025526	0.06807 -0.06807	
18.85	0.019577	0.05221 -0.05221	
18.875	0.016641	0.04438 -0.04438	
18.9	0.01671 0.04456	-0.04456	
18.925	0.016638	0.04437 -0.04437	
18.95	0.01408 0.03755	-0.03755	
18.975	0.008263	0.02203 -0.02203	
19	0.00833 0.00888	-0.00888	
19.025	-0.008193	-0.02185	0.02185
19.05	-0.016034	-0.04276	0.04276
19.075	-0.021744	-0.05798	0.05798
19.1	-0.022918	-0.06111	0.06111
19.125	-0.019367	-0.05165	0.05165
19.15	-0.012719	-0.03392	0.03392
19.175	-0.005444	-0.01452	0.01452
19.2	0.001194	0.00318 -0.00318	
19.225	0.009104	0.02428 -0.02428	
19.25	0.018824	0.05020 -0.05020	

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19.275	0.028039	0.07477 -0.07477	
19.3	0.035945	0.09585 -0.09585	
19.325	0.041196	0.10986 -0.10986	
19.35	0.040439	0.10784 -0.10784	
19.375	0.034201	0.09120 -0.09120	
19.4	0.026837	0.07157 -0.07157	
19.425	0.019112	0.05097 -0.05097	
19.45	0.01807 0.02899	-0.02899	
19.475	0.003093	0.00825 -0.00825	
19.5	-0.001904	-0.00508	0.00508
19.525	-0.003526	-0.00940	0.00940
19.55	-0.006157	-0.01642	0.01642
19.575	-0.011609	-0.03096	0.03096
19.6	-0.016409	-0.04376	0.04376
19.625	-0.019024	-0.05073	0.05073
19.65	-0.019707	-0.05255	0.05255
19.675	-0.019632	-0.05235	0.05235
19.7	-0.019130	-0.05103	0.05103
19.725	-0.017 -0.04533	0.04533	
19.75	-0.013574	-0.03620	0.03620
19.775	-0.010936	-0.02916	0.02916
19.8	-0.009954	-0.02654	0.02654
19.825	-0.011360	-0.03031	0.03031
19.85	-0.01506	-0.04016	0.04016
19.875	-0.017777	-0.04741	0.04741
19.9	-0.015277	-0.04074	0.04074
19.925	-0.008009	-0.02136	0.02136
19.95	0.008797	0.00213 -0.00213	
19.975	0.007637	0.02037 -0.02037	
20	0.00979 0.02611	-0.02611	
20.025	0.007341	0.01958 -0.01958	
20.05	0.001498	0.00399 -0.00399	
20.075	-0.004392	-0.01171	0.01171
20.1	-0.006512	-0.01737	0.01737
20.125	-0.007628	-0.02034	0.02034
20.15	-0.010533	-0.02809	0.02809
20.175	-0.014923	-0.03979	0.03979
20.2	-0.016079	-0.04821	0.04821
20.225	-0.01777	-0.04739	0.04739
20.25	-0.016743	-0.04465	0.04465
20.275	-0.017586	-0.04690	0.04690
20.3	-0.020184	-0.05382	0.05382
20.325	-0.024305	-0.06481	0.06481
20.35	-0.027927	-0.07447	0.07447
20.375	-0.028643	-0.07638	0.07638
20.4	-0.02757	-0.07352	0.07352
20.425	-0.026839	-0.07157	0.07157
20.45	-0.024083	-0.06422	0.06422
20.475	-0.017471	-0.04659	0.04659
20.5	-0.009998	-0.02666	0.02666
20.525	-0.006099	-0.01626	0.01626
20.55	-0.006112	-0.01630	0.01630
20.575	-0.006243	-0.01665	0.01665
20.6	-0.004071	-0.01086	0.01086
20.625	-0.000283	-0.00075	0.00075
20.65	0.005533	0.01475 -0.01475	
20.675	0.012739	0.03397 -0.03397	
20.7	0.017487	0.04663 -0.04663	
20.725	0.016616	0.04431 -0.04431	
20.75	0.012176	0.03247 -0.03247	

20.775	0.009101	0.02448 -0.02448	
20.8	0.009446	0.02519 -0.02519	
20.825	0.010959	0.02922 -0.02922	
20.85	0.013891	0.03491 -0.03491	
20.875	0.016061	0.04283 -0.04283	
20.9	0.018425	0.04913 -0.04913	
20.925	0.016437	0.04383 -0.04383	
20.95	0.009655	0.02575 -0.02575	
20.975	0.002779	0.00741 -0.00741	
21	0.000313	0.00083 -0.00083	
21.025	0.000857	0.00229 -0.00229	
21.05	0.000357	0.00095 -0.00095	
21.075	-0.001771	-0.00472	0.00472
21.1	-0.003646	-0.00972	0.00972
21.125	-0.003417	-0.00911	0.00911
21.15	-0.000138	-0.00037	0.00037
21.175	0.005103	0.01361 -0.01361	
21.2	0.011462	0.03057 -0.03057	
21.225	0.017721	0.04726 -0.04726	
21.25	0.021825	0.05820 -0.05820	
21.275	0.02247 0.05992	-0.05992	
21.3	0.019542	0.05211 -0.05211	
21.325	0.013974	0.03726 -0.03726	
21.35	0.008846	0.02359 -0.02359	
21.375	0.004844	0.01292 -0.01292	
21.4	0.000433	0.00115 -0.00115	
21.425	-0.002547	-0.00679	0.00679
21.45	-0.001538	-0.00410	0.00410
21.475	0.001417	0.00378 -0.00378	
21.5	0.003958	0.01055 -0.01055	
21.525	0.006275	0.01673 -0.01673	
21.55	0.008976	0.02394 -0.02394	
21.575	0.012695	0.03385 -0.03385	
21.6	0.018745	0.04999 -0.04999	
21.625	0.024062	0.06417 -0.06417	
21.65	0.023421	0.06246 -0.06246	
21.675	0.0165 0.04400	-0.04400	
21.7	0.006564	0.01750 -0.01750	
21.725	-0.00299	-0.00797	0.00797
21.75	-0.009645	-0.02572	0.02572
21.775	-0.013677	-0.03647	0.03647
21.8	-0.01667	-0.04445	0.04445
21.825	-0.019378	-0.05167	0.05167
21.85	-0.020988	-0.05575	0.05575
21.875	-0.018882	-0.05014	0.05014
21.9	-0.010932	-0.02915	0.02915
21.925	0.000277	0.00074 -0.00074	
21.95	0.010714	0.02857 -0.02857	
21.975	0.018678	0.04981 -0.04981	
22	0.024555	0.06548 -0.06548	
22.025	0.0276 0.07360	-0.07360	
22.05	0.028576	0.07620 -0.07620	
22.075	0.029147	0.07773 -0.07773	
22.1	0.026397	0.07039 -0.07039	
22.125	0.017589	0.04690 -0.04690	
22.15	0.005903	0.01574 -0.01574	
22.175	-0.003784	-0.01009	0.01009
22.2	-0.007593	-0.02025	0.02025
22.225	-0.005264	-0.01404	0.01404
22.25	-0.000035	-0.00009	0.00009

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22.275	0.004251	0.01134 -0.01134	
22.3	0.00661 0.01763	-0.01763	
22.325	0.007452	0.01987 -0.01987	
22.35	0.006236	0.01663 -0.01663	
22.375	0.002834	0.00756 -0.00756	
22.4	-0.000629	-0.00168	0.00168
22.425	-0.002898	-0.00773	0.00773
22.45	-0.005678	-0.01514	0.01514
22.475	-0.010449	-0.02786	0.02786
22.5	-0.015558	-0.04149	0.04149
22.525	-0.017893	-0.04771	0.04771
22.55	-0.015156	-0.04042	0.04042
22.575	-0.011164	-0.02977	0.02977
22.6	-0.011136	-0.02970	0.02970
22.625	-0.012886	-0.03436	0.03436
22.65	-0.010341	-0.02758	0.02758
22.675	-0.002893	-0.00771	0.00771
22.7	0.005287	0.01410 -0.01410	
22.725	0.010526	0.02807 -0.02807	
22.75	0.010897	0.02906 -0.02906	
22.775	0.007100	0.01895 -0.01895	
22.8	0.003126	0.00834 -0.00834	
22.825	0.002136	0.00570 -0.00570	
22.85	0.003554	0.00948 -0.00948	
22.875	0.003807	0.01037 -0.01037	
22.9	0.001145	0.00305 -0.00305	
22.925	-0.002507	-0.00669	0.00669
22.95	-0.003462	-0.00923	0.00923
22.975	-0.002382	-0.00635	0.00635
23	-0.001503	-0.00401	0.00401
23.025	-0.001043	-0.00278	0.00278
23.05	-0.000974	-0.00260	0.00260
23.075	-0.003222	-0.00859	0.00859
23.1	-0.009078	-0.02421	0.02421
23.125	-0.017285	-0.04609	0.04609
23.15	-0.025011	-0.06670	0.06670
23.175	-0.031336	-0.08356	0.08356
23.2	-0.036598	-0.09759	0.09759
23.225	-0.039471	-0.10526	0.10526
23.25	-0.038485	-0.10263	0.10263
23.275	-0.034539	-0.09210	0.09210
23.3	-0.028775	-0.07673	0.07673
23.325	-0.022332	-0.05955	0.05955
23.35	-0.016224	-0.04326	0.04326
23.375	-0.010560	-0.02818	0.02818
23.4	-0.00409	-0.01091	0.01091
23.425	0.002666	0.00711 -0.00711	
23.45	0.00854 0.02277	-0.02277	
23.475	0.01397 0.03725	-0.03725	
23.5	0.018635	0.04969 -0.04969	
23.525	0.021029	0.05608 -0.05608	
23.55	0.020561	0.05483 -0.05483	
23.575	0.016178	0.04314 -0.04314	
23.6	0.008243	0.02198 -0.02198	
23.625	-0.000818	-0.00218	0.00218
23.65	-0.008858	-0.02362	0.02362
23.675	-0.014429	-0.03848	0.03848
23.7	-0.016622	-0.04433	0.04433
23.725	-0.015279	-0.04074	0.04074
23.75	-0.010663	-0.02843	0.02843

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23.775	-0.00524	-0.01397	0.01397
23.8	-0.001773	-0.00473	0.00473
23.825	-0.000419	-0.00112	0.00112
23.85	0.000586	0.00156	-0.00156
23.875	0.001542	0.00411	-0.00411
23.9	0.001806	0.00482	-0.00482
23.925	0.001439	0.00384	-0.00384
23.95	0.001079	0.00288	-0.00288
23.975	0.0008	0.00213	-0.00213
24	0.000952	0.00254	-0.00254
025	0.001003	0.00267	-0.00267
05	0.000621	0.00166	-0.00166
.075	0.00087	0.00232	-0.00232
24.1	0.003944	0.01052	-0.01052
24.125	0.010677	0.02847	-0.02847
24.15	0.017649	0.04706	-0.04706
24.175	0.021085	0.05623	-0.05623
24.2	0.024035	0.06409	-0.06409
24.225	0.029720	0.07927	-0.07927
24.25	0.03437	0.09165	-0.09165
24.275	0.033703	0.08987	-0.08987
24.3	0.029933	0.07982	-0.07982
24.325	0.025895	0.06905	-0.06905
24.35	0.021423	0.05713	-0.05713
24.375	0.017799	0.04746	-0.04746
24.4	0.016652	0.04441	-0.04441
24.425	0.01529	0.04077	-0.04077
24.45	0.011691	0.03118	-0.03118
24.475	0.00728	0.01941	-0.01941
24.5	0.004151	0.01107	-0.01107
24.525	0.002527	0.00674	-0.00674
24.55	0.001763	0.00470	-0.00470
24.575	0.00119	0.00317	-0.00317
24.6	0.000598	0.00159	-0.00159
24.625	-0.000173	-0.00046	0.00046
24.65	-0.000359	-0.00096	0.00096
24.675	0.001254	0.00334	-0.00334
24.7	0.004674	0.01246	-0.01246
24.725	0.007627	0.02034	-0.02034
24.75	0.009017	0.02405	-0.02405
24.775	0.009584	0.02556	-0.02556
24.8	0.009799	0.02613	-0.02613
24.825	0.009368	0.02498	-0.02498
24.85	0.009302	0.02481	-0.02481
24.875	0.009741	0.02598	-0.02598
24.9	0.00784	0.02091	-0.02091
24.925	0.001841	0.00491	-0.00491
24.95	-0.005939	-0.01584	0.01584
24.975	-0.01286	-0.03429	0.03429
25	-0.017335	-0.04623	0.04623
25.025	-0.018532	-0.04942	0.04942
25.05	-0.017203	-0.04587	0.04587
25.075	-0.016337	-0.04357	0.04357
25.1	-0.017463	-0.04657	0.04657
25.125	-0.01963	-0.05235	0.05235
25.15	-0.021688	-0.05783	0.05783
25.175	-0.024318	-0.06485	0.06485
25.2	-0.027427	-0.07314	0.07314
25.225	-0.029021	-0.07739	0.07739
25.25	-0.028714	-0.07657	0.07657

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275	-0.027986	-0.07442	0.07442
.3	-0.02591	-0.06909	0.06909
25.325	-0.021915	-0.05844	0.05844
25.35	-0.017359	-0.04629	0.04629
25.375	-0.014659	-0.03909	0.03909
25.4	-0.013718	-0.03658	0.03658
25.425	-0.012725	-0.03393	0.03393
25.45	-0.010981	-0.02928	0.02928
25.475	-0.009656	-0.02575	0.02575
25.5	-0.009057	-0.02415	0.02415
25.525	-0.00839	-0.02237	0.02237
25.55	-0.008443	-0.02251	0.02251
25.575	-0.010564	-0.02817	0.02817
25.6	-0.013819	-0.03685	0.03685
25.625	-0.017287	-0.04610	0.04610
25.65	-0.020014	-0.05337	0.05337
25.675	-0.020536	-0.05476	0.05476
25.7	-0.017917	-0.04778	0.04778
25.725	-0.013723	-0.03659	0.03659
25.75	-0.010355	-0.02761	0.02761
25.775	-0.008409	-0.02242	0.02242
25.8	-0.00706	-0.01883	0.01883
25.825	-0.005519	-0.01472	0.01472
25.85	-0.003199	-0.00853	0.00853
25.875	-0.000513	-0.00137	0.00137
25.9	0.002742	0.00731	-0.00731
25.925	0.006483	0.01729	-0.01729
25.95	0.009707	0.02589	-0.02589
25.975	0.012925	0.03447	-0.03447
26	0.01795	0.04787	-0.04787
26.025	0.023546	0.06279	-0.06279
26.05	0.026405	0.07041	-0.07041
26.075	0.025158	0.06709	-0.06709
26.1	0.021884	0.05836	-0.05836
26.125	0.019468	0.05191	-0.05191
26.15	0.018665	0.04977	-0.04977
26.175	0.016736	0.04463	-0.04463
26.2	0.012416	0.03311	-0.03311
26.225	0.008494	0.02265	-0.02265
26.25	0.007326	0.01954	-0.01954
26.275	0.007571	0.02019	-0.02019
26.3	0.007958	0.02122	-0.02122
26.325	0.008981	0.02395	-0.02395
26.35	0.010845	0.02892	-0.02892
26.375	0.01246	0.03323	-0.03323
26.4	0.013016	0.03471	-0.03471
26.425	0.012614	0.03364	-0.03364
26.45	0.012342	0.03291	-0.03291
26.475	0.012177	0.03247	-0.03247
26.5	0.012214	0.03257	-0.03257
525	0.012875	0.03433	-0.03433
55	0.013952	0.03721	-0.03721
.575	0.014421	0.03846	-0.03846
26.6	0.013856	0.03695	-0.03695
26.625	0.012814	0.03417	-0.03417
6.65	0.012504	0.03334	-0.03334
26.675	0.013011	0.03683	-0.03683
26.7	0.016123	0.04299	-0.04299
26.725	0.017457	0.04655	-0.04655
26.75	0.017378	0.04634	-0.04634

26.775	0.017639	0.04704	-0.04704
26.8	0.019088	0.05069	-0.05069
26.825	0.019013	0.05070	-0.05070
26.85	0.015697	0.04186	-0.04186
26.875	0.009523	0.02539	-0.02539
26.9	0.001711	0.00456	-0.00456
26.925	-0.006607	-0.01762	0.01762
26.95	-0.012543	-0.03345	0.03345
26.975	-0.014323	-0.03819	0.03819
27	-0.013181	-0.03515	0.03515
27.025	-0.011398	-0.03039	0.03039
27.05	-0.009242	-0.02465	0.02465
27.075	-0.006097	-0.01626	0.01626
27.1	-0.002413	-0.00643	0.00643
27.125	0.000504	0.00134	-0.00134
27.15	0.002556	0.00682	-0.00682
27.175	0.004106	0.01095	-0.01095
27.2	0.004496	0.01199	-0.01199
27.225	0.002231	0.00595	-0.00595
27.25	-0.002227	-0.00594	0.00594
27.275	-0.006513	-0.01737	0.01737
27.3	-0.00860	-0.02315	0.02315
27.325	-0.00946	-0.02523	0.02523
27.35	-0.009458	-0.02522	0.02522
27.375	-0.007668	-0.02045	0.02045
27.4	-0.004014	-0.01070	0.01070
27.425	0.000024	0.00006	-0.00006
27.45	0.004037	0.01077	-0.01077
27.475	0.007297	0.01946	-0.01946
27.5	0.007914	0.02110	-0.02110
27.525	0.006548	0.01746	-0.01746
27.55	0.00493	0.01315	-0.01315
27.575	0.001511	0.00403	-0.00403
27.6	-0.003811	-0.01016	0.01016
27.625	-0.008834	-0.02356	0.02356
27.65	-0.011883	-0.03169	0.03169
27.675	-0.012759	-0.03402	0.03402
27.7	-0.012546	-0.03346	0.03346
27.725	-0.012567	-0.03351	0.03351
27.75	-0.012482	-0.03329	0.03329
27.775	-0.011425	-0.03047	0.03047
27.8	-0.008853	-0.02361	0.02361
27.825	-0.005871	-0.01566	0.01566
27.85	-0.004228	-0.01127	0.01127
27.875	-0.004233	-0.01129	0.01129
27.9	-0.004311	-0.01150	0.01150
27.925	-0.003576	-0.00954	0.00954
27.95	-0.002192	-0.00585	0.00585
27.975	-0.000578	-0.00154	0.00154
28	0.000349	0.00093	-0.00093
28.025	0.000294	0.00078	-0.00078
28.05	0.000484	0.00129	-0.00129
28.075	0.000965	0.00257	-0.00257
28.1	0.001938	0.00517	-0.00517
28.125	0.003105	0.00828	-0.00828
28.15	0.003386	0.00903	-0.00903
28.175	0.002214	0.00590	-0.00590
28.2	0.000139	0.00037	-0.00037
28.225	-0.001942	-0.00518	0.00518
28.25	-0.00265	-0.00707	0.00707

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28.275	-0.001662	-0.00443	0.00443
28.3	-0.000861	-0.00230	0.00230
28.325	-0.001862	-0.00497	0.00497
28.35	-0.003567	-0.00951	0.00951
28.375	-0.004259	-0.01136	0.01136
28.4	-0.003332	-0.00889	0.00889
28.425	-0.002329	-0.00621	0.00621
28.45	-0.002369	-0.00632	0.00632
28.475	-0.002498	-0.00666	0.00666
28.5	-0.00151	-0.00403	0.00403
28.525	-0.000466	-0.00124	0.00124
28.55	-0.000877	-0.00234	0.00234
28.575	-0.002013	-0.00537	0.00537
28.6	-0.002105	-0.00561	0.00561
28.625	-0.001941	-0.00518	0.00518
28.65	-0.002328	-0.00621	0.00621
28.675	-0.001989	-0.00530	0.00530
28.7	-0.000245	-0.00065	0.00065
28.725	0.001506	0.00402	-0.00402
28.75	0.002356	0.00628	-0.00628
28.775	0.002367	0.00631	-0.00631
28.8	0.002643	0.00705	-0.00705
28.825	0.003549	0.00946	-0.00946
28.85	0.004028	0.01074	-0.01074
28.875	0.003727	0.00994	-0.00994
28.9	0.004469	0.01192	-0.01192
28.925	0.006696	0.01786	-0.01786
28.95	0.007253	0.01934	-0.01934
28.975	0.003959	0.01056	-0.01056
29	-0.00003	-0.00008	0.00008
29.025	-0.002384	-0.00636	0.00636
29.05	-0.004476	-0.01194	0.01194
29.075	-0.007243	-0.01931	0.01931
29.1	-0.010057	-0.02682	0.02682
29.125	-0.012138	-0.03237	0.03237
29.15	-0.011746	-0.03132	0.03132
29.175	-0.008878	-0.02367	0.02367
29.2	-0.005177	-0.01381	0.01381
29.225	-0.001862	-0.00497	0.00497
29.25	0.00101	0.00269	-0.00269
29.275	0.004067	0.01085	-0.01085
29.3	0.007026	0.01874	-0.01874
29.325	0.008221	0.02192	-0.02192
29.35	0.007405	0.01975	-0.01975
29.375	0.005092	0.01358	-0.01358
29.4	0.001863	0.00497	-0.00497
29.425	-0.001535	-0.00409	0.00409
29.45	-0.004366	-0.01164	0.01164
29.475	-0.006372	-0.01699	0.01699
29.5	-0.007275	-0.01940	0.01940
29.525	-0.007578	-0.02021	0.02021
29.55	-0.008025	-0.02140	0.02140
29.575	-0.008956	-0.02388	0.02388
29.6	-0.00940	-0.02520	0.02520
29.625	-0.007807	-0.02103	0.02103
29.65	-0.004147	-0.01106	0.01106
29.675	-0.001116	-0.00298	0.00298
29.7	0.000438	0.00117	-0.00117
29.725	0.002067	0.00551	-0.00551
29.75	0.003743	0.00998	-0.00998

29.775	0.003781	0.01888	-0.01888
29.8	0.002033	0.00542	-0.00542
29.825	-0.000560	-0.00151	0.00151
29.85	-0.002729	-0.00728	0.00728
29.875	-0.00426	-0.01136	0.01136
29.9	-0.00589	-0.01571	0.01571
29.925	-0.007667	-0.02045	0.02045
29.95	-0.008302	-0.02214	0.02214
29.975	-0.007073	-0.01886	0.01886
30	-0.004474	-0.01193	0.01193
30.025	-0.001342	-0.00358	0.00358
30.05	0.00233	0.00621	-0.00621
30.075	0.006788	0.01810	-0.01810
30.1	0.01159	0.03091	-0.03091
30.125	0.014536	0.03876	-0.03876
30.15	0.014597	0.03893	-0.03893
30.175	0.012684	0.03382	-0.03382
30.2	0.00927	0.02472	-0.02472
30.225	0.004238	0.01130	-0.01130
30.25	-0.001083	-0.00289	0.00289
30.275	-0.005545	-0.01479	0.01479
30.3	-0.008392	-0.02238	0.02238
30.325	-0.009866	-0.02410	0.02410
30.35	-0.008648	-0.02306	0.02306
30.375	-0.009584	-0.02556	0.02556
30.4	-0.012226	-0.03260	0.03260
30.425	-0.014336	-0.03823	0.03823
30.45	-0.013795	-0.03679	0.03679
30.475	-0.011452	-0.03054	0.03054
30.5	-0.009319	-0.02485	0.02485
30.525	-0.008637	-0.02303	0.02303
30.55	-0.008284	-0.02209	0.02209
30.575	-0.006396	-0.01706	0.01706
30.6	-0.003678	-0.00981	0.00981
30.625	-0.001788	-0.00477	0.00477
30.65	-0.000198	-0.00053	0.00053
30.675	0.001081	0.00288	-0.00288
30.7	0.001	0.00267	-0.00267
30.725	-0.00057	-0.00152	0.00152
30.75	-0.001929	-0.00514	0.00514
30.775	-0.002177	-0.00581	0.00581
30.8	-0.001308	-0.00349	0.00349
30.825	0.000068	0.00018	-0.00018
30.85	0.000942	0.00251	-0.00251
30.875	0.001515	0.00404	-0.00404
30.9	0.002734	0.00729	-0.00729
30.925	0.003692	0.00985	-0.00985
30.95	0.003142	0.00838	-0.00838
30.975	0.001321	0.00352	-0.00352
31	0.00022	0.00059	-0.00059
31.025	0.000813	0.00217	-0.00217
31.05	0.001625	0.00433	-0.00433
31.075	0.001006	0.00268	-0.00268
31.1	0.000148	0.00039	-0.00039
31.125	0.001004	0.00268	-0.00268
31.15	0.002963	0.00790	-0.00790
31.175	0.003616	0.00964	-0.00964
31.2	0.003104	0.00828	-0.00828
31.225	0.003318	0.00885	-0.00885
31.25	0.005305	0.01415	-0.01415

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31.275	0.007871	0.02099	-0.02099
31.3	0.009731	0.02595	-0.02595
31.325	0.010667	0.02845	-0.02845
31.35	0.011366	0.03031	-0.03031
31.375	0.011799	0.03146	-0.03146
31.4	0.011726	0.03127	-0.03127
31.425	0.011372	0.03033	-0.03033
31.45	0.010922	0.02913	-0.02913
31.475	0.010727	0.02861	-0.02861
31.5	0.011546	0.03079	-0.03079
31.525	0.012783	0.03409	-0.03409
31.55	0.013377	0.03567	-0.03567
31.575	0.012820	0.03421	-0.03421
31.6	0.011358	0.03029	-0.03029
31.625	0.009648	0.02573	-0.02573
31.65	0.008724	0.02326	-0.02326
31.675	0.008304	0.02214	-0.02214
31.7	0.007856	0.02095	-0.02095
31.725	0.007198	0.01919	-0.01919
31.75	0.00653	0.01741	-0.01741
31.775	0.005976	0.01594	-0.01594
31.8	0.005456	0.01455	-0.01455
31.825	0.005151	0.01374	-0.01374
31.85	0.005877	0.01567	-0.01567
31.875	0.007285	0.01943	-0.01943
31.9	0.008196	0.02186	-0.02186
31.925	0.007799	0.02080	-0.02080
31.95	0.007091	0.01891	-0.01891
31.975	0.007146	0.01906	-0.01906
32	0.007563	0.02017	-0.02017
32.025	0.00751	0.02003	-0.02003
32.05	0.006822	0.01819	-0.01819
32.075	0.004966	0.01324	-0.01324
32.1	0.002358	0.00629	-0.00629
32.125	-0.00002	-0.00005	0.00005
32.15	-0.002029	-0.00541	0.00541
32.175	-0.003877	-0.01034	0.01034
32.2	-0.005023	-0.01339	0.01339
32.225	-0.005283	-0.01409	0.01409
32.25	-0.004731	-0.01262	0.01262
32.275	-0.003719	-0.00992	0.00992
32.3	-0.00232	-0.00619	0.00619
32.325	-0.000992	-0.00265	0.00265
32.35	-0.000633	-0.00169	0.00169
32.375	-0.001596	-0.00426	0.00426
32.4	-0.002945	-0.00785	0.00785
32.425	-0.004269	-0.01138	0.01138
32.45	-0.005655	-0.01508	0.01508
32.475	-0.00664	-0.01771	0.01771
32.5	-0.006235	-0.01663	0.01663
32.525	-0.005639	-0.01504	0.01504
32.55	-0.006411	-0.01710	0.01710
32.575	-0.007622	-0.02033	0.02033
32.6	-0.008238	-0.02197	0.02197
32.625	-0.009378	-0.02501	0.02501
32.65	-0.011417	-0.03045	0.03045
32.675	-0.013768	-0.03671	0.03671
32.7	-0.015976	-0.04260	0.04260
32.725	-0.017795	-0.04745	0.04745
32.75	-0.017761	-0.04736	0.04736

32.775	-0.014742	-0.03931	0.03931
32.8	-0.010039	-0.02677	0.02677
32.825	-0.006332	-0.01689	0.01689
32.85	-0.004367	-0.01165	0.01165
32.875	-0.003447	-0.00919	0.00919
32.9	-0.002804	-0.00748	0.00748
32.925	-0.002629	-0.00701	0.00701
32.95	-0.003842	-0.01025	0.01025
32.975	-0.006965	-0.01857	0.01857
33	-0.011251	-0.03000	0.03000
33.025	-0.014862	-0.03963	0.03963
33.05	-0.015941	-0.04251	0.04251
33.075	-0.015167	-0.04045	0.04045
33.1	-0.013554	-0.03614	0.03614
33.125	-0.011029	-0.02941	0.02941
33.15	-0.007169	-0.01912	0.01912
33.175	-0.002526	-0.00674	0.00674
33.2	0.001592	0.00425	-0.00425
33.225	0.003686	0.00983	-0.00983
33.25	0.004093	0.01091	-0.01091
33.275	0.004107	0.01095	-0.01095
33.3	0.00467	0.01245	-0.01245
33.325	0.005044	0.01345	-0.01345
33.35	0.004467	0.01191	-0.01191
33.375	0.003824	0.01020	-0.01020
33.4	0.003536	0.00943	-0.00943
33.425	0.002704	0.00721	-0.00721
33.45	0.001287	0.00343	-0.00343
33.475	-0.000067	-0.00018	0.00018
33.5	-0.000652	-0.00174	0.00174
33.525	-0.000804	-0.00214	0.00214
33.55	-0.000699	-0.00186	0.00186
33.575	-0.000021	-0.00006	0.00006
33.6	0.001705	0.00455	-0.00455
33.625	0.004051	0.01080	-0.01080
33.65	0.005883	0.01569	-0.01569
33.675	0.006239	0.01664	-0.01664
33.7	0.00565	0.01507	-0.01507
33.725	0.005508	0.01469	-0.01469
33.75	0.006583	0.01755	-0.01755
33.775	0.007904	0.02108	-0.02108
33.8	0.008907	0.02375	-0.02375
33.825	0.00952	0.02539	-0.02539
33.85	0.009616	0.02564	-0.02564
33.875	0.009053	0.02414	-0.02414
33.9	0.008068	0.02151	-0.02151
33.925	0.006885	0.01836	-0.01836
33.95	0.005857	0.01562	-0.01562
33.975	0.004488	0.01197	-0.01197
34	0.002562	0.00683	-0.00683
34.025	0.000597	0.00159	-0.00159
34.05	-0.0004	-0.00107	0.00107
34.075	0.000258	0.00069	-0.00069
34.1	0.002341	0.00624	-0.00624
34.125	0.004278	0.01141	-0.01141
34.15	0.004479	0.01194	-0.01194
34.175	0.003207	0.00855	-0.00855
34.2	0.002309	0.00616	-0.00616
34.225	0.001536	0.00410	-0.00410
34.25	-0.000453	-0.00121	0.00121

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34.275	-0.003226	-0.00860	0.00860
34.3	-0.004851	-0.01294	0.01294
34.325	-0.004909	-0.01309	0.01309
34.35	-0.004448	-0.01186	0.01186
34.375	-0.004199	-0.01120	0.01120
34.4	-0.003424	-0.00913	0.00913
34.425	-0.001818	-0.00485	0.00485
34.45	0.000044	0.00012	-0.00012
34.475	0.00139	0.00371	-0.00371
34.5	0.001855	0.00495	-0.00495
34.525	0.001308	0.00349	-0.00349
34.55	0.000326	0.00087	-0.00087
34.575	-0.000589	-0.00157	0.00157
34.6	-0.000554	-0.00148	0.00148
34.625	0.00062	0.00165	-0.00165
34.65	0.001939	0.00517	-0.00517
34.675	0.002711	0.00723	-0.00723
34.7	0.003787	0.01010	-0.01010
34.725	0.005323	0.01419	-0.01419
34.75	0.005936	0.01583	-0.01583
34.775	0.004537	0.01210	-0.01210
34.8	0.002295	0.00612	-0.00612
34.825	0.000442	0.00118	-0.00118
34.85	-0.001262	-0.00337	0.00337
34.875	-0.003749	-0.01000	0.01000
34.9	-0.00685	-0.01827	0.01827
34.925	-0.009544	-0.02545	0.02545
34.95	-0.010825	-0.02887	0.02887
34.975	-0.011119	-0.02965	0.02965
35	-0.010953	-0.02921	0.02921
35.025	-0.009947	-0.02653	0.02653
35.05	-0.007505	-0.02001	0.02001
35.075	-0.004301	-0.01147	0.01147
35.1	-0.001735	-0.00463	0.00463
35.125	-0.000694	-0.00185	0.00185
35.15	-0.000929	-0.00248	0.00248
35.175	-0.002006	-0.00535	0.00535
35.2	-0.002879	-0.00768	0.00768
35.225	-0.003251	-0.00867	0.00867
35.25	-0.003182	-0.00849	0.00849
35.275	-0.002463	-0.00657	0.00657
35.3	-0.001001	-0.00267	0.00267
35.325	0.00048	0.00128	-0.00128
35.35	0.001611	0.00430	-0.00430
35.375	0.002509	0.00669	-0.00669
35.4	0.003253	0.00867	-0.00867
35.425	0.003151	0.00840	-0.00840
35.45	0.002193	0.00585	-0.00585
35.475	0.001141	0.00304	-0.00304
35.5	0.000279	0.00074	-0.00074
35.525	-0.000523	-0.00139	0.00139
35.55	-0.000435	-0.00116	0.00116
35.575	0.000563	0.00150	-0.00150
35.6	0.001399	0.00373	-0.00373
35.625	0.001194	0.00318	-0.00318
35.65	0.000476	0.00127	-0.00127
35.675	0.000277	0.00074	-0.00074
35.7	0.000012	0.00217	-0.00217
35.725	0.001214	0.00324	-0.00324
35.75	0.001457	0.00389	-0.00389

35.775	0.001837	0.00490	-0.00490
35.8	0.002578	0.00687	-0.00687
35.825	0.003457	0.00922	-0.00922
35.85	0.00411	0.01096	-0.01096
35.875	0.004219	0.01125	-0.01125
35.9	0.004179	0.01114	-0.01114
35.925	0.004234	0.01129	-0.01129
35.95	0.004258	0.01135	-0.01135
35.975	0.00369	0.00984	-0.00984
[illegible]	0.002567	0.00685	-0.00685
[illegible]025	0.001524	0.00406	-0.00406
[illegible]05	0.001122	0.00299	-0.00299
[illegible].075	0.001137	0.00303	-0.00303
[illegible].1	0.00158	0.00421	-0.00421
36.125	0.002641	0.00704	-0.00704
36.15	0.004035	0.01076	-0.01076
36.175	0.004658	0.01242	-0.01242
36.2	0.00457	0.01219	-0.01219
36.225	0.004601	0.01227	-0.01227
36.25	0.005204	0.01388	-0.01388
36.275	0.005322	0.01419	-0.01419
36.3	0.003602	0.00961	-0.00961
36.325	0.000238	0.00063	-0.00063
36.35	-0.002727	-0.00727	0.00727
36.375	-0.004029	-0.01074	0.01074
36.4	-0.003685	-0.00983	0.00983
36.425	-0.002706	-0.00722	0.00722
36.45	-0.002077	-0.00554	0.00554
36.475	-0.001952	-0.00521	0.00521
36.5	-0.001559	-0.00416	0.00416
36.525	-0.000448	-0.00119	0.00119
36.55	0.001278	0.00341	-0.00341
36.575	0.002648	0.00706	-0.00706
36.6	0.002498	0.00666	-0.00666
36.625	0.000755	0.00201	-0.00201
36.65	-0.000633	-0.00169	0.00169
36.675	-0.00068	-0.00181	0.00181
36.7	0.000042	0.00011	-0.00011
36.725	0.000531	0.00142	-0.00142
36.75	0.000572	0.00153	-0.00153
36.775	0.000276	0.00074	-0.00074
36.8	-0.000359	-0.00096	0.00096
36.825	-0.001422	-0.00379	0.00379
36.85	-0.002597	-0.00693	0.00693
36.875	-0.00368	-0.00981	0.00981
36.9	-0.004096	-0.01092	0.01092
36.925	-0.003938	-0.01050	0.01050
36.95	-0.003695	-0.00985	0.00985
36.975	-0.00345	-0.00920	0.00920
37	-0.002729	-0.00728	0.00728
37.025	-0.001581	-0.00422	0.00422
37.05	-0.000195	-0.00052	0.00052
37.075	0.001009	0.00269	-0.00269
37.1	0.001697	0.00453	-0.00453
37.125	0.001387	0.00370	-0.00370
37.15	0.000037	0.00010	-0.00010
37.175	-0.00184	-0.00491	0.00491
37.2	-0.003234	-0.00862	0.00862
37.225	-0.003623	-0.00966	0.00966
37.25	-0.002794	-0.00745	0.00745

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[illegible].275	-0.001256	-0.00335	0.00335
[illegible].3	0.00011	0.00029	-0.00029
37.325	0.000665	0.00177	-0.00177
37.35	0.000703	0.00187	-0.00187
37.375	0.000593	0.00158	-0.00158
37.4	0.000899	0.00240	-0.00240
37.425	0.00155	0.00413	-0.00413
37.45	0.001839	0.00490	-0.00490
37.475	0.001289	0.00344	-0.00344
37.5	0.000534	0.00142	-0.00142
37.525	0.000008	0.00002	-0.00002
37.55	-0.000423	-0.00113	0.00113
37.575	-0.000955	-0.00255	0.00255
37.6	-0.000959	-0.00256	0.00256
37.625	-0.000558	-0.00149	0.00149
37.65	-0.000322	-0.00086	0.00086
37.675	-0.000167	-0.00045	0.00045
37.7	0.00063	0.00168	-0.00168
37.725	0.002197	0.00586	-0.00586
37.75	0.004142	0.01105	-0.01105
37.775	0.005687	0.01517	-0.01517
37.8	0.006688	0.01783	-0.01783
37.825	0.007395	0.01972	-0.01972
37.85	0.00786	0.02096	-0.02096
37.875	0.007733	0.02062	-0.02062
37.9	0.007209	0.01922	-0.01922
37.925	0.006319	0.01685	-0.01685
37.95	0.005485	0.01463	-0.01463
37.975	0.004774	0.01273	-0.01273
38	0.003711	0.00990	-0.00990
38.025	0.002342	0.00625	-0.00625
38.05	0.001627	0.00434	-0.00434
38.075	0.001703	0.00454	-0.00454
38.1	0.00193	0.00515	-0.00515
38.125	0.001768	0.00471	-0.00471
38.15	0.001588	0.00423	-0.00423
38.175	0.001009	0.00269	-0.00269
38.2	-0.00076	-0.00203	0.00203
38.225	-0.003216	-0.00858	0.00858
38.25	-0.004682	-0.01249	0.01249
38.275	-0.00502	-0.01339	0.01339
38.3	-0.004773	-0.01273	0.01273
38.325	-0.00392	-0.01045	0.01045
38.35	-0.002355	-0.00628	0.00628
38.375	-0.000802	-0.00214	0.00214
38.4	0.000277	0.00074	-0.00074
38.425	0.00099	0.00264	-0.00264
38.45	0.001733	0.00462	-0.00462
38.475	0.002259	0.00602	-0.00602
38.5	0.002442	0.00651	-0.00651
[illegible]525	0.002146	0.00572	-0.00572
[illegible]55	0.001297	0.00346	-0.00346
[illegible].575	-0.000038	-0.00010	0.00010
38.6	-0.00149	-0.00397	0.00397
38.625	-0.002823	-0.00753	0.00753
38.65	-0.003706	-0.00988	0.00988
38.675	-0.004758	-0.01269	0.01269
38.7	-0.006081	-0.01622	0.01622
38.725	-0.006714	-0.01790	0.01790
38.75	-0.006178	-0.01647	0.01647

38.775	-0.005294	-0.01412	0.01412
38.8	-0.004663	-0.01243	0.01243
38.825	-0.004447	-0.01186	0.01186
38.85	-0.004392	-0.01171	0.01171
38.875	-0.004365	-0.01164	0.01164
38.9	-0.00423	-0.01128	0.01128
38.925	-0.004193	-0.01118	0.01118
38.95	-0.004172	-0.01113	0.01113
38.975	-0.004061	-0.01083	0.01083
39	-0.004055	-0.01081	0.01081
39.025	-0.004453	-0.01187	0.01187
39.05	-0.004729	-0.01261	0.01261
39.075	-0.004547	-0.01213	0.01213
39.1	-0.003747	-0.00999	0.00999
39.125	-0.00231	-0.00616	0.00616
39.15	-0.000256	-0.00068	0.00068
39.175	0.001665	0.00444	-0.00444
39.2	0.003013	0.00803	-0.00803
39.225	0.003776	0.01007	-0.01007
39.25	0.003789	0.01010	-0.01010
39.275	0.00315	0.00840	-0.00840
39.3	0.002826	0.00754	-0.00754
39.325	0.002778	0.00741	-0.00741
39.35	0.002508	0.00669	-0.00669
39.375	0.001952	0.00521	-0.00521
39.4	0.001502	0.00401	-0.00401
39.425	0.001176	0.00314	-0.00314
39.45	0.001152	0.00307	-0.00307
39.475	0.001266	0.00338	-0.00338
39.5	0.001366	0.00364	-0.00364
39.525	0.001552	0.00414	-0.00414
39.55	0.002032	0.00542	-0.00542
39.575	0.002395	0.00639	-0.00639
39.6	0.002424	0.00646	-0.00646
39.625	0.001951	0.00520	-0.00520
39.65	0.001049	0.00280	-0.00280
39.675	-0.000114	-0.00030	0.00030
39.7	-0.001322	-0.00353	0.00353
39.725	-0.0026	-0.00693	0.00693
39.75	-0.003221	-0.00859	0.00859
39.775	-0.002779	-0.00741	0.00741
39.8	-0.001812	-0.00483	0.00483
39.825	-0.000929	-0.00248	0.00248
39.85	-0.00005	-0.00013	0.00013
39.875	0.000572	0.00153	-0.00153
39.9	0.001142	0.00305	-0.00305
39.925	0.001853	0.00494	-0.00494
39.95	0.002421	0.00646	-0.00646
39.975	0.002406	0.00642	-0.00642
40	0.001928	0.00514	-0.00514
40.025	0.000767	0.00205	-0.00205
40.05	-0.001286	-0.00343	0.00343
40.075	-0.003823	-0.01019	0.01019
40.1	-0.005721	-0.01526	0.01526
40.125	-0.006614	-0.01764	0.01764
40.15	-0.006752	-0.01801	0.01801
40.175	-0.006466	-0.01724	0.01724
40.2	-0.00582	-0.01552	0.01552
40.225	-0.005337	-0.01423	0.01423
40.25	-0.005043	-0.01345	0.01345

40.275	-0.004342	-0.01158	0.01158
40.3	-0.002753	-0.00734	0.00734
40.325	-0.001286	-0.00343	0.00343
40.35	-0.000834	-0.00222	0.00222
40.375	-0.000895	-0.00239	0.00239
40.4	-0.000689	-0.00184	0.00184
40.425	-0.000462	-0.00123	0.00123
40.45	-0.000467	-0.00125	0.00125
40.475	-0.000796	-0.00212	0.00212
40.5	-0.001224	-0.00326	0.00326
40.525	-0.001559	-0.00416	0.00416
40.55	-0.001578	-0.00421	0.00421
40.575	-0.001461	-0.00390	0.00390
40.6	-0.001063	-0.00283	0.00283
40.625	-0.000561	-0.00150	0.00150
40.65	-0.000373	-0.00099	0.00099
40.675	-0.000843	-0.00225	0.00225
40.7	-0.001668	-0.00445	0.00445
40.725	-0.002409	-0.00642	0.00642
40.75	-0.002367	-0.00631	0.00631
40.775	-0.001641	-0.00438	0.00438
40.8	-0.001014	-0.00270	0.00270
40.825	-0.000903	-0.00241	0.00241
40.85	-0.000553	-0.00147	0.00147
40.875	0.000209	0.00056	-0.00056
40.9	0.00067	0.00179	-0.00179
40.925	0.000425	0.00113	-0.00113
40.95	0.000187	0.00050	-0.00050
40.975	0.000295	0.00079	-0.00079
41	0.000464	0.00124	-0.00124
41.025	0.000392	0.00105	-0.00105
41.05	0.000777	0.00207	-0.00207
41.075	0.00165	0.00440	-0.00440
41.1	0.00255	0.00680	-0.00680
41.125	0.003189	0.00850	-0.00850
41.15	0.003301	0.00880	-0.00880
41.175	0.002601	0.00694	-0.00694
41.2	0.001532	0.00409	-0.00409
41.225	0.000585	0.00156	-0.00156
41.25	0.000327	0.00087	-0.00087
41.275	0.000772	0.00206	-0.00206
41.3	0.001596	0.00426	-0.00426
41.325	0.002316	0.00618	-0.00618
41.35	0.003002	0.00801	-0.00801
41.375	0.003579	0.00954	-0.00954
41.4	0.003758	0.01002	-0.01002
41.425	0.003481	0.00928	-0.00928
41.45	0.00317	0.00845	-0.00845
41.475	0.002594	0.00692	-0.00692
41.5	0.001619	0.00432	-0.00432
41.525	0.000541	0.00144	-0.00144
41.55	-0.000281	-0.00075	0.00075
41.575	-0.001075	-0.00287	0.00287
41.6	-0.001837	-0.00490	0.00490
41.625	-0.002474	-0.00660	0.00660
41.65	-0.002718	-0.00725	0.00725
41.675	-0.002461	-0.00656	0.00656
41.7	-0.001415	-0.00377	0.00377
41.725	0.000022	0.00006	-0.00006
41.75	0.001058	0.00282	-0.00282

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41.775	0.001126	0.00300	-0.00300
41.8	0.000752	0.00201	-0.00201
41.825	0.000507	0.00135	-0.00135
41.85	0.000357	0.00095	-0.00095
41.875	-0.000011	-0.00003	0.00003
41.9	-0.000523	-0.00139	0.00139
41.925	-0.001284	-0.00342	0.00342
41.95	-0.00201	-0.00536	0.00536
41.975	-0.002388	-0.00615	0.00615
42	-0.001878	-0.00501	0.00501
42.025	-0.001023	-0.00273	0.00273
42.05	-0.000074	-0.00020	0.00020
42.075	0.00066	0.00176	-0.00176
42.1	0.001437	0.00383	-0.00383
42.125	0.00225	0.00600	-0.00600
42.15	0.002959	0.00789	-0.00789
42.175	0.003292	0.00878	-0.00878
42.2	0.003018	0.00805	-0.00805
42.225	0.001967	0.00525	-0.00525
42.25	0.000773	0.00206	-0.00206
42.275	0.000031	0.00008	-0.00008
42.3	-0.000361	-0.00096	0.00096
42.325	-0.000793	-0.00211	0.00211
42.35	-0.000793	-0.00211	0.00211
42.375	-0.000292	-0.00078	0.00078
42.4	0.000149	0.00040	-0.00040
42.425	-0.000079	-0.00021	0.00021
42.45	-0.000503	-0.00134	0.00134
42.475	-0.000582	-0.00155	0.00155
42.5	-0.000062	-0.00017	0.00017
42.525	0.001019	0.00272	-0.00272
42.55	0.002319	0.00618	-0.00618
42.575	0.003161	0.00843	-0.00843
42.6	0.003666	0.00978	-0.00978
42.625	0.003901	0.01040	-0.01040
42.65	0.003726	0.00994	-0.00994
42.675	0.003132	0.00835	-0.00835
42.7	0.002741	0.00731	-0.00731
42.725	0.002868	0.00765	-0.00765
42.75	0.003531	0.00942	-0.00942
42.775	0.00441	0.01176	-0.01176
42.8	0.005323	0.01419	-0.01419
42.825	0.005987	0.01597	-0.01597
42.85	0.006396	0.01706	-0.01706
42.875	0.006433	0.01715	-0.01715
42.9	0.006020	0.01607	-0.01607
42.925	0.005211	0.01390	-0.01390
42.95	0.004405	0.01175	-0.01175
42.975	0.003508	0.00935	-0.00935
43	0.002452	0.00654	-0.00654
43.025	0.00136	0.00363	-0.00363
43.05	0.000707	0.00189	-0.00189
43.075	0.000574	0.00153	-0.00153
43.1	0.000615	0.00164	-0.00164
43.125	0.000384	0.00102	-0.00102
43.15	0.00009	0.00024	-0.00024
43.175	-0.000434	-0.00116	0.00116
43.2	-0.001213	-0.00323	0.00323
43.225	-0.001863	-0.00497	0.00497
43.25	-0.001991	-0.00531	0.00531

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43.275	-0.001828	-0.00487	0.00487
43.3	-0.001395	-0.00372	0.00372
43.325	-0.000862	-0.00230	0.00230
43.35	-0.000288	-0.00077	0.00077
43.375	0.000376	0.00100	-0.00100
43.4	0.001329	0.00354	-0.00354
43.425	0.002467	0.00658	-0.00658
43.45	0.003405	0.00908	-0.00908
43.475	0.00335	0.00893	-0.00893
43.5	0.002343	0.00625	-0.00625
43.525	0.000821	0.00219	-0.00219
43.55	-0.000697	-0.00186	0.00186
43.575	-0.001859	-0.00496	0.00496
43.6	-0.00232	-0.00619	0.00619
43.625	-0.002395	-0.00639	0.00639
43.65	-0.002423	-0.00646	0.00646
43.675	-0.002645	-0.00705	0.00705
43.7	-0.002914	-0.00777	0.00777
43.725	-0.002923	-0.00779	0.00779
43.75	-0.002354	-0.00628	0.00628
43.775	-0.001627	-0.00434	0.00434
43.8	-0.001015	-0.00271	0.00271
43.825	-0.000635	-0.00169	0.00169
43.85	-0.000468	-0.00125	0.00125
43.875	-0.000827	-0.00221	0.00221
43.9	-0.001657	-0.00442	0.00442
43.925	-0.00259	-0.00691	0.00691
43.95	-0.00307	-0.00819	0.00819
43.975	-0.00321	-0.00856	0.00856
44	-0.003225	-0.00860	0.00860
44.025	-0.003084	-0.00822	0.00822
44.05	-0.002537	-0.00677	0.00677
44.075	-0.001968	-0.00525	0.00525
44.1	-0.001711	-0.00456	0.00456
44.125	-0.001737	-0.00463	0.00463
44.15	-0.001497	-0.00399	0.00399
44.175	-0.001142	-0.00305	0.00305
44.2	-0.001026	-0.00274	0.00274
44.225	-0.001019	-0.00272	0.00272
44.25	-0.000793	-0.00211	0.00211
44.275	-0.000765	-0.00204	0.00204
44.3	-0.0009	-0.00240	0.00240
44.325	-0.001019	-0.00272	0.00272
44.35	-0.00116	-0.00309	0.00309
44.375	-0.001552	-0.00414	0.00414
44.4	-0.00207	-0.00552	0.00552
44.425	-0.002731	-0.00728	0.00728
44.45	-0.003315	-0.00884	0.00884
44.475	-0.003652	-0.00974	0.00974
44.5	-0.003333	-0.00889	0.00889
44.525	-0.002432	-0.00649	0.00649
44.55	-0.001576	-0.00420	0.00420
44.575	-0.001400	-0.00375	0.00375
44.6	-0.001649	-0.00440	0.00440
44.625	-0.001815	-0.00484	0.00484
44.65	-0.001553	-0.00414	0.00414
44.675	-0.001159	-0.00309	0.00309
44.7	-0.000821	-0.00219	0.00219
44.725	-0.000595	-0.00159	0.00159
44.75	-0.000424	-0.00113	0.00113

44.775	-0.00039	-0.00104	0.00104
44.8	-0.000205	-0.00055	0.00055
44.825	0.000164	0.00044	-0.00044
44.85	0.000703	0.00187	-0.00187
44.875	0.001146	0.00306	-0.00306
44.9	0.001534	0.00409	-0.00409
44.925	0.001947	0.00519	-0.00519
44.95	0.00237	0.00632	-0.00632
44.975	0.002551	0.00680	-0.00680
45	0.002653	0.00707	-0.00707
45.025	0.002685	0.00716	-0.00716
45.05	0.002471	0.00659	-0.00659
45.075	0.001679	0.00448	-0.00448
45.1	0.000551	0.00147	-0.00147
45.125	-0.000626	-0.00167	0.00167
45.15	-0.001446	-0.00386	0.00386
45.175	-0.001718	-0.00458	0.00458
45.2	-0.001316	-0.00351	0.00351
45.225	-0.000505	-0.00135	0.00135
45.25	0.000385	0.00103	-0.00103
45.275	0.001005	0.00268	-0.00268
45.3	0.001583	0.00422	-0.00422
45.325	0.002107	0.00562	-0.00562
45.35	0.002346	0.00626	-0.00626
45.375	0.002177	0.00581	-0.00581
45.4	0.002078	0.00554	-0.00554
45.425	0.002008	0.00535	-0.00535
45.45	0.001663	0.00443	-0.00443
45.475	0.001059	0.00282	-0.00282
45.5	0.000736	0.00196	-0.00196
45.525	0.000711	0.00190	-0.00190
45.55	0.000823	0.00219	-0.00219
45.575	0.000787	0.00210	-0.00210
45.6	0.000771	0.00206	-0.00206
45.625	0.000857	0.00229	-0.00229
45.65	0.000969	0.00258	-0.00258
45.675	0.000954	0.00254	-0.00254
45.7	0.000966	0.00258	-0.00258
45.725	0.000729	0.00194	-0.00194
45.75	0.000295	0.00079	-0.00079
45.775	-0.000077	-0.00021	0.00021
45.8	-0.000244	-0.00065	0.00065
45.825	-0.000415	-0.00111	0.00111
45.85	-0.000489	-0.00130	0.00130
45.875	-0.000455	-0.00121	0.00121
45.9	-0.000337	-0.00090	0.00090
45.925	-0.000287	-0.00077	0.00077
45.95	-0.000214	-0.00057	0.00057
45.975	-0.00033	-0.00088	0.00088
46	-0.000579	-0.00154	0.00154
46.025	-0.000759	-0.00202	0.00202
46.05	-0.000624	-0.00166	0.00166
46.075	-0.00056	-0.00149	0.00149
46.1	-0.000751	-0.00200	0.00200
46.125	-0.001129	-0.00301	0.00301
46.15	-0.001574	-0.00420	0.00420
46.175	-0.002252	-0.00601	0.00601
46.2	-0.002787	-0.00743	0.00743
46.225	-0.002836	-0.00756	0.00756
46.25	-0.002444	-0.00652	0.00652

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46.275	-0.002143	-0.00571	0.00571
46.3	-0.00213	-0.00568	0.00568
46.325	-0.002441	-0.00651	0.00651
46.35	-0.002865	-0.00764	0.00764
46.375	-0.003269	-0.00872	0.00872
46.4	-0.003379	-0.00901	0.00901
46.425	-0.003256	-0.00868	0.00868
46.45	-0.002828	-0.00754	0.00754
46.475	-0.002114	-0.00564	0.00564
46.5	-0.00118	-0.00315	0.00315
46.525	-0.000508	-0.00135	0.00135
46.55	-0.000171	-0.00046	0.00046
46.575	-0.000045	-0.00012	0.00012
46.6	-0.000013	-0.00003	0.00003
46.625	-0.000266	-0.00071	0.00071
46.65	-0.000537	-0.00143	0.00143
46.675	-0.000652	-0.00174	0.00174
46.7	-0.00057	-0.00152	0.00152
46.725	-0.000355	-0.00095	0.00095
46.75	0.000071	0.00019	-0.00019
46.775	0.000433	0.00115	-0.00115
46.8	0.000733	0.00195	-0.00195
46.825	0.000923	0.00246	-0.00246
46.85	0.00111	0.00296	-0.00296
46.875	0.001197	0.00319	-0.00319
46.9	0.001192	0.00318	-0.00318
46.925	0.001008	0.00269	-0.00269
46.95	0.000711	0.00190	-0.00190
46.975	0.000287	0.00077	-0.00077
47	0.000046	0.00012	-0.00012
47.025	0.000010	0.00005	-0.00005
47.05	0.000058	0.00015	-0.00015
47.075	-0.000016	-0.00004	0.00004
47.1	0.000072	0.00019	-0.00019
47.125	0.000275	0.00073	-0.00073
47.15	0.000467	0.00125	-0.00125
47.175	0.000573	0.00153	-0.00153
47.2	0.000812	0.00217	-0.00217
47.225	0.001164	0.00310	-0.00310
47.25	0.001746	0.00466	-0.00466
47.275	0.002266	0.00604	-0.00604
47.3	0.00257	0.00685	-0.00685
47.325	0.002874	0.00766	-0.00766
47.35	0.003353	0.00894	-0.00894
47.375	0.003554	0.00948	-0.00948
47.4	0.003504	0.00934	-0.00934
47.425	0.003232	0.00862	-0.00862
47.45	0.002705	0.00721	-0.00721
47.475	0.002093	0.00558	-0.00558
47.5	0.001715	0.00457	-0.00457
47.525	0.001215	0.00324	-0.00324
47.55	0.00068	0.00181	-0.00181
47.575	0.000384	0.00102	-0.00102
47.6	0.000399	0.00106	-0.00106
47.625	0.000598	0.00159	-0.00159
47.65	0.001147	0.00306	-0.00306
47.675	0.001795	0.00479	-0.00479
47.7	0.002317	0.00618	-0.00618
47.725	0.002518	0.00671	-0.00671
47.75	0.002447	0.00653	-0.00653

47.775	0.002029	0.00541	-0.00541
47.8	0.001541	0.00411	-0.00411
47.825	0.001195	0.00319	-0.00319
47.85	0.001122	0.00299	-0.00299
47.875	0.000984	0.00262	-0.00262
47.9	0.000676	0.00180	-0.00180
47.925	0.000209	0.00056	-0.00056
47.95	-0.000249	-0.00066	0.00066
47.975	-0.000643	-0.00171	0.00171
48	-0.000689	-0.00184	0.00184
.025	-0.000358	-0.00095	0.00095
05	0.000322	0.00086	-0.00086
.075	0.000902	0.00241	-0.00241
48.1	0.001155	0.00308	-0.00308
48.125	0.001087	0.00290	-0.00290
48.15	0.000993	0.00265	-0.00265
48.175	0.000819	0.00218	-0.00218
48.2	0.000521	0.00139	-0.00139
48.225	-0.000087	-0.00023	0.00023
48.25	-0.000779	-0.00208	0.00208
48.275	-0.00131	-0.00349	0.00349
48.3	-0.001696	-0.00452	0.00452
48.325	-0.002117	-0.00565	0.00565
48.35	-0.00232	-0.00619	0.00619
48.375	-0.002422	-0.00646	0.00646
48.4	-0.002434	-0.00649	0.00649
48.425	-0.002268	-0.00605	0.00605
48.45	-0.001812	-0.00483	0.00483
48.475	-0.001274	-0.00340	0.00340
48.5	-0.000675	-0.00180	0.00180
48.525	-0.000336	-0.00090	0.00090
48.55	-0.000269	-0.00072	0.00072
48.575	-0.000309	-0.00082	0.00082
48.6	-0.000337	-0.00090	0.00090
48.625	-0.000573	-0.00153	0.00153
48.65	-0.000965	-0.00257	0.00257
48.675	-0.0015 -0.00400	0.00400	
48.7	-0.001876	-0.00500	0.00500
48.725	-0.00198	-0.00528	0.00528
48.75	-0.001815	-0.00484	0.00484
48.775	-0.001638	-0.00437	0.00437
48.8	-0.001477	-0.00394	0.00394
48.825	-0.001489	-0.00397	0.00397
48.85	-0.001489	-0.00397	0.00397
48.875	-0.00141	-0.00376	0.00376
48.9	-0.001306	-0.00348	0.00348
48.925	-0.001313	-0.00350	0.00350
48.95	-0.001334	-0.00356	0.00356
48.975	-0.001445	-0.00385	0.00385
49	-0.001431	-0.00382	0.00382
49.025	-0.001174	-0.00313	0.00313
49.05	-0.000564	-0.00150	0.00150
49.075	0.000105	0.00028	-0.00028
49.1	0.000539	0.00144	-0.00144
49.125	0.000508	0.00135	-0.00135
49.15	0.000277	0.00074	-0.00074
49.175	0.000051	0.00014	-0.00014
49.2	-0.000018	-0.00005	0.00005
49.225	-0.000141	-0.00038	0.00038
49.25	-0.000106	-0.00028	0.00028

275	0.000143	0.00038	-0.00038
.3	0.00041 0.00109	-0.00109	
49.325	0.000641	0.00171	-0.00171
49.35	0.000992	0.00265	-0.00265
49.375	0.001143	0.00305	-0.00305
49.4	0.001215	0.00324	-0.00324
49.425	0.001272	0.00339	-0.00339
49.45	0.00122 0.00325	-0.00325	
49.475	0.000856	0.00228	-0.00228
49.5	0.000432	0.00115	-0.00115
49.525	0.000121	0.00032	-0.00032
49.55	0.000096	0.00026	-0.00026
49.575	0.000335	0.00089	-0.00089
49.6	0.000842	0.00225	-0.00225
49.625	0.001325	0.00353	-0.00353
49.65	0.001828	0.00487	-0.00487
49.675	0.002352	0.00627	-0.00627
49.7	0.002829	0.00754	-0.00754
49.725	0.002972	0.00793	-0.00793
49.75	0.002985	0.00796	-0.00796
49.775	0.003006	0.00802	-0.00802
49.8	0.002986	0.00796	-0.00796
49.825	0.002717	0.00725	-0.00725
49.85	0.002284	0.00609	-0.00609
49.875	0.001552	0.00414	-0.00414
49.9	0.000649	0.00173	-0.00173
49.925	-0.000202	-0.00054	0.00054
49.95	-0.000877	-0.00234	0.00234
49.975	-0.001588	-0.00423	0.00423
50	-0.002103	-0.00561	0.00561
50.025	-0.002296	-0.00612	0.00612
50.05	-0.002121	-0.00566	0.00566
50.075	-0.001869	-0.00498	0.00498
50.1	-0.0016 -0.00427	0.00427	
50.125	-0.001417	-0.00378	0.00378
50.15	-0.001387	-0.00370	0.00370
50.175	-0.001668	-0.00445	0.00445
50.2	-0.001916	-0.00511	0.00511
50.225	-0.001879	-0.00501	0.00501
50.25	-0.001537	-0.00410	0.00410
50.275	-0.001142	-0.00305	0.00305
50.3	-0.00065	-0.00173	0.00173
50.325	-0.000173	-0.00046	0.00046
50.35	0.000241	0.00064	-0.00064
50.375	0.000301	0.00080	-0.00080
50.4	0.00004 0.00011	-0.00011	
50.425	-0.000386	-0.00103	0.00103
50.45	-0.000729	-0.00194	0.00194
50.475	-0.000953	-0.00254	0.00254
.5	-0.000948	-0.00253	0.00253
525	-0.001065	-0.00284	0.00284
55	-0.001263	-0.00337	0.00337
.575	-0.00144	-0.00384	0.00384
50.6	-0.001504	-0.00401	0.00401
50.625	-0.001563	-0.00417	0.00417
50.65	-0.001554	-0.00414	0.00414
50.675	-0.001571	-0.00419	0.00419
50.7	-0.001552	-0.00414	0.00414
50.725	-0.001566	-0.00418	0.00418
50.75	-0.001515	-0.00404	0.00404

50.775	-0.001454	-0.00388	0.00388
50.8	-0.001306	-0.00348	0.00348
50.825	-0.00115	-0.00307	0.00307
50.85	-0.000913	-0.00243	0.00243
50.875	-0.000679	-0.00181	0.00181
50.9	-0.000377	-0.00101	0.00101
50.925	-0.000089	-0.00024	0.00024
50.95	0.000228	0.00061	-0.00061
50.975	0.000463	0.00123	-0.00123
51	0.000665	0.00177	-0.00177
51.025	0.000745	0.00199	-0.00199
51.05	0.000788	0.00210	-0.00210
51.075	0.000742	0.00198	-0.00198
51.1	0.000712	0.00190	-0.00190
51.125	0.000647	0.00173	-0.00173
51.15	0.000633	0.00169	-0.00169
51.175	0.000591	0.00158	-0.00158

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SHAKE91 SHEAR STRESS TIME HISTORY - OUTPUT FILE

STRESS — stress in level 2 * FINAL COVER SYSTEM LAYER 2

.000043	.000024	.000042	.000022	.000048	.000021	.000039	.000019
1							
.000037	.000016	.000034	.000013	.000030	.000009	.000025	.000002
2							
000016	-.000010	-.000001	-.000035	-.000042	-.000100	-.000129	-.000202
3							
.000240	-.000316	-.000357	-.000445	-.000504	-.000598	-.000628	-.000654
4							
-.000593	-.000520	-.000403	-.000388	-.000402	-.000434	-.000349	-.000272
5							
-.000234	-.000379	-.000601	-.000885	-.001094	-.001307	-.001510	-.001785
6							
-.001953	-.001983	-.001767	-.001394	-.000845	-.000323	.000088	.000203
7							
.000187	.000060	-.000274	-.000988	-.001754	-.002243	-.002245	-.001989
8							
-.001674	-.001513	-.001148	-.000401	.000621	.001369	.001485	.000780
9							
-.000706	-.002959	-.005191	-.006278	-.005624	-.004007	-.002101	-.000486
10							
.000334	.000613	.001435	.002683	.003425	.003836	.004584	.004603
11							
.004053	.004137	.004797	.005575	.006479	.006972	.006700	.005304
12							
.003555	.002734	.002700	.002528	.002616	.003894	.003877	.004814
13							
.005485	.004944	.003405	.001110	-.002268	-.005314	-.006396	-.006697
14							
-.007339	-.008680	-.010735	-.012381	-.012181	-.010452	-.007728	-.004647
15							
-.001823	-.000539	-.001775	-.004601	-.006577	-.006613	-.005477	-.003106
16							
.000802	.003247	.003004	.002197	.000714	-.002574	-.007129	-.012532
17							
-.015967	-.016577	-.016732	-.015467	-.010731	-.004092	.003433	.012526
18							
.022842	.031215	.033129	.027232	.019939	.018171	.019987	.019275
19							
.015720	.013610	.015453	.019692	.023670	.025598	.025364	.024221
20							
.022608	.019022	.013208	.006350	-.001981	-.010517	-.016392	-.020617
21							
-.023035	-.019860	-.011775	-.006054	-.004912	-.005255	-.004697	-.001397
22							
.001749	.000043	-.005326	-.011108	-.016470	-.018869	-.014915	-.008473
23							
-.006215	-.009626	-.015476	-.018055	-.015122	-.010778	-.010230	-.015605
24							
-.021400	-.021114	-.015678	-.008461	-.001156	.003326	.002618	-.002473
25							
-.006936	-.006052	.001174	.012494	.025889	.039051	.048634	.051629
26							
.046504	.034881	.019959	.002578	-.015352	-.029436	-.033560	-.025847
27							

.014324	-.009007	-.009986	-.009921	-.005425	-.000292	.001560	-.000238
28							
-.003032	-.005618	-.008427	-.010809	-.011625	-.010633	-.009235	-.007622
29							
-.002543	.006019	.015184	.016981	.014549	.013404	.012086	.004675
30							
-.006643	-.017831	-.030918	-.043518	-.048581	-.046245	-.039798	-.030996
31							
-.019838	-.005049	.012204	.020972	.040678	.044195	.042793	.039109
32							
.033384	.028090	.023804	.018956	.012572	.002834	-.009607	-.019320
33							
-.024131	-.028975	-.034671	-.035916	-.031441	-.026601	-.024097	-.022236
34							
-.019025	-.014045	-.012268	-.008595	.003062	.019674	.031095	.033574
35							
.030265	.026268	.025508	.023303	.015700	.007148	.001549	.000192
36							
.002784	.004894	.005011	.006646	.009877	.012788	.018059	.027306
37							
.034998	.035262	.029165	.019632	.009596	-.000156	-.009810	-.015988
38							
-.015707	-.009146	.001690	.012168	.018375	.020503	.020623	.018097
39							
.011690	.000788	-.012640	-.023249	-.025059	-.017652	-.007307	-.001216
40							
-.003542	-.011932	-.019197	-.021107	-.017135	-.009860	-.003570	-.000305
41							
.002275	.004420	.003755	.000972	-.001286	-.004548	-.010386	-.015605
42							
-.020239	-.030056	-.042969	-.049066	-.044547	-.034748	-.024191	-.013633
43							
-.004210	.002414	.006579	.008599	.007371	.002362	-.003528	-.009530
44							
-.014004	-.012750	-.006243	.001606	.007666	.010833	.012862	.015195
45							
.016639	.017362	.016701	.010693	.000515	-.009499	-.017700	-.024187
46							
-.024637	-.014893	.002763	.023424	.041685	.051479	.053490	.051498
47							
.046127	.037798	.027699	.017455	.007603	-.002202	-.008832	-.010588
48							
-.008552	-.002615	.003531	.003633	-.000033	.001373	.008870	.016213
49							
.022102	.027174	.027901	.022809	.018891	.021061	.022849	.016240
50							
.002519	-.013162	-.024701	-.026938	-.026294	-.032916	-.043320	-.049040
51							
-.046927	-.038649	-.026086	-.013574	-.006768	-.005045	-.004053	-.005560
52							
.007865	-.011871	-.014149	-.018028	.001293	.014229	.020547	.017271
53							
.010435	.005800	.003571	.002281	.001277	.000201	-.001523	-.001790
54							
.002104	.007734	.011514	.009149	-.000821	-.012945	-.020668	-.023208
55							
-.022634	-.018279	-.010702	-.000357	.015004	.029926	.034872	.029980
56							
.021506	.014116	.010595	.010702	.012452	.014110	.015073	.013034
57							

.011977	.015466	.022302	.020845	.008615	-.006137	-.015228	-.017509
58							
-.017387	-.017356	-.015351	-.008639	.000488	.007991	.016528	.027475
59							
.035430	.033959	.022387	.007866	-.006480	-.017159	-.025319	-.032401
60							
-.037055	-.036470	-.031539	-.025737	-.020560	-.014432	-.004934	.002899
61							
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62							
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63							
-.032228	-.025540	-.015051	-.005344	-.002348	-.004684	-.003802	.005189
64							
.014489	.021447	.027487	.030952	.030885	.029438	.023986	.013963
65							
.010039	.012893	.011648	.003994	-.004849	-.013482	-.021664	-.026735
66							
-.027705	-.028268	-.029111	-.026166	-.019320	-.010851	.000611	.012802
67							
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.002212	.007872	.011610	.012406	.013562	.015824	.014291	.004099
71							
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73							
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74							
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75							
-.007254	-.008633	-.014008	-.019131	-.021051	-.019488	-.015565	-.011427
76							
-.008841	-.006872	-.004626	-.004678	-.007495	-.010971	-.012112	-.009290
77							
-.005025	-.002896	-.001013	-.001076	-.000842	.001555	.008900	-.001516
78							
-.008836	.006418	.017010	.026341	.034039	.040380	.043414	.038760
79							
.027573	.017481	.011573	.007231	.002418	-.002054	-.001700	.006004
80							
.019134	.030886	.034459	.033265	.034365	.035671	.032689	.026816
81							
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82							
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83							
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84							
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90							
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91							
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92							
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93							
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117							

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207
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237
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 256
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SHAKE91 SHEAR STRESS TIME HISTORY - OUTPUT FILE

* SHEAR STRESS TIME HISTORY AT BASE OF IMPACTED MATERIALS

STRESS -- stress in level 8 *LAYER 8

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   2
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   3
-.004963 -.006113 -.007351 -.008592 -.009710 -.010550 -.010959 -.010927
   4
-.010623 -.010214 -.009687 -.008943 -.008032 -.007254 -.007008 -.007506
   5
-.008733 -.010612 -.013182 -.016569 -.020684 -.025043 -.028931 -.031662
   6
-.032686 -.031642 -.028494 -.023675 -.018041 -.012361 -.007465 -.004591
   7
-.004913 -.008612 -.014548 -.021076 -.026892 -.031589 -.034823 -.035426
```



```
   8
-.032166 -.024946 -.015323 -.005728  .001362  .003331 -.002251 -.015871
   9
-.034479 -.053161 -.067680 -.075061 -.074364 -.066670 -.053125 -.034624
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-.013878  .005333  .022228  .037208  .054724  .060680  .064686  .072364
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  12
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  13
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-.145940 -.168470 -.182401 -.186731 -.179921 -.161596 -.135859 -.110675
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-.020972 -.002370  .002609 -.011609 -.043600 -.093310 -.147723 -.201480
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-.246219 -.270418 -.266197 -.229062 -.156624 -.051136  .077000  .204793
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  24
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APPENDIX A

COMPUTER SOFTWARE USED TO PREPARE CALCULATION PACKAGE

XSTABL - Version 5

Sharma, S., "*XSTABL: An Integrated Slope Stability Analysis Program for Personal Computers, Version 5*," Interactive Software Designs, Moscow, ID, 1994.

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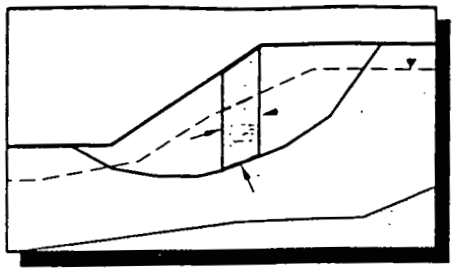

XSTABL©

An Integrated Slope Stability Analysis Program for Personal Computers

Reference Manual

Version 5

prepared by

Sunil Sharma

for

Interactive Software Designs, Inc
953 N. Cleveland Street
Moscow, ID 83843, U.S.A.

000891

XSTABL

VERSION 5.00

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1202a

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2. Transmit **XSTABL** via any electronic media;

3. Duplicate the **XSTABL** Reference Manual,

4. Attempt to disassemble the **XSTABL** machine-code for any purpose whatsoever.

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CHAPTER 1

1.0 INTRODUCTION

XSTABL is a fully integrated slope stability analysis program designed to operate on an IBM personal computer, or close compatible. It permits the engineer to develop the slope geometry interactively and perform the slope analysis from within a single program. The slope analysis portion of **XSTABL** uses a modified version of the popular STABL program, originally developed at Purdue University.

XSTABL performs a two dimensional limit equilibrium analysis to compute the factor of safety for a layered slope according to:

(a) General Limit Equilibrium (GLE) Method,

(b) Janbu's Generalized Procedure of Slices (GPS),

(c) Simplified Bishop,

(d) Simplified Janbu.

If the program is used to search for the most critical surface, only the simplified Bishop and Janbu methods are available for calculating the factor of safety. The program can be used to search for the most critical surface or the factor of safety may be determined for specific surfaces. **XSTABL**, version 5.0, is programmed to handle:

1. heterogenous soil systems with up to 20 soil units,
2. The strength of a soil unit may be defined using:
   (a) conventional, c-ϕ parameters,
   (b) undrained strengths as a function of vertical effective stress,
   (c) a nonlinear Mohr-Coulomb envelop.
3. Anisotropic soil strength properties,

4. Reinforced slopes,
5. Pore water pressures for effective stress analysis using:
   (a) phreatic and piezometric surfaces
   (b) pore pressure grid
   (c) R_u factor
   (d) constant pore water pressure
6. Pseudo-static earthquake loading,
7. Surcharge boundary loads,
8. Automatic generation and analysis of an unlimited number of circular, noncircular and block-shaped failure surfaces,
9. Analysis of right-facing slopes,
10. Both SI and Imperial units.

1.1 Summary of Interactive Features of XSTABL

XSTABL is intended for use on an IBM-PC, or near compatible, suitably equipped for screen graphics. The program uses menus and data-tables to "guide" the potential user through the many options available for performing a slope stability analysis. The interactive features of **XSTABL** include:

1. Selection of options via intuitive, easy to understand menus,
2. Context sensitive help information,
3. All numeric data is entered through prompts into a table,
4. Error checking during data entry phase,
5. Slope geometry may be readily reviewed on-screen,
6. Previously entered data can be edited,
7. Single failure surfaces may be analyzed using several rigorous procedures that satisfy force and moment equilibrium,
8. Previously saved files can be edited and saved as "new" files,

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9. **XSTABL** files may be copied, deleted, printed, renamed or viewed *without* exiting the program,

10. Screen plots may be saved to disk in one of several different formats for later printing or inclusion within a document prepared with a wordprocessing or charting software.

11. High quality plots may be generated, using **XSTABL**, on several different types of output devices if the screen plots are saved in the default format.

It is expected that the approach offered by **XSTABL** will minimize potential errors and provide a more appropriate data preparation method for the less familiar user. The time expended in learning to use the program is expected to be nominal and users can be expected to generate input data files almost immediately.

1.2 General Information

The **XSTABL** Reference Manual is intended to provide information about the interactive features that allow the user to prepare data files and perform a slope stability analysis. The next six chapters of the Reference Manual provides details concerning the following topics:

1. **XSTABL** program components,
2. **XSTABL** menus and available options,
3. Data tables for establishing the slope geometry, and assigning soil properties and boundary loads,
4. Methods of analysis,
5. Slope stability analysis, including the creation and saving of screen plots,
6. Printing of hardcopy plots.

Further details about the limit equilibrium theory, search procedures and slice development are given in Appendix D.

This manual concentrates on the interactive features and is not intended to provide the necessary engineering background for slope stability analysis. If the user wishes to obtain more information concerning slope stability analysis, the following publications are recommended:

1. *The Stability of Slopes*, by E.N. Bromhead, Surrey University Press, Chapman and Hall, NY, 411 pages, ISBN 0 412 01061 5, 1992.

2. *Landslides: Analysis and Control*, by R.L. Schuster and R.J. Krizek (editors), Special Report 176, Transportation Research Board, National Academy of Sciences, 234 pages, ISBN 0 309 02804 3, 1978. (new edition, edited by R.L. Schuster and K. Turner will be published in 1994)

3. *Rock Slope Engineering*, by E. Hoek and J.W. Bray, Inst. of Mining and Metallurgy, London, England, Third Edition, 358 pages, ISBN 0 900488 573, 1981.

Please note that the above list represents ***a very small*** portion of literature available on the subject of slope stability analysis.

1.3 Hardware Requirements

In order to use **XSTABL**, the user will require:

1. An IBM-PC, or near compatible, with either dual floppy disk drives or a hard disk (preferred) and one floppy disk drive, 640 kb RAM and DOS 2.1 (or later).

   Execution of XSTABL will require at least 450,000 bytes of free RAM. The user may check the amount of RAM available by using the "MEM/C" command, as documented in the DOS manual.

2. An IBM compatible VGA, EGA or CGA graphics adaptor with an appropriate monitor,

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3. One of the following devices for hardcopy output:

   (a) A laser printer, e.g. Hewlett Packard LaserJet with at least 1 Mb of RAM, or

   (b) An IBM Graphics compatible, 9 or 24 pin, dot matrix printer, e.g. EPSON FX-85.

   (c) A HPGL compatible pen plotter, e.g. Hewlett Packard 7475A Plotter.

1.4 XSTABL INSTALLATION

The **XSTABL** programs and example data files are supplied on one 3.5 inch or one 5.25 inch disk in a compressed format. To copy these files to a subdirectory on your hard disk, please follow the instruction listed below:

1. create a directory on your hard disk (e.g. MD XSTABL etc....)
2. change to this newly created directory (e.g. CD XSTABL etc....)
3. from this directory type either :

   (a) A:INSTALL --> if the **XSTABL** disk is in "A" drive, or

   (b) B:INSTALL --> if the **XSTABL** disk is in "B" drive

The installation program will place the XSTABL files in the current directory and copy all example datafiles into a subdirectory named: "EXAMPLES". The complete installation of these files will required about 500 kb of disk space. The PACK.LST file on the original disk includes a list, and description, of **all** files that should have been copied to the current directory on your disk.

NOTE:
The above procedure will work if you are preparing to use **XSTABL** from a hard-disk or at least a 720 kb floppy diskette. However if you would like to use the program on dual 360 kb disk drive system, please contact ***Interactive Software Designs, Inc.***, for special instructions to order a non-compressed version of **XSTABL**.

1.5 XSTABL Components

Before using **XSTABL**, the user should ensure that files listed below, and section 2.2, have been copied :

1. PACK.LST . . . . . summary of file descriptions
2. README . . . . . special "last-minute" notes or revisions to this Manual
3. DEMO.TXT . . . . . dialogue script for demonstration/tutorial

1.6 Files for using XSTABL

1. **XSTABL.EXE** . . . . executable version of program
2. SETUP1.STB . . . . . file used during program startup
3. XSTABL.HLP . . . . . help screen information
4. XSTABL.ERR . . . . . XSTABL error descriptions
5. XSTABL.FN1 . . . . . font file for screen characters
6. XSTABL.FN2 . . . . . font file for hardcopy plots
7. XPLOT.EXE . . . . . executable program for hardcopy plots

The installation process will also copy the example input data files and the output (4 files) corresponding to an analysis using the file EX_1.IPT to the "EXAMPLES" subdirectory. These "extra" files may be deleted to conserve disk space.

The program can then be started by typing, **XSTABL** at the DOS prompt. **The program will NOT operate without the SETUP1.STB file.**

> **Please note that the XSTABL software and documentation is copyrighted and may NOT be copied without permission.** However, the user is permitted to make ONE archival backup copy of these files to guard against possible disk failure.

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1.7 Supporting XSTABL files

File: **SETUP1.STB** -- contains initialization information that sets several parameters at the start of the **XSTABL** program. Also, the first line of this file may be modified to control the amount of information that is written into the output file following a slope analysis. A typical unmodified file will have the following form:

Line 1:	0	10	10	10
Line 2:	1.000	1.000	0.30	9.80
Line 3:	(blank line)			

Let the four values on the *first line* be labeled as **var-1**, **var-2**, **var-3** and **var-4**. Then the user is permitted to modify these according to the following:

var-1 = 0 (zero) for all cases, unless advised otherwise;

var-2 = value between 1 and 10, inclusive, for controlling the number of failure surface coordinates that will be listed in the output file following each slope analysis;

var-3 = value between 1 and 10, inclusive, for controlling the number of critical surfaces that will be *displayed on the screen* at the end of the slope analysis;

var-4 = value between 1 and 10, inclusive, for controlling the number of surfaces *plotted to the hardcopy file.*

Please note that the default for the number of surfaces is set at ten for all cases (i.e. var-2 = var-3 = var-4 = 10). These parameters may be changed directly by editing the SETUP1.STB file. Alternatively these may be changed from within **XSTABL** via the F5 key just before the start of the multiple search analysis.

The four values listed on the second line control the scaling and location of the hardcopy plot on paper. The first two values assign the scaling in the x and y direction of the plot. The last two numbers fix the origin of the plot on the basis of a global origin located in the right-hand corner of the printed 11 x 8.5 inch (landscape) page. The user can manipulate these values to scale the hardcopy plots, but must ensure that the aspect ratio of the vertical to horizontal axes is maintained at unity.

Other Files:

The two files, **XSTABL.HLP** and **XSTABL.ERR**, are used by **XSTABL** to provide help and input data error information, respectively. Although the program can function without these files, on-line help information will not be available and error messages will not be written to the output file created during the slope stability analysis. However, error numbers will be written to the output file and the user can determine the corresponding message from the complete list of possible errors given in Appendix B.

1.8 Connecting HP Plotters

XSTABL screen plots may be successfully plotted using HP plotter models: 7440A, 7470A, 7475A and 7550A connected to a personal computer. The cable should be connected to the PC with a DB 9 or DB 25 connector via the serial or asynchronous port. At the plotter, a DB 25 connector should be used to connect the cable to the computer/modem port. **XSTABL** uses the XON/XOFF protocol and thus only requires ***three*** connecting wires in accordance with Fig 1.1.

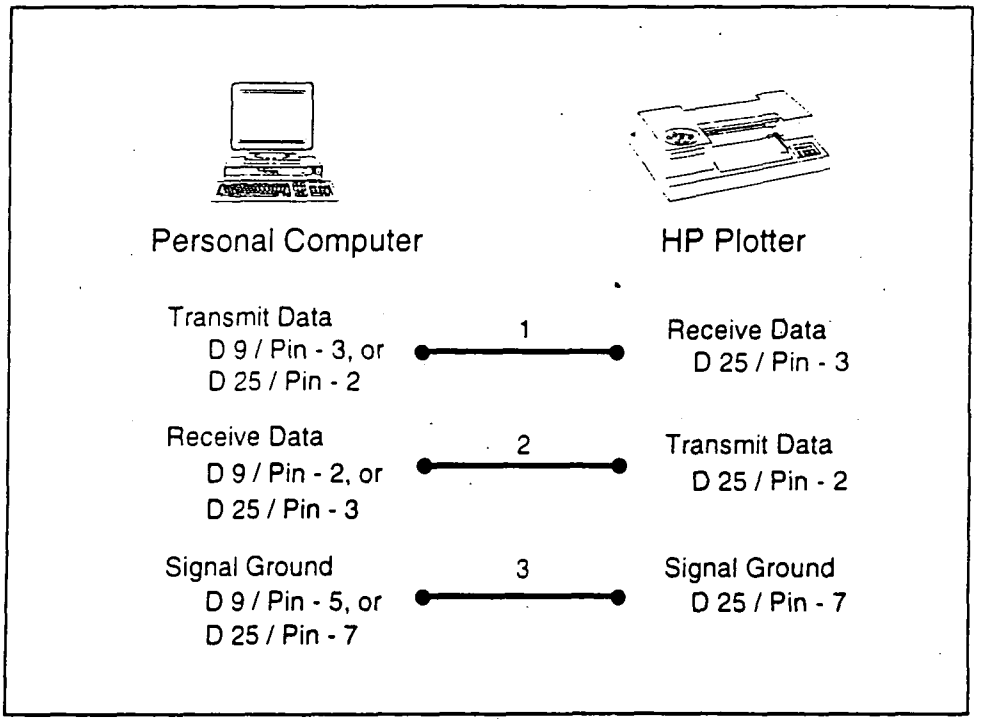

Fig. 1.1. Wire connections for PC - HP plotter cable

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1.9 Starting XSTABL

XSTABL should be executed from the directory occupied by the program's files by typing "XSTABL" at the DOS prompt. Please note that an error will be reported if the user attempts to execute **XSTABL** from a directory which does not have the SETUP1.STB file. Also, the program ***expects*** to access the files: XSTABL.HLP and XSTABL.ERR (i.e. the help and error files) from the current directory only. If these files are not in the current directory, **XSTABL** will be unable to provide a complete report on the errors and the context sensitive help information will not be available.

In executing the program, **XSTABL** offers the user an opportunity to change three default parameters via a command line option. If the user executes the program by only typing "XSTABL", the following default options are invoked:

(a) Imperial units, i.e. pounds, psf, pcf and feet;

(b) Parallel printer port selected as LPT1;

(c) Serial port selected as COM1.

The parallel port is used for printing input and output files and for printing all slope analysis plots, except those sent to a plotter. In this case the plotter is assumed to be connected to the COM1 serial port. If the above default selection is not appropriate, the user may change any of these according to the command-line switches given below.

Alternative SI Units may be selected by executing the program by typing: "XSTABL -m" at the DOS prompt. In this case the program will startup with SI units represented by: kN, kPa (kilo Pascals), kN/m^3 and meters.

The Alternative Parallel Port LPT2 may be selected by starting the program by typing: "XSTABL LPT2". This selection will send all parallel port output to the LPT2 port.

The Alternative Serial Port COM2 may be selected by starting the program by typing: "XSTABL COM2". This selection will send the plotter output to the alternative serial port.

Any combination of the above three options is possible. For example by typing : "XSTABL COM2 LPT2 -m" the user may invoke (1) COM2 as the serial port, (2) LPT2 as the default parallel printer port and (3) SI units.

1.10 Example Input and Output Files

Several data files are provided with the main programs, on the enclosed disk, for evaluating the **XSTABL** software. These files are based on the slope geometry described in Appendix A of this manual. The output files, for example EX_1.IPT, are also included for the convenience of the user and to check for proper operation of **XSTABL** on your computer. A complete description of these example files is summarized in the disk file: PACK.LST.

1.11 XSTABL Tutorial

A dialogue script for a tutorial that demonstrates some of the unique features of **XSTABL** is included with the program disk(s) in the file: DEMO.TXT. The user is encouraged to print this file, and follow the suggested instructions. This tutorial will familiarize users with the editing features, special commands and other data tables that are used to assemble a data file for slope stability analysis.

1.12 ANSI.SYS Device Driver

The **XSTABL** program has been designed to access the video hardware directly, thus minimizing the response time between keyboard entry and subsequent actions. However if the **ANSI.SYS** device driver is loaded, it "filters" the data before it is written to the screen. Thus in order to maximize the speed of **XSTABL**, the use of the ANSI.SYS device driver is not recommended as it tends to slow the response time for data written to screen.

The user may check to see if the ANSI.SYS driver is loaded by examining the CONFIG.SYS file in the root directory. A line of the general form :

DEVICE=ANSI.SYS

will indicate that the device driver is loaded at the start of every session. The user must then choose to either load or omit the ANSI.SYS device driver.

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1.13 Loading and Execution Errors

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It is possible that an "unexplainable" error may occur during the loading and execution phase of the program. If such an error occurs, please check you data thoroughly. If your data appears to be correct and the error condition persists, please contact:

Dr. Sunil Sharma,
Interactive Software Designs, Inc.,
953 N. Cleveland,
Moscow, ID 83843.

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M. Gleason
20 Oct 95

APPENDIX B

COMPUTER SOFTWARE USED TO PREPARE CALCULATION PACKAGE

YSLIP_C

Yan, L.P., "Seismic Deformation Analysis of Earth Dams: A Simplified Method," Research Report No. SML-91-01, California Institute of Technology, Soil Mechanics Laboratory, Pasadena, California, 1991.

M Gleason
20 Oct 95

B2/4

USER GUIDE FOR YSLIP_C

By Liping Yan

PREPARATION OF INPUT DATA FILE:

CARD 1 : PHI, THETA, RC, R, RI
CARD 2: BETA, NCR, NSIGN
CARD 3: NA, INDEX, MNA, STEP, KREAD
CARD 4: EARTHQUAKE RECORD IN SPECIFIED FORMAT

NOTE:

PHI [UNIT: DEGREE]--- FRICTION ANGLE, CHOSEN TO GIVE DESIRED YIELD ACCELERATION
THETA [UNIT: DEGREE]--- INCLINED ANGLE
RC [UNIT: METER]---- DISTANCE FROM CENTER OF CIRCLE TO CENTER OF MASS
R [UNIT: METER]---- RADIUS OF CIRCLE
RI [UNIT: METER]---- RADIUS OF GYRATION OF MASS

BETA [UNIT: DEGREE]--- ANGLE OF TANGENTIAL LINE OF ARC AT CREST TO VERTICAL

NCR: = 0, OUTPUT IS FOR THE LOCATION AT SLIDING MASS CENTER;
= 1, OUTPUT IS FOR THE LOCATION AT CREST
NSIGN: = 1, RECORD (AT) IS POSITIVE AS ASSUMED IN THE INPUT FILE;

=-1, RECORD (AT) IS POSITIVE INVERSELY AS ASSUMED IN THE INPUT FILE

NA [INTEGER]-------- NUMBER OF RECORDING POINTS
INDEX [INTEGER]-------- NUMBER OF RECORDING LINES
MNA [INTEGER]-------- 8*MNA
STEP [[UNIT: SECOND]-- TIME INTERVAL OF RECORD
KREAD [INTEGER]-------- SPECIFIED RECORD FORMAT
=0, FORMAT(8F9.6,I7)
=1, FORMAT(1X,8F9.6)
=2, FREE FORMAT, TWO VALUES PER LINE (TIME, ACCELERATION)
=3, FREE FORMAT, NA VALUES OF ACCELERATION

M. Gleason
20 Oct 95

B3/4

TT,TV [UNIT: SECOND]--- TIME
EARTHQUAKE RECORDS [UNIT: G]: AT---TRANSVERSE COMPONENT;
AV---VERTICAL COMPONENT.
SLIDING---POSITIVE IN DOWNSLOPE DIRECTION.
AV---POSITIVE IN UPWARD DIRECTION.
IF SLIDING OCCURS ON THE UPSTREAM SIDE OF DAM:
AT---POSITIVE IN DOWNSTREAM DIRECTION.
IF SLIDING OCCURS ON THE DOWNSTREAM SIDE OF DAM:
AT---POSITIVE IN UPSTREAM DIRECTION.

FOUTA---OUTPUT FILE NAME FOR ABSOLUTE MOTION OF BLOCK.
FOUTS---OUTPUT FILE NAME FOR SLIDING MOTION OF BLOCK.

M. Gleason
20 Oct 92

BH/4

```
**********************************************
**                YSLIP_C                   **
**A COMPUTER PROGRAM FOR NUMERICAL SIMULATION**
**   OF A SLIDING BLOCK ON A CIRCULAR ARC    **
**      [INPUT MOTION: EARTHQUAKE RECORD]    **
**          DEVELOPER: Liping Yan            **
**            ADVISOR: R.F.Scott             **
**     VAX VERSION 1.0: SEPTEMBER, 1986      **
**     VAX VERSION 2.0:      JUNE, 1990      **
**     VAX VERSION 3.0: SEPTEMBER, 1991      **
**      PC VERSION 1.0:    AUGUST, 1992      **
**      PC VERSION 1.1: SEPTEMBER, 1992      **
**                                           **
**********************************************
```

READ -- PHI,THETA; RC, R, RI

READ -- BETA, NCR; NSIGN

READ -- NA,INDEX,MNA,STEP,KREAD

READ -- ACCELERATION RECORD

OUTPUT FILE FOR ABSOLUTE ACC. OF BLOCK WILL
LIST ROW BY ROW OF:
Time, Horizontal ACC., Alpha

OUTPUT FILE FOR SLIDING MOTION OF BLOCK WILL
LIST ROW BY ROW OF:
Time, Sliding ACC., VEL., DISP.-in INCHES !

YOU GOT IT ! THANKS FOR USING YSLIP_C !

SECTION 5

5. HYDROSTATIC UPLIFT

5.1 Hydrostatic Forces

5.1 Hydrostatic Forces

COMPUTATION COVER SHEET

SUBJECT OF CALCULATION: HYDROSTATIC FORCES

Computations By: (Cognizant Engineer)
Signature: Majdy Ahmed Othman — Date: 29 Sep 1995
Printed Name and Title: MAJDI A. OTHMAN, PROJECT ENGINEER

Assumptions and Procedures Checked by: (Checker)
Signature: Paul J. Sabatini — Date: 2 Oct 95
Printed Name and Title: Paul J. Sabatini, Sr. Staff Engineer

Computations Checked by:
Signature: Paul J. Sabatini — Date: 2 Oct 95
Printed Name and Title: Paul J. Sabatini, Sr. Staff Engineer

Computations Backchecked by: (Cognizant Engineer)
Signature: Majdy Ahmed Othman — Date: 2 Oct 95
Printed Name and Title: MAJDI A. OTHMAN, PROJECT ENGINEER

Approved by: (PDP)
Signature: Majdy Ahmed Othman — Date: 2 Oct 95
Printed Name and Title: MAJDI A. OTHMAN, PROJECT ENGINEER

Approved by: (DTL and TETL)
Signature: Rudolph Bonaparte — Date: 2 Oct 95
Printed Name and Title: Rudolph Bonaparte, Project Manager and Team Leader

Record of Revision (Number and initial all revisions)

NO.	REASON	DATE	BY	CHECKED	APPROVAL	
Ø	30% Submittal	NA	NA	NA	NA	No changes
B	Preliminary Design ~~EPA Submittal~~	15 Dec 95				

Signature: _____
Number: _____
Registration Stamp (if applicable)

HYDROSTATIC PRESSURE APPLIED ON LINER SYSTEM

EXECUTIVE SUMMARY

Purpose of Analysis

The purpose of this analysis is to estimate the factor of safety against hydrostatic uplift of the liner system caused by the perched ground water table.

Methods of Analysis

The factor of safety was calculated as the ratio of overburden pressure to hydrostatic pressure beneath the liner system.

Conclusions

For the short-term condition (i.e., after liner construction), minimum calculated factor of safety (FOS) = 2.05. For the long-term condition (i.e., post closure), minimum calculated FOS = 5.50. These factors of safety exceed the allowable factor of safety of 1.4.

Written by: MAO Date: 95/9/19 (YY MM DD) Reviewed by: Date: / / (YY MM DD)

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE3900 Task No.: 08.9

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HYDROSTATIC PRESSURES APPLIED ON LINER SYSTEM

CALCULATIONS PROCEDURES

PURPOSE OF ANALYSIS

The purpose of this analysis is to estimate factors of safety against hydrostatic uplift of the liner system. This uplift is caused by the perched water table in the clay layer below the ground surface.

METHOD OF ANALYSIS

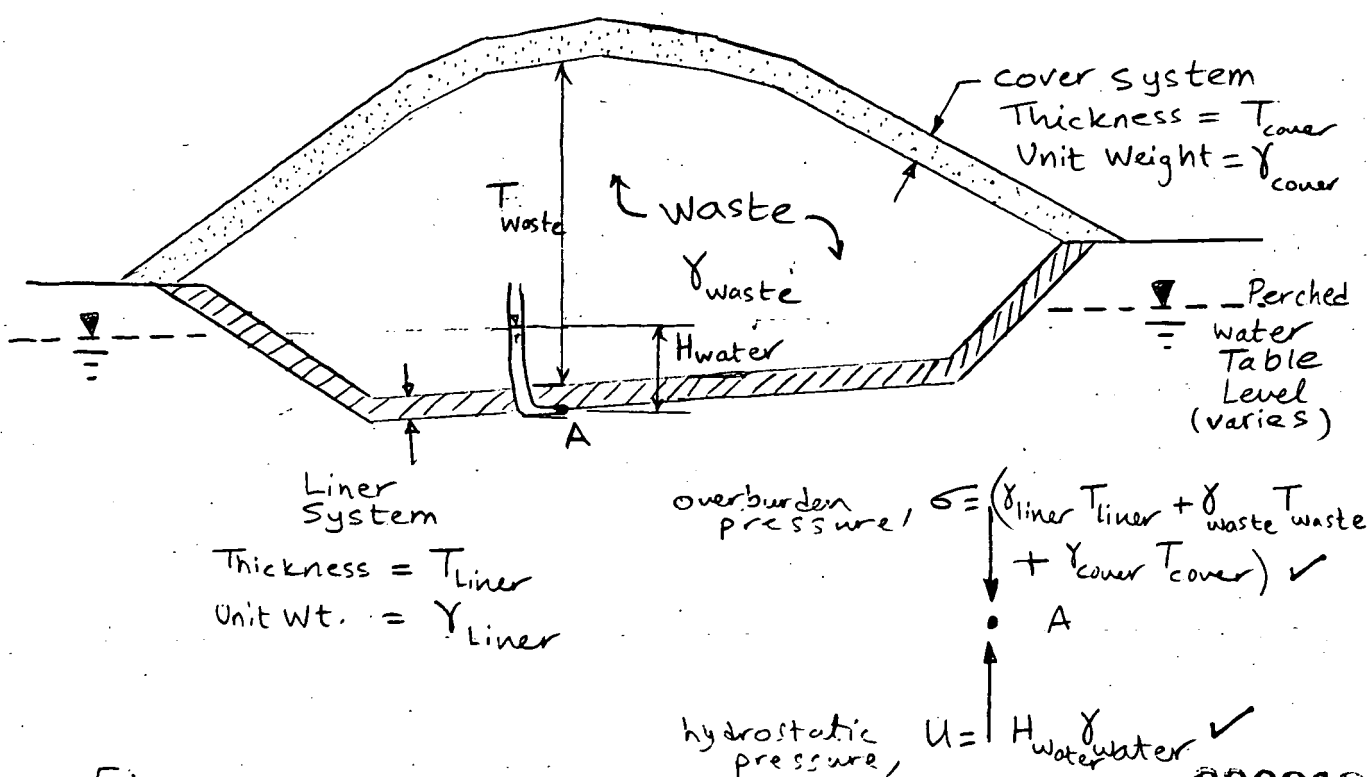

Figure 1. Definitions and Terminology

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- Gravity pressure applied downward on any point A located at the bottom of the liner can be calculated as the sum of the products of thickness and unit weight of all materials above point A:

i.e., $$\sigma = \gamma_{liner} T_{liner} + \gamma_{waste} T_{waste} + \gamma_{cover} T_{cover} \quad (1)$$

- Hydrostatic pressure applied upward on point A is the product of hydraulic head at point A and unit weight of water

i.e., $$u = H_{water} \gamma_{water} \quad (2)$$

- The factor of safety (FOS) against liner uplift is calculated as follows:

$$FOS = \frac{\gamma_{liner} T_{liner} + \gamma_{waste} T_{waste} + \gamma_{cover} T_{cover}}{H_{water} \gamma_{water}} \quad (3)$$

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CASES TO BE ANALYZED

Two cases will be analyzed as follows:

- Case 1: After Liner Construction and Prior to Waste Placement (i.e., short term)

It is assumed that drainage techniques will be used to lower the level of the perched water table to allow construction of the liner system. However, after the liner has been constructed, drainage will be stopped. Therefore, the ground water system will readjust to reach equilibrium conditions. It is anticipated that due to the low hydraulic conductivity of the existing clay layers beneath the liner system, this process may take a long time. Therefore, assuming full development of hydrostatic pressures (i.e., H_{water} in Figure 1) beneath the liner system for the analysis of Case 1 is conservative. For Case 1, Equation 3 reduces to:

$$FOS = \frac{\gamma_{liner}\, T_{liner}}{H_{water}\, \gamma_{water}} \quad (4)$$

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- Case 2: Post-Closure Period (i.e., long term)

For this case, it is assumed that waste is at its maximum height and the final cover system is placed on the waste. For Case 2, Equation (3) is applicable✓. It is assumed that the perched water table level has reached equilibrium.

INTERPRETATION OF RESULTS

The calculated factors of safety will be compared to the acceptable factor of safety of 1.4 based on the DCP. If the calculated factors of safety exceed 1.4, then they are acceptable. Otherwise, more detailed analysis methods will be utilized, or the design and construction procedures should be modified.

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HYDROSTATIC PRESSURES APPLIED ON LINER SYSTEM

DATA VERIFICATION PACKAGE

INTRODUCTION

As described in calculations procedures package, two cases will be analyzed which are: (i) Case 1, representing conditions after liner construction and prior to waste placement; and (ii) Case 2, representing post-closure conditions. Data requirements include the following:

- perched water table levels for both Case 1 and Case 2;
- excavation (i.e., bottom of liner system) grades; and
- thicknesses (T) and unit weights (γ) of the liner and cover systems and the waste.

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ANALYSIS APPROACH

1. Select several locations in the foot print of the landfill to perform liner hydrostatic uplift analyses.

2. for each location, estimate the following:
   - existing ground elevation;
   - excavation (i.e, bottom of liner) elevation;
   - perched water table elevation; and
   - maximum thickness of waste.

3. calculate factors of safety for Cases 1 and 2 using equations presented in procedures package.

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PERCHED WATER TABLE ELEVATIONS

Examination of monitoring well data suggests that the perched water table level at any particular location varies significantly with time. It further appears that water level is sensitive to precipitation. For example, data from MW 1843 (see attached figure) shows that perched water table level varied between 581.7' measured on 22 Nov. 1994 and 587.0' measured on 23 Jan 1995. This 5.3 ft change in level occured within a relatively short period of time (i.e., approximately two months). Furthermore, during this period of time, the maximum amount of precipitation which occured on any one day was less than 1 in. It is anticipated that sustained rainfall with larger precipitation amounts may cause the water level to increase significantly within a short period of time. Data from other monitoring wells are consistent with the observations described above.

From "Predesign Investigation and Site Selection Report for the On-Site Disposal Facility" Vol. 2 of 3, July 1995.

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MW 1843

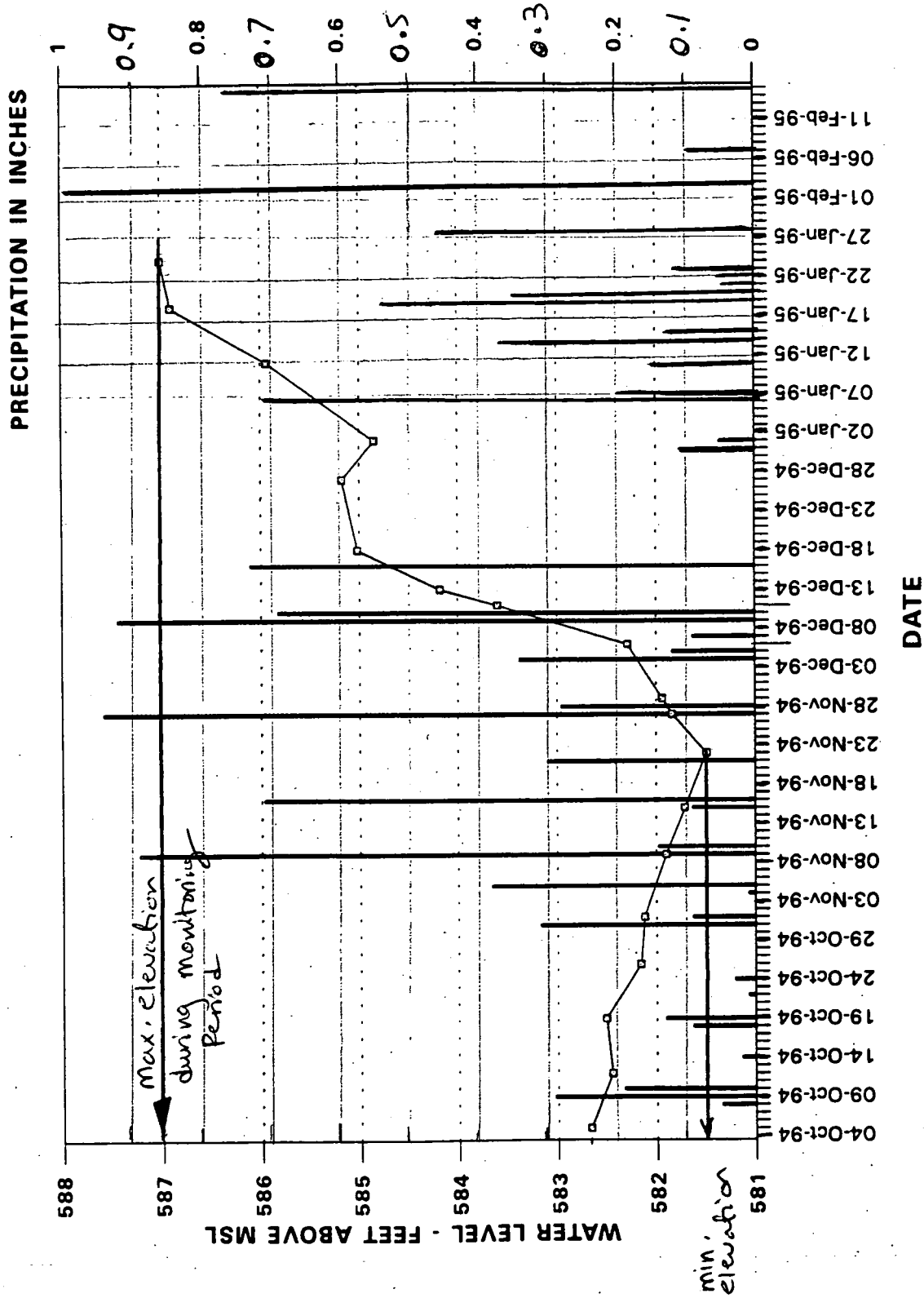

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Figure 2-20 from the July 1995 predesign investigation report is attached. This figure shows perched groundwater contours which, according to the report, represent the uppermost limit as identified from the monitoring wells. It should be noted that these contours were based on data collected over a short period of time (i.e., months), and therefore, the perched groundwater table could potentially be several feet higher than shown in Figure 2-20. This would especially be true under conditions of sustained large precipitation.

Examination of Figure 2-20 and the existing ground elevations (see topographic map attached) shows that, within the few month monitoring period, the perched groundwater table was at or just below the ground surface. As a conservative approach, it will be assumed that the perched water table is at the ground surface for analysis of Case 2.

From "Predesign Investigation and Site Selection Report for the On-Site Disposal Facility" vol. 1 of 3 July 1995

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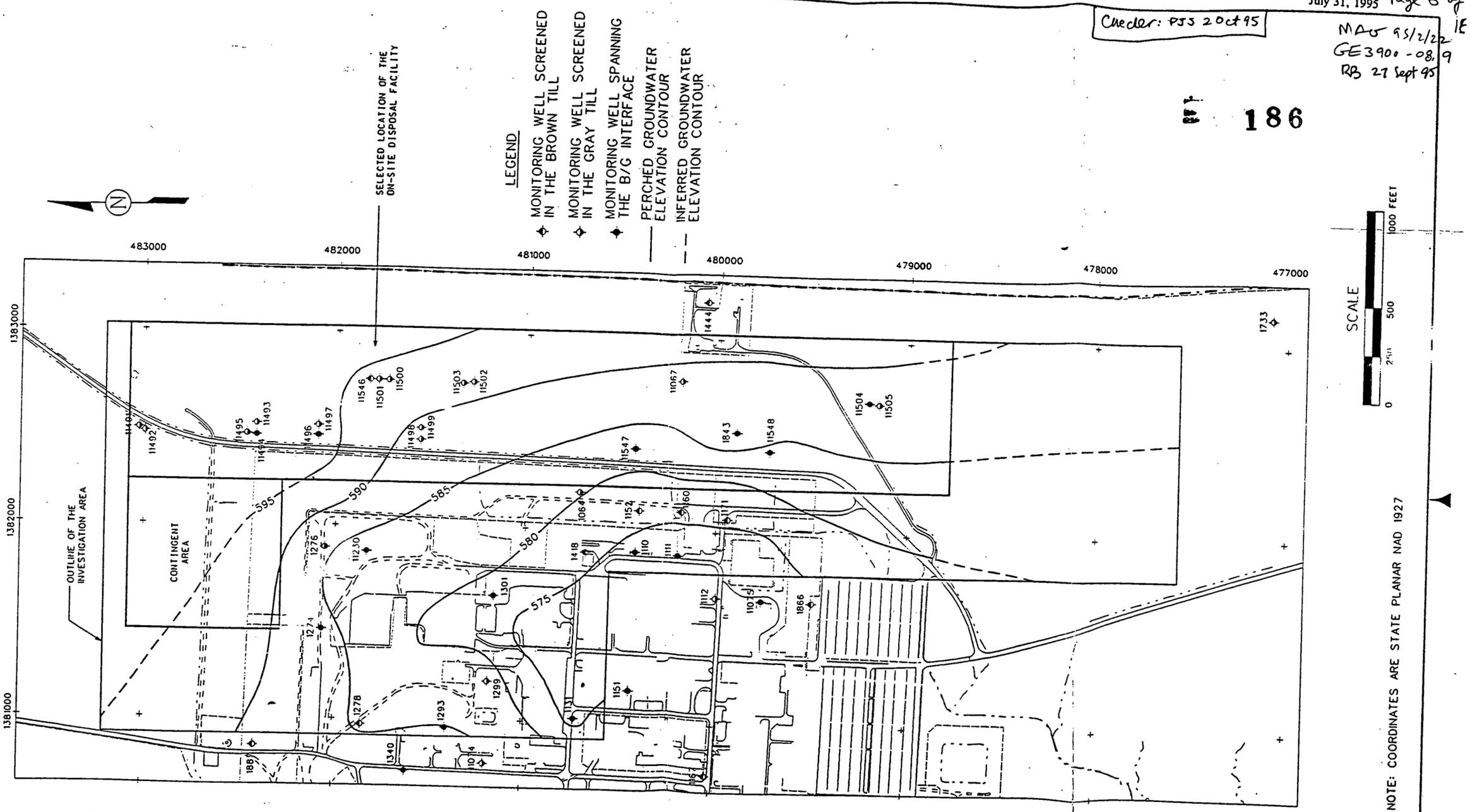

000928

FERNALD ENVIRONMENTAL RESTORATION MANAGEMENT CORPORATION
FERMCO
Fernald Environmental Management Project
U.S. DEPARTMENT OF ENERGY

PERCHED GROUNDWATER CONTOURS FOR WELLS SCREENED ACROSS THE BROWN/GRAY INTERFACE

DATE 5-02-95
DRAWN DEG

FIGURE 2-20

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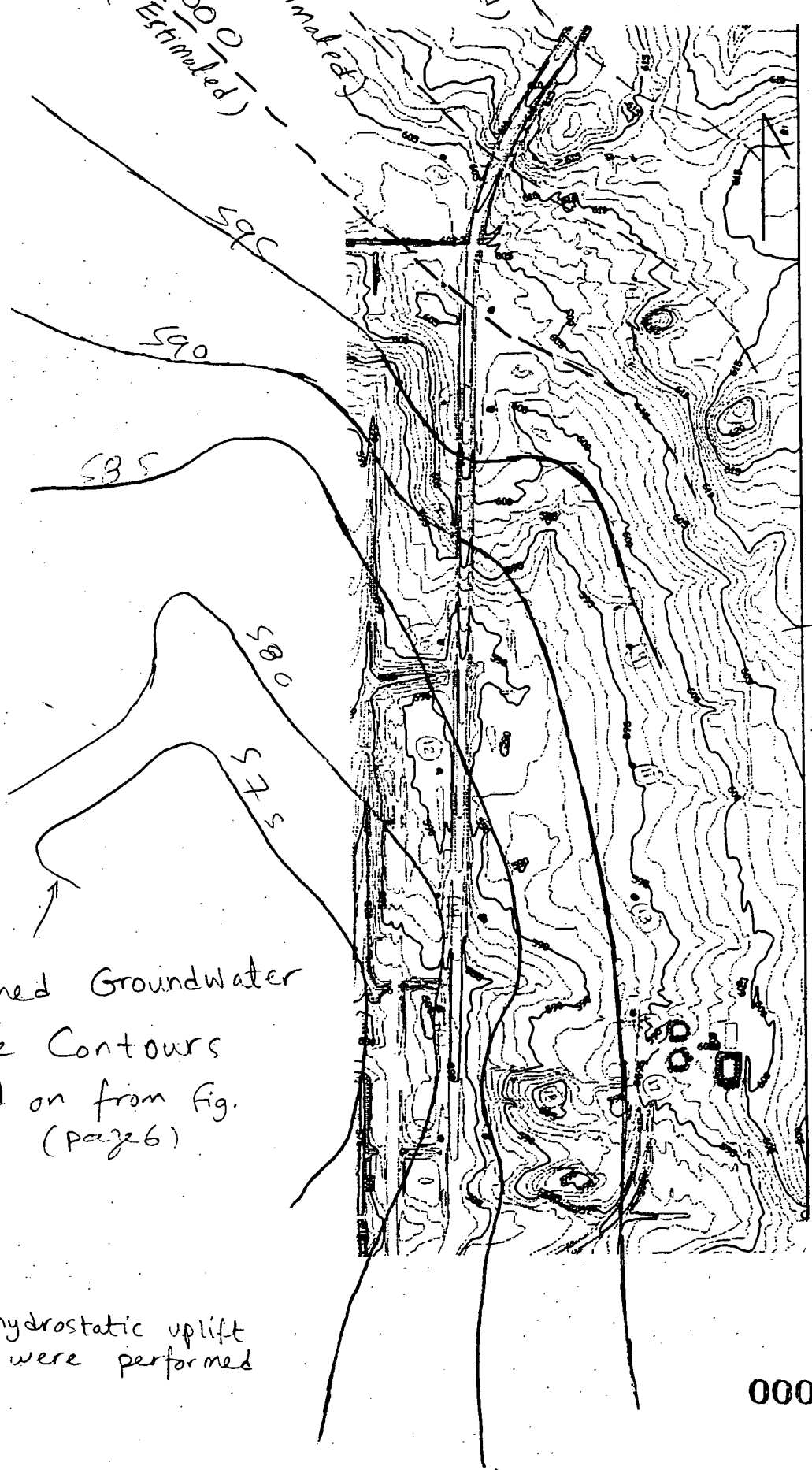

Perched Groundwater Table Contours traced on from fig. 2-20 (page 6)

Legend:

① location hydrostatic uplift analyses were performed

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In the long term, if storm events are capable of flooding the OSDF, then water level to be used for the hydrostatic uplift analysis should be equal to the water level during the flood stage. Review of report entitled "2,000-Year Flood and Probable Maximum Flood Site wide Flood Plain Determination" prepared by Parsons in August 1995 shows that the OSDF is not within the limits of the 2000-yr flood plain. Therefore, the assumption that the perched water table is at the ground surface is still a conservative assumption for the long-term case (i.e., Case 2).

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For the short-term condition (i.e., Case 1), the perched ground water table will be assumed to be represented by the contour map shown on pages 6 and 7. This assumption is based on several reasons which are:

- The period of construction of the cell liner system is expected to occur in the summer and should take only a few months. During the summer, the perched ground water table is low and due to the short period of construction, total equilibrium of the pore water pressures may not occur.
- The liner system of the OSDF which contains a geomembrane/compacted clay geocomposite will reduce the amount of rainwater infiltration (recharge) into the ground beneath the OSDF.
- Drainage techniques will be implemented during construction to control the perched ground water table.

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EXCAVATION GRADES

Excavation (bottom of liner system) grades are shown on plan attached.

FINAL COVER SYSTEM GRADES

Top of final closure cover system are shown on attached plan.

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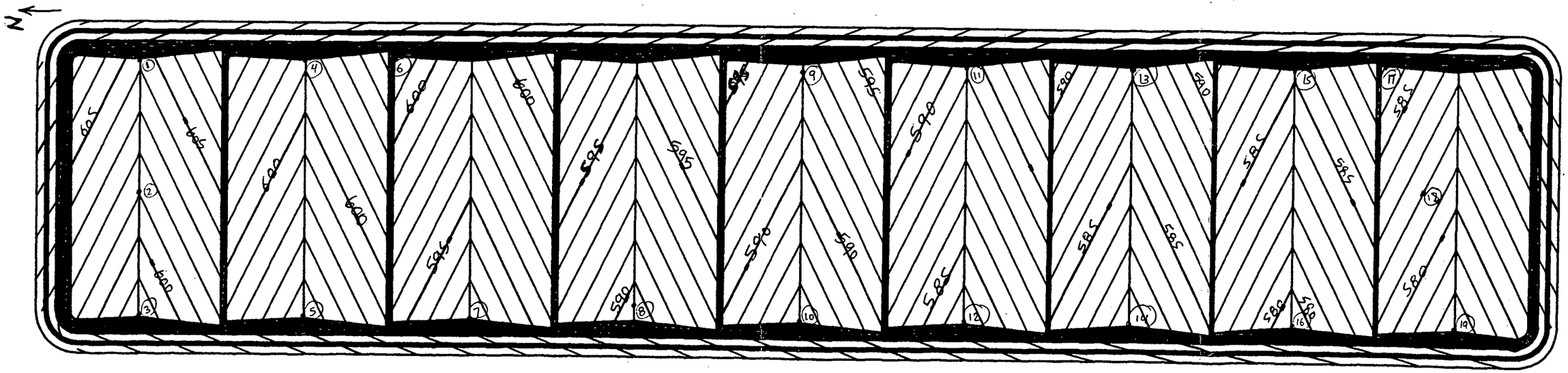
Excavation Grading Plan



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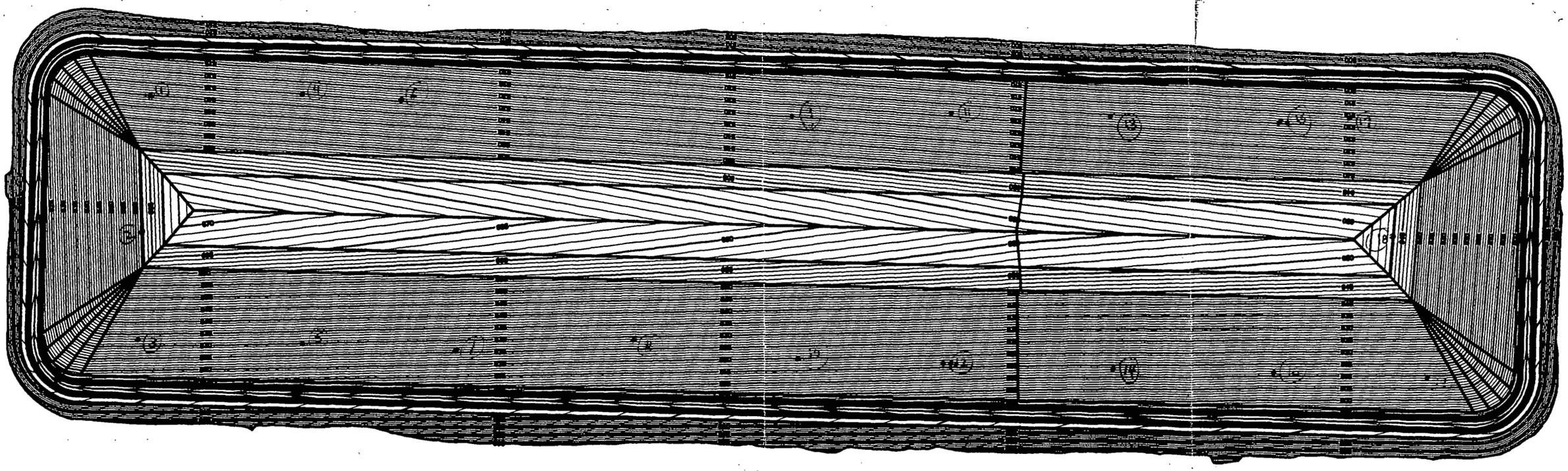
Final Cover System Grading Plan



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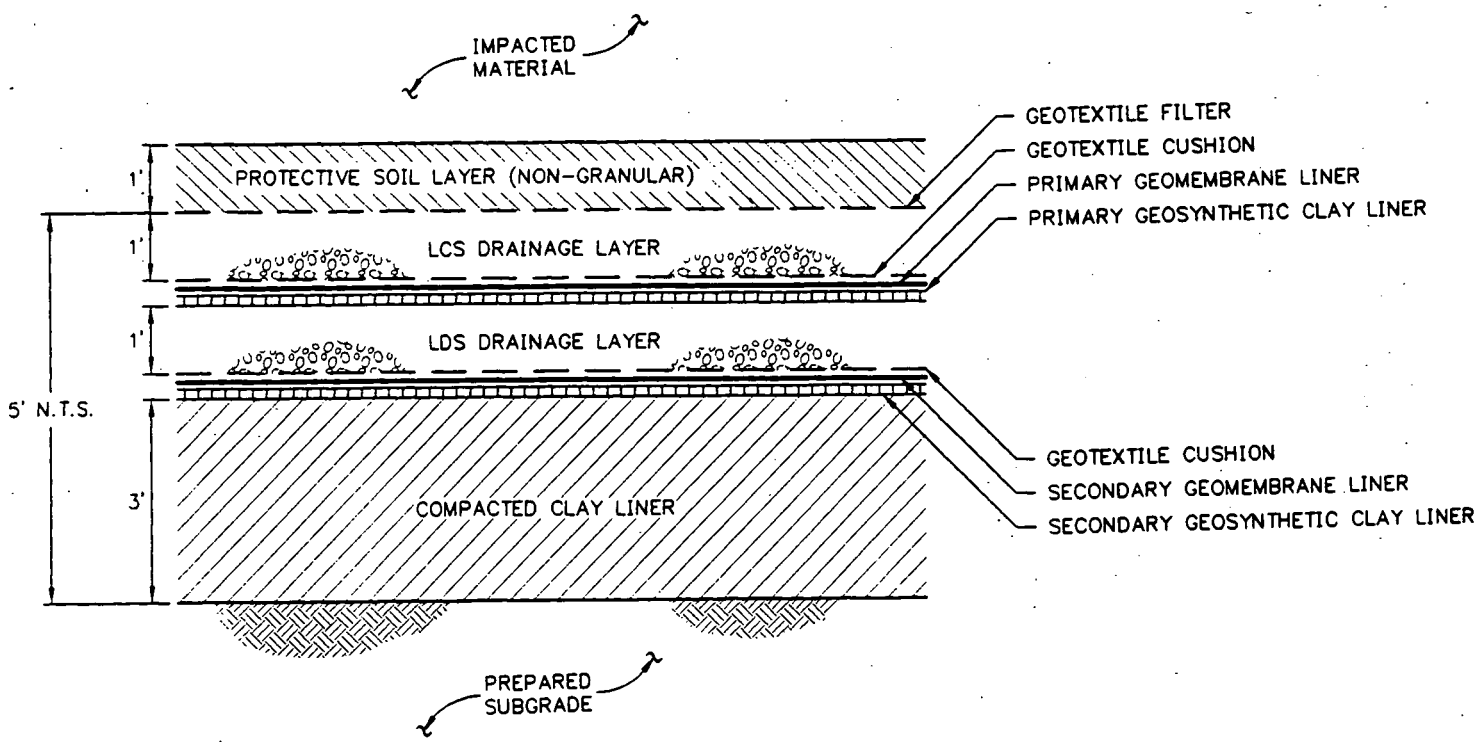
LINER SYSTEM:

Thickness (T_{liner}) = 5 ft ✓

Unit Weight (γ_{liner}):

Assume unit weight of LCS and LDS drainage layers = 125 pcf and compacted clay liner = 130 pcf

$$\rightarrow \gamma_{liner\,(avg.)} = \frac{2\text{ ft} \times 125\text{ pcf} + 3\text{ ft} \times 130\text{ pcf}}{5\text{ ft}} = 128\text{ pcf} \checkmark$$



WASTE:

Waste unit weight (γ_{waste}) is conservatively assumed equal to 80 pcf.

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FINAL COVER SYSTEM

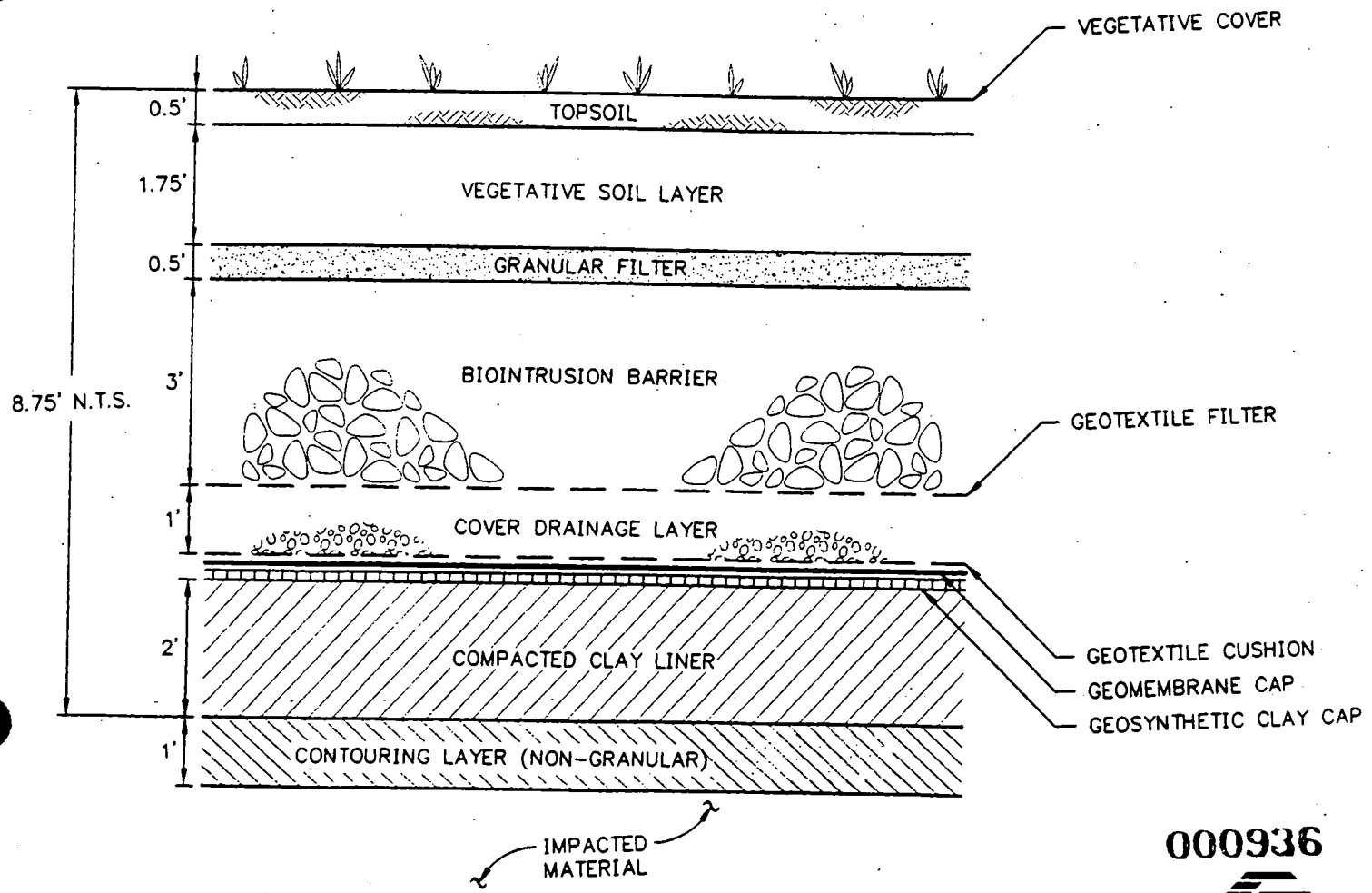
Thickness (T_{cover}) = 8.75 ft

Unit Weight (γ_{cover}):

Assume unit weight of compacted clay cap = 130 pcf and all other final cover system layers = 125 pcf

$$\rightarrow \gamma_{cover\,(avg.)} = \frac{2\text{ ft} \times 130\text{pcf} + 6.75\text{ ft} \times 125\text{pcf}}{8.75\text{ ft}}$$

$$= 126.1\text{ pcf}$$



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DATA SUMMARY

Analyses will be performed to calculate factors of safety against hydrostatic uplift of the liner system at specific locations within the footprint of the OSDF. These locations were selected to represent conservative conditions (i.e., large hydraulic head and small thickness of waste). The locations at which analyses will be performed are shown on the excavation and final cover system grading plans shown on pages 10 and 11. These locations are numbered from 1 to 19. Data relevant to the uplift analyses are summarized for these locations in Table 1 included on page 15.

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Table 1. HYDROSTATIC UPLIFT ANALYSIS DATA SUMMARY

Location ID Number	Existing Ground Elevation (ft)	Excavation Elevation (ft)	Perched GWT Elevation(1) (ft)		Hydrostatic Head Beneath Liner(2) (ft)		Final Cover System Elevation (ft)	Thickness of Waste(3) (ft)
			Short-term	Long-term	Short-term	Long-term		
1	613	605	608	613	3	8	640	21
2	615	601	606	615	5	14	663	48
3	604	598	603	604	5	6	632	20
4	609	602	604	609	2	7	635	19
5	604	596	600	604	4	8	630	20
6	610	602	602	610	0	8	634	18
7	602.5	593	596	602.5	3	9.5	626	19
8	600	589.5	590	600	0.5	10.5	629	26
9	597	592.5	594	597	1.5	4.5	630	24
10	591	587	587	591	0	4	620	19
11	595	590	592	595	2	5	624	20
12	590	584	584	590	0	6	616	18
13	594.5	587	592	594.5	5	7.5	621	20
14	588	582	580	588	-(4)	6	614	18
15	593.5	586	591	593.5	5	7.5	620	20
16	584	580	580	584	0	4	611	17
17	595	587	591	595	4	8	616	15
18	595	582	587	595	5	13	647	51
19	584	578	581	584	3	6	610	18

Notes:

(1) perched GWT for short-term conditions (i.e., Case 1) are obtained from map on Page 7. For long-term conditions, perched GWT is assumed to be at ground surface.

(2) Hydrostatic head beneath liner = perched GWT elevation − excavation elevation

(3) liner system thickness = 5 ft, final cover system thickness = 8.75 ft → Thickness of waste = final cover system elevation − (excavation elevation + liner system thickness + cover system thickness)

(4) perched GWT is below excavation level.

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HYDROSTATIC PRESSURE APPLIED ON LINER SYSTEM ANALYSIS RESULTS

INTRODUCTION

Hydrostatic uplift of the liner system after its construction and for post-closure (i.e., long-term) conditions is evaluated herein in accordance with the procedures and data described earlier. The factors of safety are calculated at 19 locations within the limits of the OSDF footprint.

RESULTS

Table 1 presented on the following page summarizes the calculated factors of safety. As shown in Table 1, the calculated factor of safety was greater than 2.05 for the short-term case and greater than 5.50 for the long-term case, for all 19 locations considered in the analysis.

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Table 1. Liner System Hydrostatic Uplift Analysis – Summary of Results

(1) Location ID Number	(1) Hydrostatic Head Beneath Liner, Hwater (ft)		(1) Thickness of Waste, Twaste (ft)	(3) FOS after Liner Construction	(4) FOS Post-Closure Condition
	Short-Term	Long-Term			
1	3	8	21	3.42	6.86
2	5	14	48	2.05	6.39
3	5	6	20	2.05	8.93
4	2	7	19	5.13	7.47
5	4	8	20	2.57	6.70
6	0 (2)	8	18	— (2)	6.38
7	3	9.5	19	3.42	5.50
8	0.5	10.5	26	20.52	5.83
9	1.5	4.5	24	6.84	13.04
10	0 (2)	4	19	— (2)	13.07
11	2	5	20	5.13	10.71
12	0 (2)	6	18	— (2)	8.50
13	5	7.5	20	2.05	7.14
14	— (2)	6	18	— (2)	8.50
15	5	7.5	20	2.05	7.14
16	0 (2)	4	17	— (3)	12.43
17	4	8	15	2.57	5.90
18	5	13	51	2.05	7.18
19	3	6	18	3.42	8.50

Notes:

(1) See data in Table 1 of data package.

(2) perched GWT is at or below excavation level.

(3) $FOS = \frac{\gamma_{liner} T_{liner}}{\gamma_{water} T_{water}} = \frac{128\ pcf \times 5\ ft}{62.4\ pcf \times H_{water}} = \frac{10.26\ ft}{H_{water}}$

(4) $FOS = \frac{\gamma_{liner} T_{liner} + \gamma_{waste} T_{waste} + \gamma_{cover} T_{cover}}{\gamma_{water} H_{water}}$

$= \frac{128\ pcf \times 5\ ft + 80\ pcf \times T_{waste} + 126.1\ pcf \times 8.75\ ft}{62.4\ pcf \times H_{water}}$

$= \frac{1743 + 80\ T_{waste}}{62.4\ H_{water}}$