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SUBMITTAL OF INTERMEDIATE DESIGN PACKAGE (60%) FOR THE ON-SITE DISPOSAL FACILITY - CALCULATION PACKAGE REVISION D - VOLUMES 1-4 - APRIL 1996

04/10/96

DOE-0771-96
DOE-FN EPAS
2100
DESIGN

Department of Energy
Ohio Field Office
Fernald Area Office
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APR 10 1996
DOE-0771-96

Mr. James A. Saric, Remedial Project Director
U.S. Environmental Protection Agency
Region V - SRF-5J
77 W. Jackson Blvd.
Chicago, IL 60604-3590

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 INTERMEDIATE DESIGN PACKAGE (60%) FOR THE ON-SITE DISPOSAL FACILITY

The Department of Energy, Fernald Area Office (DOE-FN) is pleased to submit the enclosed Intermediate Design Package (60%) and the Remedial Action Work Plan (RAWP) and Support Plans for the On-Site Disposal Facility. DOE-FN believes the Design Package, the RAWP and Support Plans are a 90% regulatory submittal. During previous discussions, your offices expressed an interest and willingness to review these documents as a 90% submittal.

This package includes design criteria, final design calculations (Volumes 1, 2, 3 and 4), technical specifications and design drawings. The technical specifications and design drawings included are shown with an asterisk. The other technical specifications and design drawings discuss or illustrate Certified for Construction (CFC) details.

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

Sincerely,

for Johnny W. Reising
Fernald Remedial Action
Project Manager

FN:Jalovec

Enclosure: As Stated

Recycled and Recyclable

cc w/enc:

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INTERMEDIATE DESIGN
CALCULATION PACKAGE
ON-SITE DISPOSAL FACILITY

REVISION D
VOLUME 1 OF 4
APRIL 1996

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

prepared by

GeoSyntec Consultants
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under

Fernald Environmental Restoration Management Corporation
Subcontract 95PS005028

253 No. 26

INTERMEDIATE DESIGN CALCULATION PACKAGE ON-SITE DISPOSAL FACILITY

Volume I **EDC**

April 1996
Revision D

United States Department of Energy

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INTERMEDIATE DESIGN PACKAGE
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On-Site Disposal Facility
Fernald Environmental Management Project

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1. INTRODUCTION

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1.2 Computer Program Validation
1.3 Select Technical References

1.1 Design Parameter Summary

COMPUTATION COVER SHEET

SUBJECT OF CALCULATION: DESIGN PARAMETER SUMMARY

Computations By: (Cognizant Engineer)
Signature [signature] Date 23 Feb 96
Printed Name and Title Gary R. Schmertmann, Sr. Project Engineer

Assumptions and Procedures Checked by: (Checker)
Signature Daniel G. Pass Date 26 FEB 96
Printed Name and Title DANIEL G. PASS, STAFF ENGINEER

Computations Checked by:
Signature NO COMPUTATIONS IN THIS PACKAGE Date
Checked by:
Printed Name and Title

Computations Backchecked by: (Cognizant Engineer)
Signature NO COMPUTATIONS IN THIS PACKAGE Date
Printed Name and Title

Approved by: (PDP)
Signature [signature] Date 26 Feb 96
Printed Name and Title Gary R. Schmertmann, Sr. Project Engineer

Approved by: (DTL and TETL)
Signature [signature] Date 26 Feb 96
Printed Name and Title Kenneth W. Cargill, Associate

Record of Revision (Number and initial all revisions)

Rev. No.	Reason	Date	By	Checked	Approval
C	Intermediate Design	23 Feb 96	GRS	DGP	[signature] 26 Feb 96
D	Intermediate Design - expanded discussion	5 Apr 96	GRS	DGP	[signature] 6 Apr 96

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 calculation packages for the On-Site Disposal Facility (OSDF). The summary addresses the majority of parameters that are used within the individual design calculation packages. The parameters not discussed herein are primarily those that are used only within one calculation package or group of related packages. Discussion of these parameters is provided in the Data Verification section of the individual package(s).

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, 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 eight calculation packages: 3.1 OSDF Foundation; 3.6 Access Corridor; 3.7 Borrow Area Cut Slopes; 4.3 Performance Analysis; 5.1 Foundation Settlement; 6.1 Hydrostatic Uplift; 10.3 Temporary Lift Station and Manhole Design; and 10.4 Permanent LTS Lift Station Design.

The remainder of this summary provides information regarding the values of the parameters used in the design calculations. 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 PARAMETER CATEGORIES

OSDF, Geometry

This section addresses design parameters relating to the geometry of the OSDF and OSDF support facilities. Data such as dimensions, areas, and slopes are obtained from the Design Drawings.

In addition, information needed for the "Earthwork Required Volumes" calculation and the "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 6.5 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.

OSDF, General

This category includes parameters that are associated with the OSDF and OSDF support facilities but that are unrelated to the geometry of those facilities. These parameters include; the number of seasonal closings (Required Volume calc.), transformer loadings (Electrical Power Demand calc.), water demand (Potable Water Demand calc.) and other miscellaneous parameters. The majority of these parameters are used in only a single calculation package and thus are not discussed herein.

Topography, Existing

This section addresses existing site topography. As indicated in Table 1, topography is primarily related to stormwater management calculations for the OSDF and to several Borrow Area calculations. The topography is also related to the Hydrostatic Uplift, Temporary Lift Station and Manhole, and Potable Water Demand calculations. 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 these plans.

Climate

Climate-related data such as temperature, evapotranspiration, and precipitation are addressed in this section.

Climate data for average monthly precipitation and solar radiation 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 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 sedimentation basins and erosion and sediment control calculations for the OSDF construction and the borrow area. The 25-year 24-hour storm event is used to size components of the leachate transmission system.

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;
- USDA-SCS, "Engineering Manual for Conservation Practice", Nov 1986.
- Temple et. al., "Stability Design of Glass-Lined Open Channels", 1987.

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 calculation packages: (i) calculated rates (leachate generation); (ii) required cell storage; (iii) migration through primary liner; (iv) cover system erosion resistance; (v) stormwater runon-runoff drainage control; (vi) OSDF sediment basins, stormwater runon/runoff; drainage control (after closure); (vii) drainage control structure erosion resistance; (viii) stormwater runoff routing; and (iv) borrow area sediment basin. Ground cover descriptions are determined for the OSDF area, the East Field 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).

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 light, moderate or heavy grass cover for long-term (i.e., post-development) conditions.

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 primarily from monitoring well data and Figure 2-20 of Parsons "Pre-Design Investigation and Site Selection Report for the On-Site Disposal Facility", Volume 1 of 3, July 1995. A design basis perched water table contour map was developed from this data for use in the Hydrostatic Uplift

calculation. This map was also used in the Temporary Lift Station and Manhole calculation and the Permanent Lift Station calculation.

- For the foundation stability, access corridor stability, and borrow area cut slope stability calculations, the perched ground-water table was conservatively assumed to be at the existing ground surface.

- 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 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.

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 and secondary Geosynthetic Clay Liner (GCL) - sodium montmorillonite clay core with textured 40 mil HDPE geomembrane backing; or internally reinforced sodium montmorillonite core with geotextile backing (both sides);
- GCL Cap - reinforced or unreinforced GCL conforming to the specifications stated above;
- geotextile filter and geotextile cushion - polyester or polypropylene needle-punched nonwoven geotextile; and
- geotextile separator.

Shear Strength

The shear strengths on interfaces between these geosynthetics and adjacent materials are used in several calculation packages, as are the internal shear strengths of the GCLs. Shear strength testing of interfaces and GCLs that are representative of anticipated conditions and materials are in progress but results are not yet available. Therefore, estimates of the shear strengths for the geosynthetics and the interfaces in the liner and cover system have been made for the calculations. The shear strengths estimates have been based on a number of sources including the following:

- 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;
- 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;
- Daniel, D.E., Shan, H.Y. and Anderson, J.D., "Effects of Partial Wetting on the Performance of the Bentonite Component of a Geosynthetic Clay Liner," *Proc. of Geosynthetics '93*, Vancouver, Feb 1993, pp. 1483-1496; and
- Nataraj, M.S., Magauti, R.S., and McManis, K.L., "Interface Frictional Characteristics of Geosynthetics," *Proc. of Geosynthetics '95*, Nashville, Feb 1995, pp. 1057-1069.

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

These values have been obtained from: Bonaparte, R., Othman, M.A., Rad, N.R., Swan, R.H., and Vander Linde, D.L., "Evaluation of Various Aspects of GCL Performance," *Report of 1995 Workshop on Geosynthetic Clay Liners*, USEPA National Risk Management Laboratory, 1996 (in press). A copy of this publication is ~~attached at the end of this design parameter summary~~. included in Section 1.3 of this Calculation Package.

Installation and Performance of Geomembrane

The following assumptions are made regarding installation and performance of the geomembrane for the leachate generation, leachate collection, and leak detection system calculations:

- saturated hydraulic conductivity of the geomembrane, 2xE-13 cm/s;
- pinhole density, zero;
- placement quality, good; and
- installation defect density for liner and cover system geomembranes, one sq. cm. per acre.

It is noted that the assumed installation defect density is appropriate with respect to the likely defect density. For example, Bonaparte and Giroud (1989) suggested that defect densities for geomembranes installed with strict CQA would be on the order 0.06 square centimeter per acre. Subsequently, Laine (1991) presented data indicating geomembrane defect densities even lower than those reported by Giroud and Bonaparte. The results of these studies have also been discussed by the United States EPA (EPA, 1992).

It is noted that the three references cited above are: (i) Giroud, J.P. and Bonaparte, R. (1989). "Leachate Through Liners Constructed with Geomembranes, Part I: Geomembrane Liners", *Geotextiles and Geomembranes*, Vol. 8, No. 1, pp. 26-67; (ii) Laine, D.L. (1991). "Analysis of Pinhole Seam Leaks Located in Geomembrane Liners Using the Electrical Leak Location Method", *Proceedings, Geosynthetics '91 Conference*, Vol. 1, Atlanta, pp. 239-254; and (iii) EPA, "*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, Office of Solid Waste, January 1992.

HDPE Pipe/Manholes

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 10 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.

In addition, the following data obtained from pipe manufacturer's literature is used for the pipe design calculations:

- modulus of elasticity - 2.7×10^6 psf;
- compressive yield strength - 2.16×10^5 psf;

- allowable ring deflection - 2.7 percent; and
- Manning's roughness coefficient - 0.013.

A number of identical design parameters for Class 100 HDPE manholes were used in the Temporary Lift Station and Manhole calculations and in the Permanent Lift Station calculations. The values are presented in the data verification portion of those calculation packages.

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;
- 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 addressed 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.

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 draft report entitled "Geotechnical Investigation Report On-Site Disposal Facility", Operable Unit 2, Revision 0, December, 1995. The assumed values are also consistent with a final version of this report.

It is noted that for the "Hydrostatic Uplift" 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 "Geotechnical Investigation Report On-Site

Disposal Facility", Operable Unit 2, Revision 0, December, 1995. The assumed values are also consistent with a final version of this report.

Other Parameters

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 to 85 percent of the impacted materials will be soil (see "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 95 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, "Geotechnical Investigation Report On-Site Disposal Facility", Operable Unit 2, Revision 0, December, 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 Uplift" 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). Available data on the fly ash sources at the site indicate that this assumed unit weight is reasonable.

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 Uplift" and leachate generation rates calculations, smaller thicknesses of impacted material are used in some cases. These smaller values are appropriate for the "Hydrostatic Uplift" 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 calculations 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 "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 cover system). The test data is presented in the Parson's report entitled "Geotechnical Investigation Report On-Site Disposal Facility", Operable Unit 2, Revision 0, December, 1995. The assumed value is also consistent with a final version of this report.

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 "Geotechnical Investigation Report On-Site Disposal Facility", Operable Unit 2, Revision 0, December, 1995. The assumed values also appear to be consistent with a final version of this report.

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 leak detection (LCLD) layers is taken as of 0.1 cm/s. This value is equal to the minimum hydraulic conductivity permitted by the project material specifications. A higher value of saturated hydraulic conductivity, 10 cm/s, is used for the LCLD corridor.

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: "Soil Investigation Data Report Summary Document," Revision 0, July 1995, and "Geotechnical Investigation Report, On-Site Disposal Facility," Revision 0, December 1995. It is noted that examination of the final version of the latter report did not reveal any significant data beyond

that presented in the December 1995 version. 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 calculations are used to verify the adequacy of the leachate collection, detection, and transmission system designs. The results of the calculation are used as design parameters in several other individual calculations.

Structural Fill and Backfill

This section addresses design parameters assumed for structural fill, back fill and pipe bedding. Structural fill is to be used in the construction of the LTS access corridor and for fill below the OSDF. Back fill and pipe bedding are to be used for the placement of LCS, LDS and LTS HDPE pipe located outside the OSDF footprint, the LTS forcemain, lift stations, manholes and culverts. Structural fill and backfill will be compacted brown till and pipe bedding will most likely be gravel; each will be compacted to the relative densities required by project specifications.

The following design parameter values were assumed for the calculations:

	Moist unit weight	long-term friction angle	modulus of soil reaction
Structural Fill	135 pcf	25°	432,000 psf
Backfill	120 to 135 pcf	none	none
Bedding gravel	145 pcf	35°	216,000 psf

A value 120 pcf was assumed for total unit weight of backfill for a ring compression analysis of the culvert crossing the South Access Road (Borrow Area Sediment Basin calculation). In this case the backfill was assumed at 85% relative density instead of at 95% relative density expected for the backfill. Although this assumption reduces the calculated overburden stress on the culvert this assumption is conservative given the higher load factor used for backfill at 85% relative density compared with that for backfill at 95% relative density.

Road Aggregate

This category addresses aggregate to be used for construction of the following structures: (i) construction and impacted material hauls roads (Construction Haul Road and Haul Road calculations); (ii) leachate transmission system access corridor (LTS Access Corridor calc.); and (iii) construction administration area pavement (Construction Admin. Area Surfacing calc.). Base and subbase aggregate layers are required for each of the roads and only base aggregate for the administrative area pavement.

The following design parameters were selected from the Ohio DOT, "Location and Design Manual, Volume 1, Roadway Design", 1992.

	Structural Coefficient	Modulus
Base Aggregate	0.14	30,000 psi
Subbase Aggregate	0.11	15,000 psi

Construction Vehicles

This section addresses construction vehicle loadings which are considered in 19 separate calculations including: (i) the selection of geosynthetics; (ii) stability analyses, (iii) structural design of HDPE pipes, CMP and RCP culverts and manhole covers. Vehicle loadings are expressed in terms of maximum wheel loads, maximum ground pressures and live loads. For pavement and unsurfaced road designs the number of design loadings over the lifetime of the

pavement or for a performance period used to account for repeated loadings. Although assumed vehicle loadings vary somewhat among the calculations, a typical example is as follows:

- concentrated construction loads (wheel loads) - 20,000 lbs, intended to represent an assumed wheel load for a 35-ton capacity dump truck; and

- impact factor for dynamic loads of 1.5.

These particular values are based on an ASCE publication entitled "Design and Construction of Sanitary and Storm Sewers", Manual and Report on Engineering Practice No. 37, reprinted 1979.

Concrete/Steel

This section addresses properties of concrete and steel used in calculations for the design of reinforced concrete in the following calculations: (i) LTS Temporary Lift Station and Manhole Design; (ii) Permanent LTS Lift Station Design; and (iii) Decontamination Facility Pavement.

The design parameter values were selected to be consistent with those commonly assumed in reinforced concrete design: For concrete, the following parameters were assumed:

- Unconfined compressive strength = 4,000 psi; and
- Unit weight = 150 pcf.

The yield strength for steel was assumed to be 60,000 psi. This corresponds to A572 steel, grade 60.

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 waste disposal regulations, the required sediment storage volume for use in the calculations is 5445 cubic feet per disturbed acre. This value is used for the "OSDF Sediment Basins" calculation. For the "Borrow Area Sediment Basins", which are not within the OSDF area, a value of 1800 cubic feet per disturbed acre is used in the calculations based on Soil Conservation Service regulations.

Table 1 : Design Parameter Usage Matrix

Category / Report Section	Calculation Title	OSDF Geometry	OSDF General Information	Topography, existing	Climate	Hydrology	Vegetation	Hydrogeology	Geosynthetics	HDPE pipe & manholes	Cover System	Topsoil	Vegetative Soil	Granular Filter	Biointrusion Barrier	Cover Drainage	Compacted Clay	Contouring Layer	Impacted Material	Liner System	Protective Soil	LCS Drainage	LDS Drainage	Compacted Clay	Subsurface Soils	Brown Till	Gray Till	GMA soils	Bedrock	Leachate Generation	Structural Fill & Backfill	Road Aggregate	Construction Vehicles	Concrete & Steel	E & S Control
2.	**OSDF Layout**																																		
2.1	Required Volume		X																X																
2.2	Capacity Verification	X									X	X	X	X	X	X	X	X		X	X	X	X	X											
2.3	Earthwork Required Volumes	X									X	X	X	X	X	X	X	X	X	X	X	X	X	X											
3.	**Geotechnical Static Slope Stability**																																		
3.1	OSDF Foundation	X	X					X			X								X	X		X	X	X	X	X	X		X						
3.2	Liner System	X	X		X				X											X	X	X	X	X											
3.3	Impacted Material Configurations	X	X						X		X			X	X	X	X		X																
3.4	Intercell Berm	X	X																			X	X	X	X	X			X						
3.5	Final Cover System	X	X						X		X																								
3.6	Access Corridor	X	X					X																	X	X					X		X		
3.7	Borrow Area Cut Slopes		X					X																	X	X			X				X		
4.	**Geotechnical - Seismic Slope Stability**																																		
4.1	Hazard Assessment																												X						
4.2	Site Response Analysis	X									X								X	X				X	X	X	X	X	X						
4.3	Performance Analysis	X	X						X		X			X	X	X	X		X	X		X	X	X	X	X	X	X							
5.	**Geotechnical - Settlement**																																		
5.1	Foundation Settlement	X						X			X								X	X				X	X	X	X	X	X						
5.2	Localized Impacted Material Settlement	X																	X																
5.3	Overall Impacted Material Settlement	X									X								X																
6.	**Liner System**																																		
6.1	Hydrostatic Uplift	X		X				X			X			X	X	X	X		X	X		X	X	X											
6.2	Liner Geosynthetics Selection	X							X										X	X		X	X										X		
6.3	Liner Frost Protection				X															X	X	X	X												
7.	**Leachate Management - Leachate Generation**																																		
7.1	Calculated Rates	X			X	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X											
7.2	Required Cell Storage	X			X	X	X													X		X													X
8.	**Leachate Management - Leachate Collection System**																																		
8.1	Maximum Head in LCS	X																		X		X	X							X					
8.2	Geotextile Filter Design																			X	X	X								X			X		
8.3	LCS Pipe Design	X								X									X	X		X								X	X		X		
9.	**Leachate Management - LeaK Detection System**																																		
9.1	Migration Through Primary Liner	X			X	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X											
9.2	Maximum Head in LDS	X							X											X			X							X					
9.3	Time of Travel in LDS	X								X										X			X												
9.4	LDS Pipe Design	X								X									X	X			X							X	X		X		
9.5	Action Leakage Rate	X							X											X			X												
10.	**Leachate Management - Leachate Transmission System**																																		
10.1	LTS Gravity Line Design									X																				X	X		X		
10.2	LTS Temporary Forcemain Design		X							X																					X		X		
10.3	Temporary Lift Station and Manhole Design		X	X	X			X		X																				X	X		X	X	
10.4	Permanent LTS Lift Station Design		X		X			X		X																				X	X		X	X	
10.5	LTS Pipe Hydrograph	X			X				X											X		X								X					
11.	**Final Cover System**																																		
11.1	Temporary Erosion Mat Design	X			X	X	X				X	X																							X
11.2	Vegetation Design	X									X	X																							
11.3	Cover System Erosion Resistance	X			X	X	X				X	X	X		X																				X
11.4	Cover Frost Penetration Depth				X				X		X	X	X	X	X	X	X																		
11.5	Granular Filter Layer Design										X		X	X	X																				
11.6	Biointrusion Barrier Design										X				X																				
11.7	Drainage Layer Design	X									X					X														X					
11.8	Cover Geosynthetics Selection								X		X					X																	X		
12.	**Surface-Water Management During OSDF Construction/Filling/Closure**																																		
12.1	Stormwater Runon/Runoff, Drainage Control	X	X	X	X	X	X																										X		
12.2	OSDF Sediment Basins			X	X	X	X																												X
13.	**Surface-Water Management after OSDF Closure**																																		
13.1	Stormwater Runon/Runoff, Drainage Control			X	X	X	X																								X		X		
13.2	Drainage Control Structure Erosion Resistance	X			X	X	X				X	X																		X					X
14.	**Support Facilities**																																		
14.1	Electrical Power Demand		X																																
14.2	Potable Water Demand		X	X																															
14.3	Sanitary Wastewater Discharge		X																																
14.4	Construction Water Demand	X	X																X	X				X							X				
14.5	Decontamination Facility Water Demand																																X		
14.6	Decontamination Facility Pavement																																X	X	
14.7	Construction Admin Area Surfacing																								X	X						X	X		
14.8	Construction Haul Road																		X						X	X						X	X		
14.9	Leachate Transmission System Access Corridor																								X	X						X	X		
15.	**Borrow Area**																																		
15.1	Borrow Area Required Volume										X		X				X		X	X				X	X	X					X				
15.2	Borrow Area Capacity Verification			X																					X	X									
15.3	Borrow Area Water Demand										X						X			X				X							X				
15.4	Stormwater Runoff Routing			X	X	X	X																												X
15.5	Borrow Area Sediment Basin			X	X	X	X																								X				X
16.	**Impacted Materials Management**																																		
16.2	Haul Road Design																		X						X	X						X	X		
16.3	Impacted Runoff from Haul Road			X	X	X																													
16.4	OSDF Methane Generation	X	X																																
16.5	OSDF Radon 222 Release	X	X																																

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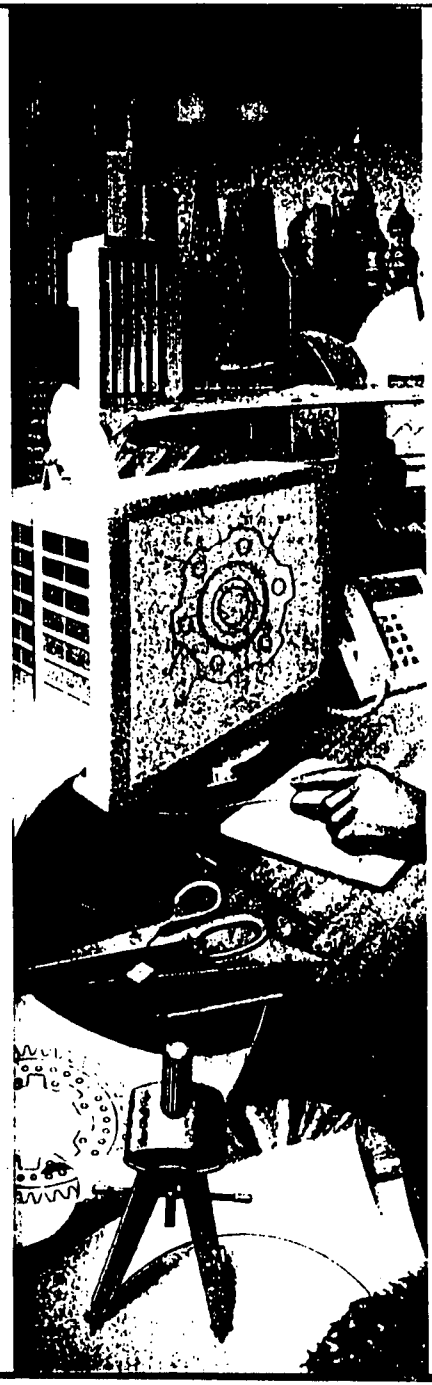
1.2 Computer Program Validation

APPENDIX A

COMPUTER SOFTWARE USED TO PREPARE CALCULATIONS PACKAGE

1. Autodesk®, Inc., AutoCAD® Release 13 User's Guide, September 1994.

2. SOFTDESK®, Inc., SOFTDESK® Civil/Survey: Earthworks Reference Manual, Henner, NH, November 1994.



Autodesk.

AutoCAD® Release 13

USER'S GUIDE

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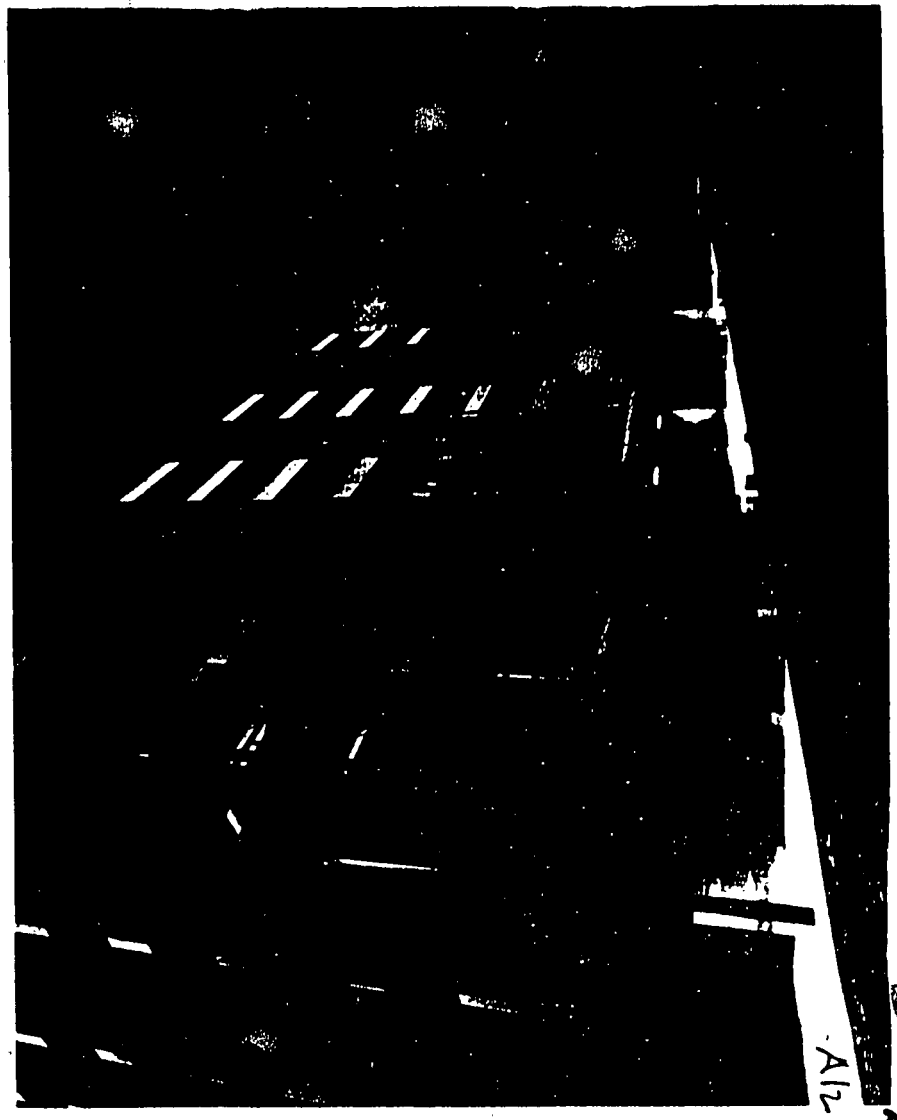

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Softdesk® Civil/Survey

Earthworks Reference Manual

Softdesk, Inc.
7 Liberty Hill Road
Henniker, NH 03242 USA

11/94-ERMN700A

Version 7.0

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APPENDIX A

COMPUTER SOFTWARE USED TO PREPARE CALCULATION PACKAGE HydroCAD™ STORMWATER MODELING SYSTEM

Applied Microcomputer Systems, *"HydroCAD™ Stormwater Modeling System"*, version 3.10, Chocorva, NH, 1993.

HydroCAD™

STORMWATER MODELING SYSTEM

Version 3

INTRODUCTION

Developed, sold, and supported by:

APPLIED MICROCOMPUTER SYSTEMS

"Technical Software Developer Since 1977"

Copyright © 1986-1991 by

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For Non-Engineers: AN INTRODUCTION TO STORMWATER MODELING

What is Stormwater and why does it need to be modeled?

During a rainstorm the precipitation that reaches the ground is dissipated by several mechanisms: Some of the water infiltrates directly into the ground, some is lost to evaporation, and the remainder appears as stormwater runoff. This runoff can cause a variety of undesirable effects such as erosion and flooding. In order to prevent such damage the runoff must be safely conveyed through suitable channels, pipes, streams, and rivers to a suitable point of disposal, and eventually to the sea. By determining the nature of the runoff and the way it will flow through these channels, it is possible to predict how, where, and when damage may occur. Steps can then be taken to reduce the chances of damage, such as enlarging a stream to prevent overflow of its banks, or detaining some of the runoff in a pond to reduce flooding downstream.

Why is there an increased need for stormwater modeling now?

Most new construction involves changes in the usage of the surrounding land. A new shopping center, for example, may remove a stand of trees and replace it with a paved parking lot and several buildings. Such a change in the ground cover has a dramatic effect on the runoff, greatly increasing its total volume and the rate of runoff. This directly increases the potential for erosion and flooding in all areas downstream of the new construction. To prevent such damage the runoff must be predicted and analyzed before construction, so that suitable steps can be taken during the design stage to handle the runoff in a safe and effective manner.

In the past such analysis and design was often not performed, and a significant amount of stormwater damage now occurs as a direct result. This ranges from minor flooding of local streams, to erosion of farmland, to flooding of major rivers. The resultant burden on many drainage systems and the increasing rate of construction means that all new construction and development should include a careful analysis of the effects on stormwater runoff. This not only reduces possible liability for stormwater damage, but is required by law in a growing number of states and towns.

How is stormwater modeled?

Stormwater modeling can be divided into two basic fields: Hydrology, which is the study of runoff and the factors which influence it, and Hydraulics, which is the study of water flow in the channels, pipes, streams, ponds, and rivers which convey it to the sea. In each field there are many techniques available for performing the required analysis, a situation which requires a qualified engineer to choose the best methods for each situation.

In the past a number of simplified techniques have been employed for predicting runoff and its effects. With the advent of low-cost computers it is now possible to use more sophisticated techniques in order to perform a more accurate and complete analysis in less time.

Are there different ways to model stormwater?

Absolutely. There are many different approaches to stormwater modeling and drainage design. Most approaches can be divided into two groups: 1) Steady-state (constant flow) methods, such as the Rational method as applied to storm sewer pipe networks, and 2) Hydrograph generation and routing procedures designed to simulate the time-varying nature of actual runoff. Although HydroCAD can be used for steady-state designs and does include the Rational Method, it is designed primarily as a *hydrograph generation and routing* program. For a detailed comparison of these methods please see Understanding Hydrology, available from Applied Microcomputer Systems.

HydroCAD: AN OVERVIEW

HydroCAD is a Computer Aided Design program for modeling the hydrology and hydraulics of stormwater runoff. It is based primarily on hydrology techniques developed by the Soil Conservation Service (SCS) combined with standard hydraulics calculations. For any given storm, these techniques are used to generate hydrographs throughout a watershed. Typically, this allows the engineer to verify that a given drainage system is adequate for the area under consideration, or to predict where flooding or erosion are likely to occur.

HydroCAD takes this capability one step further by maintaining a complete database for the watershed and drainage system. With this database, HydroCAD becomes a *working model* for the entire system where changes can easily be made and their effects viewed. With HydroCAD this takes just minutes, not hours, so the engineer can interact with the watershed model in a way not previously possible. This lets the engineer evaluate numerous possible designs and choose the one most suitable, not just from a safety and environmental standpoint, but based on cost and other considerations as well.

HydroCAD frees the engineer to concentrate on creative design, a goal which is often sacrificed when each alternative requires hours or days of tedious calculations. No program can substitute for human creativity, but HydroCAD frees that creativity by providing a working model which lets the engineer ask *"what if...?"*

Note: This manual is intended to provide an understanding of the unique *operational* capabilities of HydroCAD. For information on the specific *calculations* please see the Technical Reference Manual.

WHAT MAKES A GOOD HYDROLOGY PROGRAM?

Creating good software is no accident. Like all engineering, *software engineering* is primarily a matter of good *planning and design*, plus a little inspiration! With HydroCAD, this began with the following basic goals:

- Operation must be straightforward yet powerful
- Dependence on printed instructions must be virtually eliminated
- The program must be tolerant of all user errors
- Operation must be very fast - The user should never wait
- Only standard engineering terminology must be used
- Results must be presented in clear, easy to comprehend form
- The latest hydrology and hydraulics techniques must be employed
- The engineer should have a choice of techniques
- Results should be easy for the engineer to verify
- The program must be suitable for projects of any size

The following pages attempt to show how HydroCAD meets these requirements by explaining the overall modeling process. Keep in mind however, that HydroCAD is a highly interactive program and therefore only a hands-on demonstration will show its true potential.

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HydroCAD DESIGN PHASES

Although HydroCAD's sequence of operations is *very* flexible, its power is most easily understood by viewing it in four phases.

Phase I - Construction of Routing Diagram

A diagram is constructed which shows the functional components, or structures, which make up the watershed. The diagram shows the location of each structure and how water is routed from one structure to another.

Phase II - Description of each Structure

Each structure is described in detail so that HydroCAD can calculate the outflow from each structure once the inflow is known.

Phase III- Calculation of flow through each Structure

Starting at the upstream end of the diagram and working downstream, HydroCAD calculates the outflow and other results for each structure. Multiple inflows are summed automatically. A *minimal recalculation* feature automatically re-uses the results of previous calculations where no changes have occurred.

Phase IV - Display and Examination of Results

After the calculations have been completed, the user examines the results to see if the watershed is behaving as desired. If any changes are required, the user may return to Phase I, II, or III and repeat the cycle until the desired results are obtained.

Initial analysis and design will generally proceed through these phases in the order shown. However, with HydroCAD the phases may be performed in virtually any order desired. For example, the user could describe several structures (Phase II), create a partial diagram containing these structures (Phase I), and then calculate the outflows (Phase III). HydroCAD doesn't restrict the user's options for solving a problem. In fact, it provides greater flexibility than any other approach to stormwater modeling.

HOW DOES HydroCAD COMPARE TO OTHER PROGRAMS AND MANUAL METHODS?

HydroCAD allows the engineer to perform stormwater analysis and design in any desired sequence, rather than in a fixed order dictated by the program. By comparison, most manual methods and existing software confine the user to working in a strict sequence. Most hydrology programs, for example, leave the diagram (Phase I) entirely to the user, and require that Phases II, III, and IV be performed in that order for each structure. Furthermore, the structures must be analyzed in strict downstream order. And when any structure is recalculated, the user must also recalculate all structures which lie downstream of it. This limits the effectiveness of such programs on all but the simplest watersheds, and makes them extremely inefficient as design tools.

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Phase I - CONSTRUCTION OF THE ROUTING DIAGRAM

To model any watershed the drainage system is represented by a network consisting of four basic components:

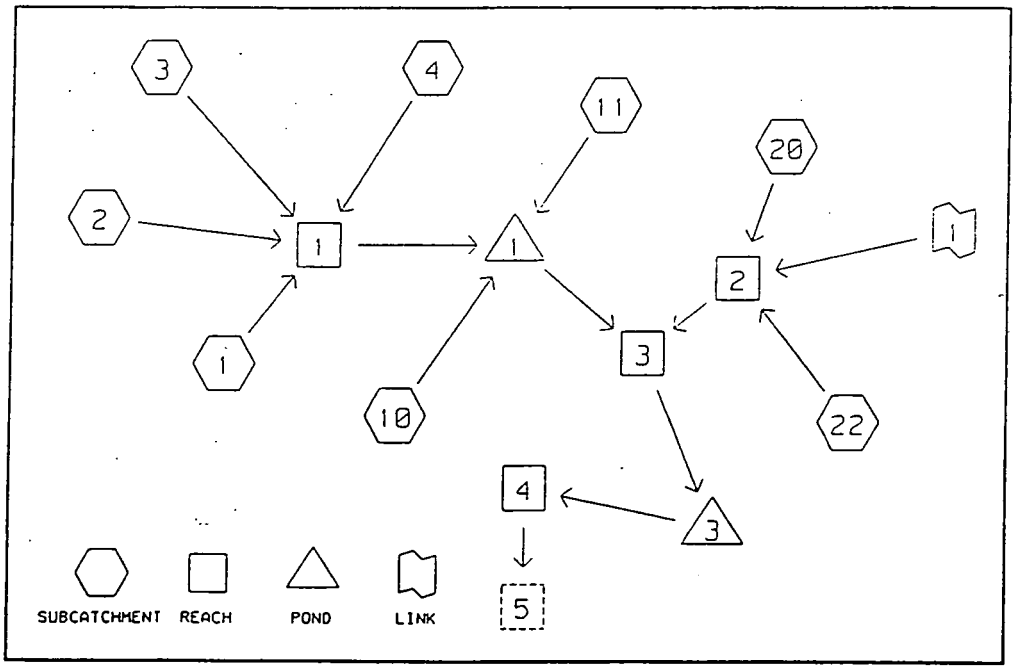
- **SUBCATCHMENT:** A relatively homogenous area of land that drains into a single reach or pond. Each subcatchment generates a *runoff hydrograph*.

- **REACH:** A uniform stream, channel, or pipe which conveys water from one point to another reach or pond. The outflow of each reach is determined by a *hydrograph routing* calculation.

- **POND:** A pond, swamp, dam, or other impoundment which fills with water from one or more sources and empties in a manner determined by a weir, culvert, or other device(s) at its outlet. A pond may empty into a reach or into another pond. The outflow of each pond is also determined by a *hydrograph routing* calculation.

- **LINK:** A multi-purpose mechanism for introducing a hydrograph from outside the diagram, either by manual entry, file import, or linkage to another diagram. A link also allows the diversion and/or scaling of hydrographs.

After identifying each of these components the system may be represented by a routing diagram such as this:



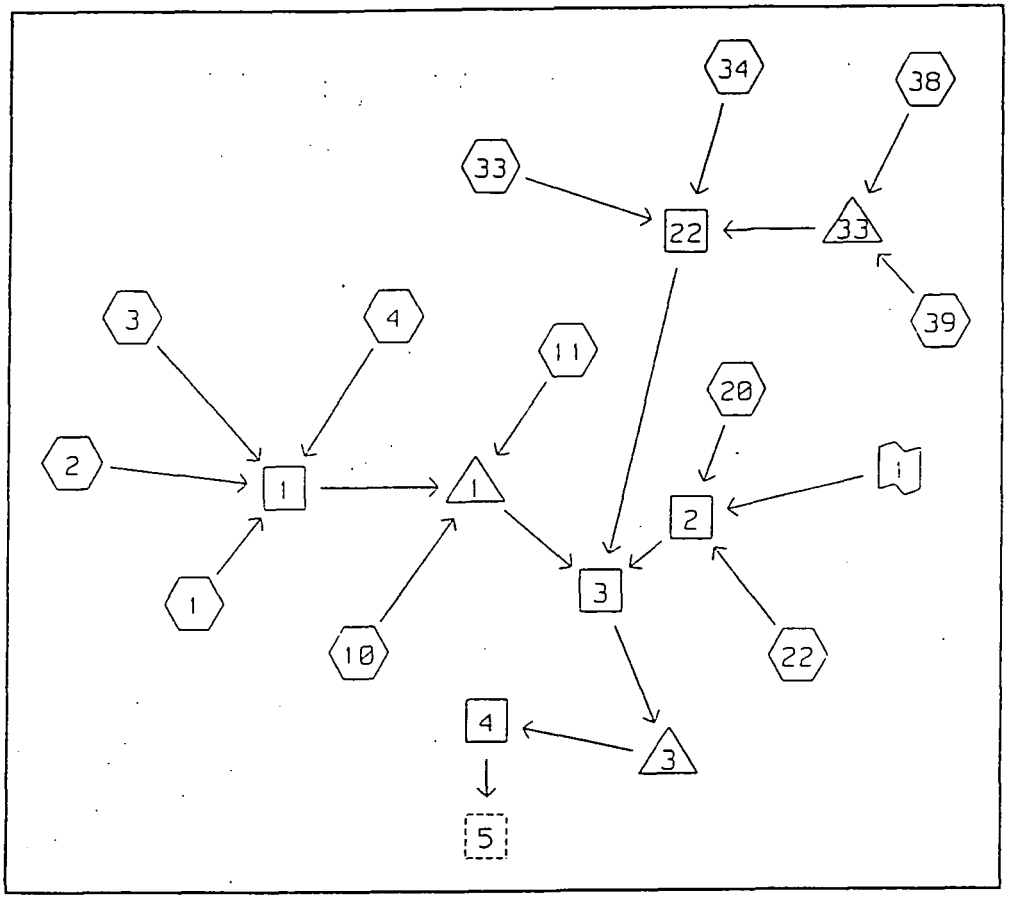
As indicated by the legend, subcatchments are represented by hexagons, reaches by squares, ponds by triangles, and links by broken squares. An arrow from each component, or *structure*, indicates where its outflow is routed.

In this example subcatchments 1, 2, 3, and 4 flow into reach 1 which flows into pond 1 along with subcatchments 10 and 11. Subcatchments 20, 22, and link 1 flow into reach 2 which flows into reach 3 along with the outflow from pond 1. Reach 3 then flows into pond 3 which flows into reach 4. Reach 4 then flows into reach 5, which has a dotted outline indicating a "phantom" structure outside the system currently being considered.

In addition to showing the routing between the structures, the routing diagram may also represent the physical location of each structure.

Constructing and modifying the routing diagram is a crucial step in building a watershed model with HydroCAD. As in most CAD programs, changes are shown immediately on the display as they are made. For example, to add a new structure to the diagram you would pick a location, specify what you want to create, and what it will flow into. In a similar manner any structure can be instantly moved, rerouted, renumbered, or deleted.

As the diagram grows beyond the edges of the screen, the user may PAN or ZOOM the display to view the region of interest. This expanded version of the previous diagram can be created in just one or two minutes:



Although the creation of the diagram is usually the first step in most projects, it can be revised at any time.

The routing diagram is the core of the watershed model. From it HydroCAD determines how to sequence all calculations. The diagram also indicates what structures are affected by a given change and therefore will need to be re-calculated. All such diagram-related bookkeeping is handled automatically by HydroCAD, thus freeing the user to concentrate on more complex design issues.

Phase II - DESCRIPTION OF EACH STRUCTURE

Before HydroCAD can determine the outflow of any structure, the user must provide the size, shape, or other descriptive information. To enter a new description, or to change an existing one, the user simply fills in the blanks in the appropriate *fill-in screen*. A completed screen for a subcatchment might look like this:

```
                SUBCATCHMENT 11 DESCRIPTION

NAME: Old Orchard

Use CHOICE keys to select Tc method(s):
 1  TR-55 Sheet Flow
 2  Shallow Concentrated Flow
 3  Parabolic Channel
 4  Circular Channel
 5
 6

RATIONAL METHOD C= .00 (optional)

TOTAL AREA=   25.00 ACRES  (optional)

  ACRES    CN   DESCRIPTION
--------   --   ------------------------------
   12.50   58   Orchard, Soil Group B, Good
    7.40   65   Orchard, Soil Group B, Fair
    5.10   60   Woods, Soil Group B, Fair
    0.00    0
    0.00    0
    0.00    0
    0.00    0
    0.00    0
```

Items are ordered on the screen for easy entry, but may be entered in any desired sequence. When all entries and corrections have been made, the user *accepts* the screen and the description is saved in the database for later use. At any time the description may be recalled, examined, and modified as needed.

Subcatchment Description

Subcatchments are described by specifying the following items (see sample screen above):

- Name or textual description (optional)
- The method(s) to be used to calculate the Time of Concentration (Tc)
- Rational method "C" value (if needed)
- The total area of the subcatchment (optional)
- A column heading of ACRES or PERCENT, depending on data to be entered
- The acreage or percentage covered by each curve number
- Up to eight SCS Curve Numbers, plus optional descriptions

Curve number data may be entered by ACRES or PERCENT simply by setting the column heading accordingly. If more than one curve number is entered, the composite curve number is automatically calculated.

HydroCAD provides several procedures for calculating the Time of Concentration including TR-55 sheet flow, shallow concentrated flow, channel flow, upland method, curve number method, and direct entry. The channel flow calculations allow direct entry of cross-sectional area and wetted perimeter, or this can be calculated automatically for circular, rectangular, vee, trapezoidal, and parabolic channels.

Each subcatchment may have up to six flow segments, the travel time for each being determined by any of these methods. The total travel time for all segments is the Tc for that subcatchment.

A separate screen is used to describe each segment in detail. This is a typical screen for the TR-55 sheet flow procedure. Note that HydroCAD contains the standard *Surface Descriptions*, and automatically supplies the corresponding Manning's number:

```
SUBCATCHMENT 11 Tc SEGMENT # 1 DESCRIPTION

        TR-55 Sheet Flow

COMMENT: Segment AB

1. Surface Description:     Cultivated: Residue<=20%
2. -or- Manning's No.       n=  .000  (for other surfaces)

3. Flow Length (<=300 ft)   L=    100 FT
4. Two-yr 24-hr Rainfall    P2=   3.6 IN
5. Land Slope               s=   .0100 FT/FT

Line numbers correspond to TR-55 Worksheet #3 rev. 6/86
```

The following screen is used to calculate the Tc contribution from a segment of channel flow. Other channel flow screens allow the direct entry of vee, rectangular, trapezoidal, parabolic, and circular geometries:

```
SUBCATCHMENT 11 Tc SEGMENT # 2 DESCRIPTION

        Channel Flow

COMMENT: Segment CD

12. X-Sec Flow Area     a=     27.0 SQ-FT
13. Wetted Perimeter    Pw=    28.2 FT
15. Channel Slope       s=     .0050 FT/FT
16. Manning's Number    n=     .05
18. Flow Length         L=     7300 FT

Line numbers correspond to TR-55 Worksheet #3 rev. 6/86
```

After entering all data for a subcatchment the runoff hydrograph *may* be generated immediately. However, this is not required, since HydroCAD will perform requisite calculations automatically when they are required as inflow for downstream calculations.

Reach Description

A completed reach screen looks like this:

```
                    REACH 3 DESCRIPTION

              NAME: EXISTING STREAM BED

PIPE DIAMETER=   0.0 INCHES (0=Auto-Size)     NO. OF PIPES: 0

CHANNEL BOTTOM WIDTH=   5.4 FT       DEPTH=   1.5 FT

SIDE SLOPE: LEFT=  .40   RIGHT=  .40   (rise/run; enter 0 if vertical)

MANNING'S NUMBER=  .040              SLOPE=  .0350 FT/FT

¦ LENGTH= 5500 FT                  1 x FINER ROUTING        ¦
¦ BASE FLOW=    0.0 CFS          EXFILTRATION=    0.0 CFS   ¦

  STREAM FLOOD ELEVATION/DEPTH=     0.0 FT  (0=last table entry)

  ELEV/DEPTH (FT)        END AREA (SQ-FT)    DISCHARGE (CFS)
        0.0                  0.0                  0.0
        0.0                  0.0                  0.0
        0.0                  0.0                  0.0
        0.0                  0.0                  0.0
        0.0                  0.0                  0.0
        0.0                  0.0                  0.0
        0.0                  0.0                  0.0
        0.0                  0.0                  0.0
        0.0                  0.0                  0.0
        0.0                  0.0                  0.0
        0.0                  0.0                  0.0
        0.0                  0.0                  0.0
        0.0                  0.0                  0.0
        0.0                  0.0                  0.0
        0.0                  0.0                  0.0
        0.0                  0.0                  0.0
```

Note that the following items are specified for a reach:

- Name
- If a pipe, the diameter (enter zero for automatic sizing)
- The number of pipes (allows several identical, parallel pipes)
- If an open channel, the width, depth, and side slopes
- Manning's Number and slope
- Length
- A finer routing interval (dt) may be selected, if desired
- Base flow and exfiltration (if any)

For reaches which can't be described with these parameters (such as an irregular stream bed) you may complete the elevation/end-area/discharge table directly. When using this table you may enter elevation *or* depth as you prefer. You also have the option of entering wetted perimeter instead of discharge by changing the heading on this column. Otherwise this table is left blank, and HydroCAD calculates the end-area and discharge vs. depth based on the specified geometry.

Pond Description

In order to perform hydrograph routing through a pond the storage and outflow characteristics must be known. Outflow vs. elevation is automatically calculated for the selected outlet device(s). Storage vs. elevation data may entered directly, or the user may enter the area at selected elevations and HydroCAD will calculate the storage. This information is entered with the following pond description screen:

POND 1 MAIN DESCRIPTION

NAME: NEW POND

OUTLET #	TYPE (Use CHOICE keys for options)
1	Orifice
2	Culvert
3	Broad-Crested Rectangular Weir
4	Sharp-Crested Rectangular Weir
5	V-Notch Weir
6	

SPECIAL OUTLET: Y 1 x FINER ROUTING
BASE FLOW= 0.0 CFS EXFILTRATION= 0.0 CFS
STARTING ELEVATION= 0.0 FT (0=bottom of pond)
FLOOD ELEVATION= 0.0 FT (0=last table entry)

ELEVATION (FT)	AREA (AF¦AC)
50.0	0.00
52.5	.75
53.0	1.50
55.0	2.75
0.0	0.00
0.0	0.00
0.0	0.00
0.0	0.00
0.0	0.00
0.0	0.00
0.0	0.00
0.0	0.00
0.0	0.00
0.0	0.00
0.0	0.00

HydroCAD pond design is very flexible, allowing for many variations and special cases:

- Up to six *standard* outlet devices may be used in any combination
- Outlet devices may be positioned at *any* desired elevation
- A *special* outlet device allows direct entry of stage-discharge data
- Base flow may be added for non-runoff inflows
- Exfiltration allows modeling of porous soils
- Adjustable pre-storm elevation handles "wet ponds"
- Both *retention* and *detention* ponds can be modeled
- Cumulative or incremental storage data can be entered directly in AF or CF -or-
- Storage can be calculated automatically from area using *conic* or *prismatic* sections

Each pond may have up to six *standard* outlet devices plus a *special* outlet device. These can be used alone or in *any* desired combination. After the desired outlet(s) are selected on the previous screen, each one is described using an individual screen. This is a typical screen for a culvert:

```
                    POND 1 OUTLET # 2 DESCRIPTION

                              Culvert

                    INVERT ELEVATION=    20.5 FT

                    DIAMETER=  18.0 INCHES

                    WIDTH=   0.0 FT    HEIGHT=   0.0 FT

MANNING'S NUMBER= .013     LENGTH=    22 FT       SLOPE=  .0250 FT/FT

                    ENTRANCE LOSS COEFFICIENT Ke= .500

                      CONTRACTION COEFFICIENT Cc= .900

                      TAIL WATER ELEVATION=     0.0 FT
```

The following screen is used for a broad-crested rectangular weir. It allows the coefficient to vary with head, as usually occurs in most real-world weirs. Sharp-crested and v-notch weirs are also available.

POND 1 OUTLET # 2 DESCRIPTION

Broad-Crested Rectangular Weir

INVERT ELEVATION= 54.0 FT

CREST LENGTH= 10.0 FT

HEAD (FT)	ENGLISH COEFFICIENT
.5	2.40
1.0	2.50
1.5	2.40
2.0	0.00
2.5	0.00
3.0	0.00
4.0	0.00
5.0	0.00

After describing each outlet HydroCAD calculates a composite discharge vs. elevation (stage-discharge) curve for the pond. This may be plotted or tabulated to aid in the selection and design of outlet control devices.

Phase III - CALCULATION OF FLOW THROUGH EACH STRUCTURE

Once a diagram has been created and each structure is described, HydroCAD can calculate the flows throughout the system. This process automatically begins at the head of the watershed and proceeds downstream so that the inflows are known when each structure is calculated.

The calculation process is entirely automatic and is controlled by data entered in the calculation control screen. Since the screen retains all settings from the last calculation, only the changes (if any) need be entered. A typical screen looks like this:

```
============ CALCULATION CONTROL ============
Verify settings and press ACCEPT to calculate


RUNOFF BY SCS TR-20   METHOD FROM  10 TO  20 HOURS

TYPE II 24-HOUR    RAINFALL =  4.3 INCHES,  U.H.=SCS
RATIONAL DURATION =   0 MINUTES,  INTENSITY = 0.00 IN/HR

REACH METHOD: STOR-IND           RE-SIZE ALL PIPES: N
POND METHOD:  STOR-IND

/ RECALC->  LINKS: N  WARNINGS: N  EVERYTHING: N  \
<                                                 > options
\  SHOW->  PROGRESS: N   INFLOWS: N   DETAILS: N  /

15 inflows & 15 calculations OK for 15 structures with 0 warnings
```

The screen allows the selection of several items:

- Runoff method and calculation period
- For SCS runoff: The storm type, rainfall, and Unit Hydrograph
- For Rational Method: The event duration and intensity
- Reach calculation method (Storage-Indication shown here)
- Option to automatically re-size pipes
- Pond calculation method (Storage-Indication shown here)
- Optional selection of structures to be calculated
- Selection of information to be shown during calculations

Note that HydroCAD not only allows the selection of storm type and rainfall, but also of calculation methods. As new methods are developed and added to HydroCAD, the engineer can choose the one best suited to the task at hand. This also permits direct comparison of different methods. These capabilities are unique to HydroCAD.

The calculation process begins when the screen is accepted. Unless otherwise specified, HydroCAD only calculates those structures whose inflow or description have changed. It also calculates just to the structure under consideration, thus keeping calculation time to an absolute minimum! This *minimal recalculation* feature is one of the key differences between HydroCAD and other programs.

If an unusual condition occurs during the calculations a warning message appears, such as "*Reach 12 overtopped by 1.2 feet.*" This does not stop the calculations, but merely indicates a condition the user should be aware of.

To calculate the outflow for each structure HydroCAD automatically performs these steps:

1) If there is more than one inflow the inflows are summed together to produce a single hydrograph. If a pipe is being re-sized, its diameter will be calculated to handle the peak inflow.

2) The inflow is routed through the structure using the description and method previously specified. For subcatchments the specified storm type and rainfall are used.

3) For a reach, the maximum depth, peak velocity, contact time, etc. are calculated.

4) For a pond, the peak elevation, peak storage, etc. are calculated.

5) Any warning messages are displayed.

6) For the inflow and outflow the peak flow and time of peak are calculated by interpolating between the three highest points.

7) The total volume of inflow and outflow are calculated.

8) All results are stored in the database for successive calculations or examination at any time.

This process is automatically repeated for each structure until the design point is reached, or until you interrupt the program. After examining the results you can make adjustments at any point in the system and repeat the process until the desired results are obtained.

UNDERSTANDING THE POWER OF HydroCAD

HydroCAD is great for the first run through a project, but it *really* shines when you want to make a change. What if you want to change the area of a subcatchment, the size of a pipe, the volume of a pond, the rainfall, or even the storm type? Just call the applicable screen, enter the change, and press CALCULATE. That's all! HydroCAD will automatically recalculate every affected structure right up to the design point. That's what HydroCAD Stormwater *Modeling* is all about!

Phase IV - DISPLAY AND EXAMINATION OF RESULTS

In order to easily evaluate data and results HydroCAD provides output in several ways:

- On the computer display for quick review during design work
- On a printer for reports or permanent records
- On a plotter for the highest quality graphics
- To a data file for use in other graphics or text programs

Regardless of how you view the results, you can also choose between numerous formats:

- A **Summary** includes the description and results for one structure
- A **Discharge Curve** shows the relationship between elevation and discharge for a reach or pond
- A **Hydrograph Plot** shows both the inflow and outflow vs. time
- The outflow may be **Tabulated** to determine exact flow at any time
- A **Table** shows several structures together for quick reference and comparison

In addition to producing these individual formats, HydroCAD provides a complete **report generator** which lets you design your own report including any combination of formats for one or more structures. This allows complete proposals and reports to be produced with an absolute minimum of manual preparation. Actual samples of various reports are included in the appendix at the end of this manual.

WANT TO KNOW MORE?

The only way to really appreciate HydroCAD is to try it yourself. The **HydroCAD Sampler** is lets you try HydroCAD in *your* office in about one hour! To assist your evaluation the following materials are also available:

- HydroCAD Data Sheet
- Output samples
- Hydrology News Letter
- Hydrology seminars
- Application Notes
- Hardware information
- Free Demo disk
- On-Site demonstrations
- Customer references

Appendix A: HydroCAD Engineering Specifications

- Subcatchments are described according to standard SCS (Soil Conservation Service) methods including area, curve number, and time-of-concentration.

- The composite curve number is calculated by weighting up to 8 individual CNs.

- The time of concentration for each subcatchment may be calculated by any combination of the following methods: TR-55 sheet flow, shallow concentrated flow, channel flow, upland method, or curve number method. Channel flow calculations also allow direct entry of circular, rectangular, vee, trapezoidal, and parabolic channel geometries.

- If you wish to use the Rational Method a "C" value may also be specified for each subcatchment.

- Subcatchment runoff is calculated by performing a *convolution of the unit hydrograph with the rainfall distribution curve.* This is the method employed by the SCS TR-20 program and HydroCAD runoff results agree within 1%.

- The user may choose between 24-hour type I, IA, II and III storms. Other rainfall distribution are easily added by the user.

- The standard SCS unit hydrograph and the Delmarva unit hydrograph are provided. Other curves may be easily added by the user.

- Rational method may also be used where appropriate to generate trapezoidal hydrographs.

- Reach calculations presently employ the Storage-Indication method. Other methods (such as Attenuation-Kinematic) will be added as the need arises, but are only needed for very long reaches. For most situations the Storage-Indication method produces comparable results in much less time.

- Each reach may have a constant base flow to represent continuous non-storm conditions, or an exfiltration to compensate for porous soils or perforated pipes.

- Reaches may be a pipe or a rectangular, vee, or trapezoidal channel. Left and right side-slopes may be different. Other channel shapes may be utilized by entering end-area and stage-discharge curves directly. Discharge can also be calculated from wetted perimeter data.

- Pipes can be automatically sized by Manning's equation based on the peak inflow. If the Manning's capacity is exceeded a warning message will appear.

- When a pipe fills with water the excess will be detained without head. If a full culvert analysis is required simply model the pipe as a pond with a culvert outlet.

- For channels which overtop HydroCAD will extrapolate from the end-area and discharge curves, and display a warning message.

- Pond calculations employ the industry standard Storage-Indication method.

- A starting elevation may be specified for each pond to represent the seasonal pre-storm water level.

- Ponds may have multiple outlet control devices including a V-Notch weir, Sharp-crested or Broad-crested weir, Orifice (horizontal or vertical), or a culvert. Culvert calculations handle all types of inlet *and* outlet control including tailwater.

- Each pond may have a special outlet device where the discharge vs. elevation curve is entered manually. This may be used alone or in combination with standard outlet(s).

- Ponds may have a base flow or exfiltration.

- Each project, or diagram, may contain from 10 to 1,000 structures, depending on the program purchased. Approximately 90% of all user projects are less than 40 structures.

- A link may be used to manually enter a hydrograph, import a hydrograph from an ASCII file, or to interconnect several diagrams when handling large projects.

- A link may also contain a flow threshold and/or scale factor, allowing it to be used to establish a flow diversion.

Appendix B: HydroCAD Computer Requirements

HydroCAD is available for IBM PC-compatibles and HP-9000 workstations in order to match your specific computing needs.

Hardware requirements for the PC version:

- IBM-compatible PC, XT, AT, 386 or 486 computer
- MS-DOS operating system
- 640K RAM
- 1MB hard disk space (recommended)
- -or- 720K or 1.2MB floppy disk drive
- Hercules, CGA, EGA, or VGA display
- Math co-processor (optional)
- All PC networks and multi-user systems are supported

Hardware requirements for the workstation version:

- HP-9000, Series 200 or 300 computer
- HP RMB operating system
- 1MB RAM
- 1MB hard disk space (recommended)
- -or- 720K floppy disk drive
- Math co-processor (optional)
- All HP networks are supported

Most HP and Epson-compatible printers are supported including:

- HP LaserJet I, II, and III
- HP PaintJet for *full color output*
- HP ThinkJet, QuietJet, & DeskJet
- 9-pin and 24-pin Epson printers
- IBM ProPrinter

HydroCAD also supports the following accessories:

- Mouse (recommended for cursor positioning)
- HP plotter (or compatible) for presentation graphics
- Graphics output to a file for use with WordPerfect® or other applications

NOTE: New features and hardware support are constantly being added. Please call for current specifications and information on your specific requirements.

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HydroCAD™

STORMWATER MODELING SYSTEM

Version 3

USER'S GUIDE

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NOTE: Ongoing software development often makes it difficult to keep printed documentation fully up-to-date. Please review any yellow update sheets at the end of this manual for information on recent changes. If you encounter any new features while running the program press HELP for further information. All new features will be included in the next update of the manual.

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Section 1 - INTRODUCTION TO HydroCAD™

What is HydroCAD?

HydroCAD is a Computer Aided Design program for modeling the hydrology and hydraulics of stormwater runoff. It utilizes the latest techniques from both fields to accurately predict the consequences of any given storm. Typically, this allows the engineer to verify that a given drainage system is adequate for the area under consideration, or to predict where flooding or erosion are likely to occur.

HydroCAD takes this capability one step further by maintaining a complete database for the watershed and drainage system. With this database, HydroCAD becomes a *working model* for the entire system where changes can easily be made and their effects viewed. With HydroCAD this takes just minutes, not hours, so the engineer can interact with the watershed model in a way not previously possible. This lets the engineer evaluate numerous possible designs and choose the one most suitable, not just from a safety and environmental standpoint, but based on cost and other considerations as well.

The advent of interactive design tools, like HydroCAD, frees the engineer to concentrate on creative design, a goal which is often sacrificed when analysis of each design requires hours or days of tedious calculations. No program can substitute for human creativity, but it can greatly aid that creativity by assisting with the critical analysis of each idea or design. This is the goal of HydroCAD.

Finding the Information You Need

This manual is a User's Guide. It contains the material needed by a qualified engineer to *operate* the program. For additional information please refer to the following publications:

- Introduction to HydroCAD provides a general discussion of the scope and purpose of HydroCAD.
- Technical Reference Manual provides a detailed description of the techniques and calculations employed.
- Applications Notes contain additional information on specific topics.
- HydroCAD Support Letter provides information on new features and commonly asked questions.

The on-line help system, as described later, also provides information on many topics.

Conventions Used In This Manual

Throughout this manual, small bold type indicates a specific key that must be pressed, such as **ENTER**. These include the actual keyboard keys such as **DELETE**, plus the function keys which are labeled on the bottom of the screen. For example:

> The **QUIT** key will terminate the current activity.
> The **ACCEPT** key will accept the data you have entered.

Underlined words designate an entry by the user. After each entry you must also press the **ENTER** or **RETURN** key. For example, <u>HYDROCAD</u> means that the user types the underlined text exactly as shown and then presses the **ENTER** key (or **RETURN** or **EXECUTE** on some keyboards).

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HydroCAD™

STORMWATER MODELING SYSTEM

Version 3

TECHNICAL REFERENCE MANUAL

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NOTE: Ongoing software development often makes it difficult to keep printed documentation fully up-to-date. Please **review any yellow update sheets at the end of this manual for information on recent changes.** If you encounter any new features while running the program you can usually get more information by pressing HELP. Any new features will be included in the next update of the manual.

Section 1 - INTRODUCTION

Understanding HydroCAD

HydroCAD is a collection of techniques for the generation and routing of hydrographs. It also provides many other related calculations such time of concentration, weighted curve numbers, pond volumes, stage-discharge curves, etc. This broad range of capabilities allows a large number of studies to be performed entirely within HydroCAD.

But HydroCAD provides features that go far beyond its computational capabilities. It provides an automatic graphical environment which provides enormous gains in productivity and clarity over traditional drainage software. Please see the HydroCAD Users Guide for details on these operational features.

HydroCAD is a *hydrograph routing model*. It is designed specifically to handle *time varying flows*, as required for pond design and other volume-sensitive calculations. As such, HydroCAD routes completely through one structure at a time. Only after determining the outflow hydrograph from a given structure does it consider the next structure downstream.

Certain calculations, such as channel backwater or pressurized pipe networks, are normally analyzed under *constant flow* conditions. These tasks are best addressed by steady-state numerical techniques, and not by a hydrograph routing system, such as HydroCAD. In fact, many problems will involve the use of HydroCAD to model the overall drainage system, plus a steady-state analysis of specific components. This is an unavoidable consequence of the different methodologies.

Using this Manual

This manual describes the exact calculations performed by HydroCAD. It is intended to provide the engineer with insight into these techniques so that their application and limitations can be better understood. This manual also provides the information necessary for independent verification of HydroCAD's results.

Where additional information is needed the reader is urged to consult the references listed at the end of this manual. In each section specific references are made to the appropriate sources. All references are of the form [3 p.12], meaning reference number 3, page 12.

This manual does *not* contain operating instructions for HydroCAD, or information on the routing diagram or other operational features. Please see the HydroCAD User's Guide for this information.

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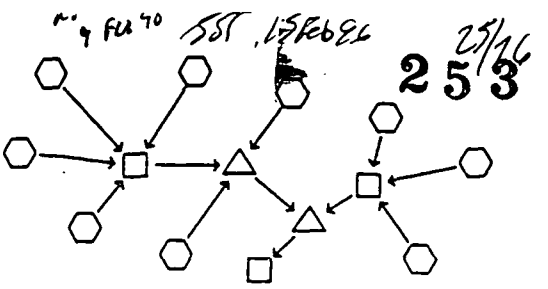
APPLICATION NOTE 4



A COMPARISON OF TR-20 and TR-55 RUNOFF METHODOLOGY

HydroCAD runoff determination is based upon the USDA Soil Conservation Service Technical Release Number 20, commonly known as SCS TR-20. TR-20 uses a numerical unit hydrograph procedure for predicting runoff. This is the most precise procedure developed by the SCS for this purpose.

Because of the complexity of TR-20 it isn't practical to perform these calculations by hand. To provide a non-computerized solution, SCS used TR-20 to develop a set of tabular hydrographs which could be manipulated by hand. This information constitutes the "Tabular Method" as published in TR-55. Since the TR-55 tables are derived *from* TR-20, the accuracy of TR-55 can at best match that of TR-20. In many situations the results will be very close, and the two methods can be used interchangeably. However, the assumptions and simplifications used to develop TR-55 can produce errors in certain cases. The TR-55 manual specifically advises:

"Use the TR-20 computer program instead of the tabular method if any of the following conditions applies:

- Tc is greater than 2 hours.
- Drainage areas of individual subareas differ by a factor of 5 or more.
- The entire composite flood hydrograph or runoff volume is required for detailed flood routings."

Other limitations stated in TR-55 include:

- The minimum Tc is .1 hours. Use of TR-55 when Tc<.1 will result in underestimation of runoff.
- Tc is rounded to the nearest tabulated value thus underestimating or overestimating runoff.
- All tables were developed with a curve number of 75. As the CN varies from 75 accuracy is reduced.

These differences are clearly summarized in the TR-55 manual:

> "This method (TR-55) approximates TR-20, a more detailed hydrograph procedure . . . Use TR-20 if the watershed is very complex or a higher degree of accuracy is required."

This applies particularly to the design of detention basins which are very sensitive to changes in the inflow hydrograph. Again quoting from TR-55:

> "The procedure (TR-55) should not be used to perform final design if an error in storage of 25 percent cannot be tolerated . . . More detailed hydrograph development and routing will often pay for itself through reduced construction costs."

For these reasons and others, users of TR-55 are gradually shifting over to products based on TR-20. While this change will insure more accurate studies, the engineer must still meet local and state requirements, some of which still specify TR-55. In response to this the following points can be made:

1) In many applications TR-20 will produce almost identical results to TR-55 and can be used interchangeably. In such cases TR-55 can be used to verify TR-20 studies, and vice versa.

2) When results do differ it is due to the inaccuracy of TR-55. In most instances, it will be found that one or more of the limitations listed above has been exceeded. In these cases ignoring the (correct) results obtained with TR-20 can lead to inadequate drainage designs and future problems.

Note: See Application Note 5 for a comparision of other aspects of TR-20 and TR-55.

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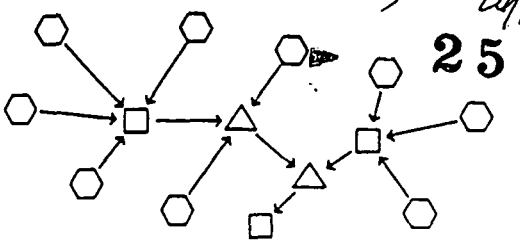
APPLICATION NOTE 5



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A COMPARISON OF HydroCAD, TR-20, AND TR-55

The following table summarizes the similarities and differences between these three programs. Note that HydroCAD combines selected features of TR-20 and TR-55 with other capabilities.

	HydroCAD	TR-20	TR-55
Runoff methodology (also see A.N. 4)	SCS unit hydrograph procedure	SCS unit hydrograph procedure	Tabular method derived from TR-20
Rainfall types	SCS type I, IA, II, & III, plus user-defined storms	SCS type I, IA, II & III	SCS type I, IA, II & III
Unit hydrograph	SCS or Delmarva U.H., plus user defined curves	SCS Unit Hydrograph or user defined curve	SCS Unit Hydrograph only
Curve number entry	Weights multiple curve numbers	Requires direct entry of composite curve number	Weights curve numbers
Curve number limitations	No restrictions	No restrictions	Reduced accuracy as CN differs from 75
Time of concentration calculations	Calculates Tc by all TR-55 methods plus common channel shapes, upland method, & CN method	Contains no Tc calculations: Requires direct entry of Tc	Calculates Tc for sheet, shallow concentrated, & channel flow
Tc limitations	No restrictions	No restrictions	Limited to .1 to 2 hrs
Tc precision	1/10 minute (1/600 hour)	1/100 hour	Rounded to nearest step
Subarea limitations	None	None	Must not differ by more than a factor of 5
Runoff accuracy	Within 1% of TR-20	"The standard"	Within 25% of TR-20
Reach routing	Storage-indication method with automatic calculation of stage-discharge	Modified Att-Kin procedure	Separate runoff tables for travel times of 0 to 3 hours
Pond routing	Storage-indication method	Storage-indication method	None, estimates effect
Stage-discharge curve hydraulics	Automatic calculation for many common outlets	Must be entered directly, no calculations provided	n/a
Stage-storage curve	Automatic calculation from areas, plus direct entry	Direct entry	n/a
Routing diagram	Interactive, on-screen	none	none
Calculation procedure	Automatically triggered by changes and sequenced by routing diagram	"Batch mode" calculation of entire watershed	Manual initiation of each calculation
Graphics capabilities	Full graphics to screen, printer, plotter, or file.	none	none
Report Generation	Automatic with graphics	Manual	Manual
Data storage	Automatic by project name	Manual	Manual

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Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.6

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APPENDIX A

COMPUTER SOFTWARE USED TO PREPARE CALCULATIONS PACKAGE

USDA-SCS TR-55

1. United States Department of Agriculture. "*Urban Hydrology for Small Watersheds.*" Soil Conservation Service. Engineering Division. Washington. DC. Technical Release 55. June 1986.

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Urban Hydrology for Small Watersheds

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Appendix C: Computer program

The TR-55 procedures have been incorporated in a computer program. The program, written in BASIC, requires less than 256K memory to operate and was developed for an MS-DOS operating system. Users of the program, however, still need to be familiar with the procedures in this TR. Features of the program include the following:

- The full screen (24 lines, 80 columns) is used to enter data. Flexibility of coding allows movement about the screen for quick data modifications.
- Function keys provide menu power to move to different modules (TR-55 chapters) within the program. Some keys are permanently defined while others vary by module.
- "Help" screens provide pertinent information to the user depending on location in the program. Two types of information are included: (1) define system operation and (2) describe input parameters.
- User files provide for optional entry of local data, such as rainfall-frequency, graphic peak discharge equation coefficients, and tabular hydrographs for other rainfall distributions.

Copies of the program can be obtained from—

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Telephone (703) 487-4650

Preface

Technical Release 55 (TR-55) presents simplified procedures to calculate storm runoff volume, peak rate of discharge, hydrographs, and storage volumes required for floodwater reservoirs. These procedures are applicable in small watersheds, especially urbanizing watersheds, in the United States. First issued by the Soil Conservation Service (SCS) in January 1975, TR-55 incorporates current SCS procedures. This revision includes results of recent research and other changes based on experience with use of the original edition.

The major revisions and additions are—

1. A flow chart for selecting the appropriate procedure;
2. Three additional rain distributions;
3. Expansion of the chapter on runoff curve numbers;
4. A procedure for calculating travel times of sheet flow;
5. Deletion of a chapter on peak discharges;
6. Modifications to the Graphical Peak Discharge method and Tabular Hydrograph method;
7. A new storage routing procedure;
8. Features of the TR-55 computer program; and
9. Worksheets.

This revision was prepared by Roger Cronshey, Hydraulic Engineer, Hydrology Unit, SCS, Washington, DC; Dr. Richard H. McCuen, Professor of Civil Engineering, University of Maryland, College Park, MD; Norman Miller, Head, Hydrology Unit, SCS, Washington, DC; Dr. Walter Rawls, Hydrologist, Agricultural Research Service, Beltsville, MD; Sam Robbins (deceased), formerly Hydraulic Engineer, SCS, South National Technical Center (NTC), Fort Worth, TX; and Don Woodward, Hydraulic Engineer, SCS, Northeast NTC, Chester, PA. Valuable contributions were made by John Chenoweth, Stan Hamilton, William Merkel, Robert Rallison (ret.), Harvey Richardson, Wendell Styner, other SCS hydraulic engineers, and Teresa Seeman.

Revised June 1986

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Metric conversions

The English system of units is used in this TR. To convert to the International System of units (metric), use the following factors:

From English unit	To metric unit	Multiply by
Acre	Hectare	0.405
Square mile	Square kilometer	2.59
Cubic feet per second	Cubic meters per second	0.0283
Inch	Millimeter	25.4
Feet per second	Meters per second	0.3048
Acre-foot	Cubic meter	1233.489
Cubic foot	Cubic meter	0.0283

Perform rounding operations as appropriate to indicate the same level of precision as that of the original measurement. For example:

1. A stream discharge is recorded in cubic feet per second with three significant digits.
2. Convert stream discharge to cubic meters per second by multiplying by 0.0283.
3. Round to enough significant digits so that, when converting back to cubic feet per second, you obtain the original value (step 1) with three significant digits.

Definitions of symbols

Symbol	Unit	Definition
a	ft^2	Cross sectional flow area
A_m	mi^2	Drainage area
CN		Runoff curve number
CN_c		Composite runoff curve number
CN_p		Pervious runoff curve number
E_{max}		Maximum stage
F_p		Pond and swamp adjustment factor
H_w	ft	Head over weir crest
I_a	in	Initial abstraction
L	ft	Flow length
L_w	ft	Weir crest length
m		Number of flow segments
n		Manning's roughness coefficient
P	in	Rainfall
P_{imp}		Percent imperviousness
P_2	in	Two-year frequency, 24-hour rainfall
p_w	ft	Wetted perimeter
q	cfs	Hydrograph coordinate
q_i	cfs	Peak inflow discharge
q_o	cfs	Peak outflow discharge
q_p	cfs	Peak discharge
q_t	csm/in	Tabular hydrograph unit discharge
q_u	csm/in	Unit peak discharge
Q	in	Runoff
r	ft	Hydraulic radius
R		Ratio of unconnected impervious area to total impervious area
s	ft/ft	Slope of hydraulic grade line
S	in	Potential maximum retention after runoff begins
t	hr	Hydrograph time
T_c	hr	Time of concentration
T_p	hr	Time to peak
T_t	hr	Travel time
V	ft/s	Average velocity
V_r	acre-ft, ft^3, or watershed-inch	Runoff volume
V_s	acre-ft, ft^3, or watershed-inch	Storage volume

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Chapter 1: Introduction

The conversion of rural land to urban land usually increases erosion and the discharge and volume of storm runoff in a watershed. It also causes other problems that affect soil and water. As part of programs established to alleviate these problems, engineers increasingly must assess the probable effects of urban development, as well as design and implement measures that will minimize its adverse effects.

Technical Release 55 (TR-55) presents simplified procedures for estimating runoff and peak discharges in small watersheds. In selecting the appropriate procedure, consider the scope and complexity of the problem, the available data, and the acceptable level of error. While this TR gives special emphasis to urban and urbanizing watersheds, the procedures apply to any small watershed in which certain limitations are met.

Effects of urban development

An urban or urbanizing watershed is one in which impervious surfaces cover or will soon cover a considerable area. Impervious surfaces include roads, sidewalks, parking lots, and buildings. Natural flow paths in the watershed may be replaced or supplemented by paved gutters, storm sewers, or other elements of artificial drainage.

Hydrologic studies to determine runoff and peak discharge should ideally be based on long-term stationary streamflow records for the area. Such records are seldom available for small drainage areas. Even where they are available, accurate statistical analysis of them is usually impossible because of the conversion of land to urban uses during the period of record. It therefore is necessary to estimate peak discharges with hydrologic models based on measurable watershed characteristics. Only through an understanding of these characteristics and experience in using these models can we make sound judgments on how to alter model parameters to reflect changing watershed conditions.

Urbanization changes a watershed's response to precipitation. The most common effects are reduced infiltration and decreased travel time, which significantly increase peak discharges and runoff. Runoff is determined primarily by the amount of precipitation and by infiltration characteristics related to soil type, soil moisture, antecedent rainfall, cover type, impervious surfaces, and surface retention. Travel time is determined primarily by slope, length of flow path, depth of flow, and roughness of flow surfaces. Peak discharges are based on the relationship of these parameters and on the total drainage area of the watershed, the location of the development, the effect of any flood control works or other natural or manmade storage, and the time distribution of rainfall during a given storm event.

The model described in TR-55 begins with a rainfall amount uniformly imposed on the watershed over a specified time distribution. Mass rainfall is converted to mass runoff by using a runoff curve number (CN). CN is based on soils, plant cover, amount of impervious areas, interception, and surface storage. Runoff is then transformed into a hydrograph by using unit hydrograph theory and routing procedures that depend on runoff travel time through segments of the watershed.

For a description of the hydrograph development method used by SCS, see chapter 16 of the SCS National Engineering Handbook, Section 4—Hydrology (NEH-4) (SCS 1985). The routing method (Modified Att-Kin) is explained in appendixes G and H of draft Technical Release 20 (TR-20) (SCS 1983).

Rainfall

TR-55 includes four regional rainfall time distributions. See appendix B for a discussion of how these distributions were developed.

All four distributions are for a 24-hour period. This period was chosen because of the general availability of daily rainfall data that were used to estimate 24-hour rainfall amounts. The 24-hour duration spans most of the applications of TR-55.

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The critical parameter in the model is time of concentration (T_c), which is the time it takes for runoff to travel to a point of interest from the hydraulically most distant point. Normally a rainfall duration equal to or greater than T_c is used. Therefore, the rainfall distributions were designed to contain the intensity of any duration of rainfall for the frequency of the event chosen. That is, if the 10-year frequency, 24-hour rainfall is used, the most intense hour will approximate the 10-year, 1-hour rainfall volume.

Runoff

To estimate runoff from storm rainfall, SCS uses the Runoff Curve Number (CN) method (see chapters 4 through 10 of NEH-4, SCS 1985). Determination of CN depends on the watershed's soil and cover conditions, which the model represents as hydrologic soil group, cover type, treatment, and hydrologic condition. Chapter 2 of this TR discusses the effect of urban development on CN and explains how to use CN to estimate runoff.

Time parameters

Chapter 3 describes a method for estimating the parameters used to distribute the runoff into a hydrograph. The method is based on velocities of flow through segments of the watershed. Two major parameters are time of concentration (T_c) and travel time of flow through the segments (T_t). These and the other parameters used are the same as those used in accepted hydraulic analyses of open channels.

Many methods are empirically derived from actual runoff hydrographs and watershed characteristics. The method in chapter 3 was chosen because it is basic; however, other methods may be used.

Peak discharge and hydrographs

Chapter 4 describes a method for approximating peak rates of discharge, and chapter 5 describes a method for obtaining or routing hydrographs. Both methods were derived from hydrographs prepared by procedures outlined in chapter 16 of NEH-4 (SCS 1985). The computations were made with a computerized SCS hydrologic model, TR-20 (SCS 1983).

The methods in chapters 4 and 5 should be used in accordance with specific guidelines. If basic data are improperly prepared or adjustments not properly used, errors will result.

Storage effects

Chapter 6 outlines procedures to account for the effect of detention-type storage. It provides a shortcut method to estimate temporary flood storage based on hydrologic data developed from the *Graphical Peak Discharge* or *Tabular Hydrograph* methods.

By increasing runoff and decreasing travel times, urbanization can be expected to increase downstream peak discharges. Chapter 6 discusses how flood detention can modify the hydrograph so that, ideally, downstream peak discharge is reduced approximately to the predevelopment condition. The shortcuts in chapter 6 are useful in sizing a basin even though the final design may require a more detailed analysis.

Selecting the appropriate procedures

Figure 1-1 is a flow chart that shows how to select the appropriate procedures to use in TR-55. In the figure, the diamond-shaped box labeled "Subareas required?" directs the user to the appropriate method based on whether the watershed needs to be divided into subareas. Watershed subdivision is required when significantly different conditions affecting runoff or timing are present in the watershed—for example, if the watershed has widely differing curve numbers or nonhomogeneous slope patterns.

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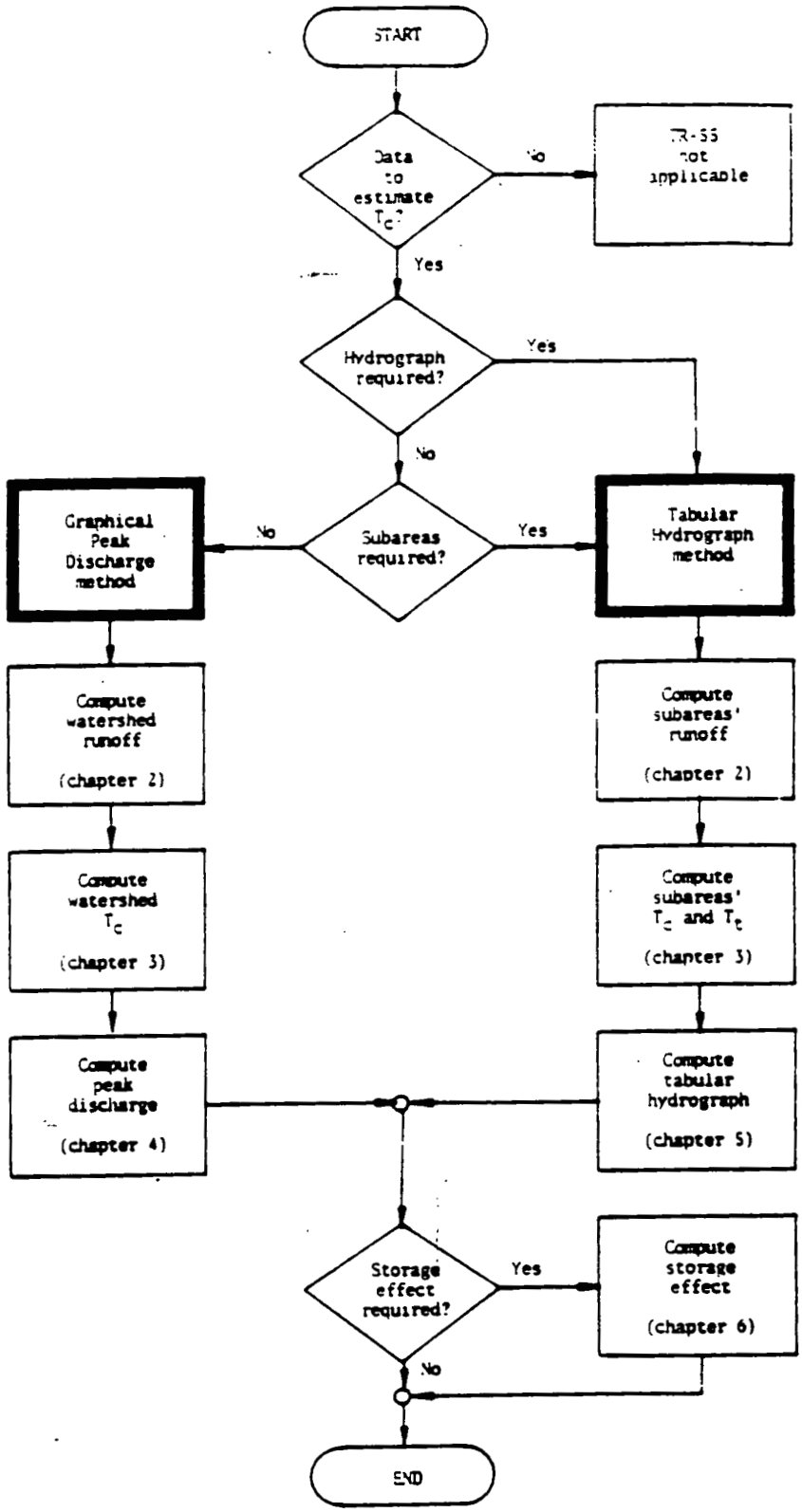

Figure 1-1.—Flow chart for selecting the appropriate procedures in TR-55.

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APPENDIX A

COMPUTER SOFTWARE USED TO PREPARE CALCULATIONS PACKAGE

USEPA HELP MODEL

1. Schroeder, P.R., Lloyd, C.M., and Zappi, P.A., "*The Hydrologic Evaluation of Landfill Performance (HELP) Model, User's Guide for Version 3*," U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C., Report No. EPA/600/R-94/168a, Sep 1994.

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User's Guide for Version 3

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THE HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE (HELP) MODEL

USER'S GUIDE FOR VERSION 3

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SECTION 1

INTRODUCTION

The Hydrologic Evaluation of Landfill Performance (HELP) computer program is a quasi-two-dimensional hydrologic model of water movement across, into, through and out of landfills. The model accepts weather, soil and design data, and uses solution techniques that account for the effects of surface storage, snowmelt, runoff, infiltration, evapotranspiration, vegetative growth, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geomembrane or composite liners. Landfill systems including various combinations of vegetation, cover soils, waste cells, lateral drain layers, low permeability barrier soils, and synthetic geomembrane liners may be modeled. The program was developed to conduct water balance analysis of landfills, cover systems and solid waste disposal and containment facilities. As such, the model facilitates rapid estimation of the amounts of runoff, evapotranspiration, drainage, leachate collection and liner leakage that may be expected to result from the operation of a wide variety of landfill designs. The primary purpose of the model is to assist in the comparison of design alternatives as judged by their water balances. The model, applicable to open, partially closed, and fully closed sites, is a tool for both designers and permit writers.

1.1 BACKGROUND

The HELP program, Versions 1, 2 and 3, was developed by the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, for the U.S. Environmental Protection Agency (EPA), Risk Reduction Engineering Laboratory, Cincinnati, OH, in response to needs in the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA, better known as Superfund) as identified by the EPA Office of Solid Waste, Washington, DC.

HELP Version 1 (Schroeder et al., 1984) represented a major advance beyond the Hydrologic Simulation on Solid Waste Disposal Sites (HSSWDS) program (Perrier and Gibson, 1980; Schroeder and Gibson, 1982), which was also developed at WES. The HSSWDS model simulated only the cover system, did not model lateral flow through drainage layers, and handled vertical drainage only in a rudimentary manner. The infiltration, percolation and evapotranspiration routines were almost identical to those used in the Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model, which was developed by Knisel (1980) for the U.S. Department of Agriculture (USDA). The runoff and infiltration routines relied heavily on the Hydrology Section of the National Engineering Handbook (USDA, Soil Conservation Service, 1985). Version 1 of the HELP model incorporated a lateral subsurface drainage model and improved unsaturated drainage and liner leakage models into the HSSWDS

model. In addition, the HELP model provided simulation of the entire landfill including leachate collection and liner systems.

Version 2 (Schroeder et al., 1988) represented a great enhancement of the capabilities of the HELP model. The WGEN synthetic weather generator developed by the USDA Agricultural Research Service (ARS) (Richardson and Wright, 1984) was added to the model to yield daily values of precipitation, temperature and solar radiation. This replaced the use of normal mean monthly temperature and solar radiation values and improved the modeling of snow and evapotranspiration. Also, a vegetative growth model from the Simulator for Water Resources in Rural Basins (SWRRB) model developed by the ARS (Arnold et al., 1989) was merged into the HELP model to calculate daily leaf area indices. Modeling of unsaturated hydraulic conductivity and flow and lateral drainage computations were improved. Accuracy was increased with the use of double precision. Default soil data were improved, and the model permitted use of more layers and initialization of soil moisture content. Input and editing were simplified. Output was clarified, and standard deviations were reported.

In Version 3, the HELP model has been greatly enhanced beyond Version 2. The number of layers that can be modeled has been increased. The default soil/material texture list has been expanded to contain additional waste materials, geomembranes, geosynthetic drainage nets and compacted soils. The model also permits the use of a user-built library of soil textures. Computation of leachate recirculation between soil layers and groundwater drainage into the landfill have been added. Moreover, HELP Version 3 accounts for leakage through geomembranes due to manufacturing defects (pinholes) and installation defects (punctures, tears and seaming flaws) and by vapor diffusion through the liner. The estimation of runoff from the surface of the landfill has been improved to account for large landfill surface slopes and slope lengths. The snowmelt model has been replaced with an energy-based model; the Priestly-Taylor potential evapotranspiration model has been replaced with a Penman method, incorporating wind and humidity effects as well as long wave radiation losses (heat loss at night). A frozen soil model has been added to improve infiltration and runoff predictions in cold regions. The unsaturated vertical drainage model has also been improved to aid in storage computations. Input and editing have been further simplified with interactive, full-screen, menu-driven input techniques.

In addition, the HELP Version 3 model provides a variety of methods for specifying precipitation, temperature and solar radiation data. Now, data from the most commonly available government and commercial sources can be imported easily. Moreover, data used in HELP Version 2 can still be used with minimum user effort. Specifying weather data manually and editing previously entered weather data can be easily done by using built-in spreadsheet facilities.

The use of data files in Version 3 is much simpler and more convenient than HELP Version 2 because data are saved permanently in user defined file names at a user-specified location. Similarly, the user has more flexibility to define units for every type

of data needed to run the HELP model. Finally, Version 3 of the HELP model provides on-line help at every step of the data preparation process.

Although applicable to most landfill applications, the HELP model was developed specifically to perform hazardous and municipal waste disposal landfill evaluations as required by RCRA. Hazardous waste disposal landfills generally should have a liner to prevent migration of waste from the landfill, a final cover to minimize the production of leachate following closure, careful controls of runon and runoff, and limits on the buildup of leachate head over the liner to no more than 1 ft. The HELP model is useful for predicting the amounts of runoff, drainage, and leachate expected for reasonable designs as well as the buildup of leachate above the liner. However, the model should not be expected to produce credible results from input unrepresentative of landfills.

1.2 OVERVIEW

The principal purpose of this User's Guide is to provide the basic information needed to use the computer program. Thus, while some attention must be given to definitions, descriptions of variables and interpretation of results, only a minimal amount of such information is provided. Detailed documentation providing in-depth coverage of the theory and assumptions on which the model is based and the internal logic of the program is also available (Schroeder et al., 1994). Potential HELP users are strongly encouraged to study the documentation and this User's Guide before attempting to use the program to evaluate a landfill design. Additional documentation concerning the sensitivity of program inputs, application of the model and verification of model predictions are under development.

1.3 SYSTEM AND OPERATING DOCUMENTATION

1.3.1 Computer Equipment

The model entitled "The Hydrologic Evaluation of Landfill Performance" (HELP) was written to run on IBM-compatible personal computers (PC) under the DOS environment.

1.3.2 Required Hardware

The following IBM-compatible CPU (8088, 80286, 80386 or 80486) hardware is required:

1. Monitor, preferably color EGA or better

2. Floppy disk drive (5.25-inch double-sided, double- or high-density; or 3.5-inch double-sided, double- or high-density)

3. Hard disk drive or a second floppy disk drive

4. 400k bytes or more of available RAM memory

5. 8087, 80287, 80387 or 80486 math co-processor

6. Printer, if a hard copy is desired

1.3.3 Software Requirements

The user must use Microsoft or compatible Disk Operating Systems (MS-DOS) Version 2.10 or a higher version. The user interface executable module was compiled and linked with Microsoft Basic Professional Development System 7.1. Other executable components were compiled with the Ryan-McFarland FORTRAN Version 2.42. The Microsoft Basic Professional Development System and Ryan-McFarland FORTRAN compiler are not needed to run the HELP Model.

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THE HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE (HELP) MODEL

ENGINEERING DOCUMENTATION FOR VERSION 3

by

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SECTION 1

PROGRAM IDENTIFICATION

PROGRAM TITLE: Hydrologic Evaluation of Landfill Performance (HELP) Model

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ORGANIZATION: U.S. Army Corps of Engineers, Waterways Experiment Station (WES)

DATE: September 1994

UPDATE: None Version No.: 3.00

SOURCE LANGUAGE: The simulation code is written in ANSI FORTRAN 77 using Ryan-McFarland Fortran Version 2.44 with assembly language and Spindrift Library extensions for Ryan-McFarland Fortran to perform system calls, and screen operations. The user interface is written in BASIC using Microsoft Basic Professional Development System Version 7.1. Several of the user interface support routines are written in ANSI FORTRAN 77 using Ryan-McFarland Fortran Version 2.44, including the synthetic weather generator and the ASCII data import utilities.

HARDWARE: The model was written to run on IBM-compatible personal computers under the DOS environment. The program requires an IBM-compatible 8088, 80286, 80386 or 80486-based CPU (preferably 80386 or 80486) with an 8087, 80287, 80387 or 80486 math co-processor. The computer system must have a monitor (preferably color EGA or better), a 3.5- or 5.25-inch floppy disk drive (preferably 3.5-inch double-sided, high-density), a hard disk drive with 6 MB of available storage, and 400k bytes or more of available low level RAM. A printer is needed if a hard copy is desired.

AVAILABILITY: The source code and executable code for IBM-compatible personal computers are available from the National Technical Information Service (NTIS). Limited distribution immediately following the initial distribution will be available from the USEPA Risk Reduction Engineering Laboratory, the USEPA Center for Environmental Research Information and the USAE Waterways Experiment Station.

ABSTRACT: The Hydrologic Evaluation of Landfill Performance (HELP) computer program is a quasi-two-dimensional hydrologic model of water movement across, into, through and out of landfills. The model accepts weather, soil and design data and uses solution techniques that account for surface storage, snowmelt, runoff, infiltration, vegetative growth, evapotranspiration, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geomembrane or composite liners. Landfill systems including combinations of vegetation, cover soils, waste cells, lateral drain layers, barrier soils, and synthetic geomembrane liners may be modeled. The program was developed to conduct water balance analyses of landfills, cover systems, and solid waste disposal facilities. As such, the model facilitates rapid estimation of the amounts of runoff, evapotranspiration, drainage, leachate collection, and liner leakage that may be expected to result from the operation of a wide variety of landfill designs. The primary purpose of the model is to assist in the comparison of design alternatives as judged by their water balances. The model, applicable to open, partially closed, and fully closed sites, is a tool for both designers and permit writers.

The HELP model uses many process descriptions that were previously developed, reported in the literature, and used in other hydrologic models. The optional synthetic weather generator is the WGEN model of the U.S. Department of Agriculture (USDA) Agricultural Research Service (ARS) (Richardson and Wright, 1984). Runoff modeling is based on the USDA Soil Conservation Service (SCS) curve number method presented in Section 4 of the National Engineering Handbook (USDA, SCS, 1985). Potential evapotranspiration is modeled by a modified Penman method (Penman, 1963). Evaporation from soil is modeled in the manner developed by Ritchie (1972) and used in various ARS models including the Simulator for Water Resources in Rural Basins (SWRRB) (Arnold et al., 1989) and the Chemicals, Runoff, and Erosion from Agricultural Management System (CREAMS) (Knisel, 1980). Plant transpiration is computed by the Ritchie's (1972) method used in SWRRB and CREAMS. The vegetative growth model was extracted from the SWRRB model. Evaporation of interception, snow and surface water is based on an energy balance. Interception is modeled by the method proposed by Horton (1919). Snowmelt modeling is based on the SNOW-17 routine of the National Weather Service River Forecast System (NWSRFS) Snow Accumulation and Ablation Model (Anderson, 1973). The frozen soil submodel is based on a routine used in the CREAMS model (Knisel et al., 1985). Vertical drainage is modeled by Darcy's (1856) law using the Campbell (1974) equation for unsaturated hydraulic conductivity based on the Brooks-Corey (1964) relationship. Saturated lateral drainage is modeled by an analytical approximation to the steady-state solution of the Boussinesq equation employing the Dupuit-Forchheimer (Forchheimer, 1930) assumptions. Leakage through geomembranes is modeled by a series of equations based on the compilations by Giroud et al. (1989, 1992). The processes are linked together in a sequential order starting at the surface with a surface water balance; then evapotranspiration from the soil profile; and finally drainage and water routing, starting at the surface with infiltration and then proceeding downward through the landfill profile to the bottom. The solution procedure is applied repetitively for each day as it simulates the water routing throughout the simulation period.

SECTION 2

NARRATIVE DESCRIPTION

The HELP program, Versions 1, 2 and 3, was developed by the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, for the U.S. Environmental Protection Agency (EPA), Risk Reduction Engineering Laboratory, Cincinnati, OH, in response to needs in the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA, better known as Superfund) as identified by the EPA Office of Solid Waste, Washington, DC. The primary purpose of the model is to assist in the comparison of landfill design alternatives as judged by their water balances.

The Hydrologic Evaluation of Landfill Performance (HELP) model was developed to help hazardous waste landfill designers and regulators evaluate the hydrologic performance of proposed landfill designs. The model accepts weather, soil and design data and uses solution techniques that account for the effects of surface storage, snowmelt, runoff, infiltration, evapotranspiration, vegetative growth, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geomembrane or composite liners. Landfill systems including various combinations of vegetation, cover soils, waste cells, lateral drain layers, low permeability barrier soils, and synthetic geomembrane liners may be modeled. Results are expressed as daily, monthly, annual and long-term average water budgets.

The HELP model is a quasi-two-dimensional, deterministic, water-routing model for determining water balances. The model was adapted from the HSSWDS (Hydrologic Simulation Model for Estimating Percolation at Solid Waste Disposal Sites) model of the U.S. Environmental Protection Agency (Perrier and Gibson, 1980; Schroeder and Gibson, 1982), and various models of the U.S. Agricultural Research Service (ARS), including the CREAMS (Chemical Runoff and Erosion from Agricultural Management Systems) model (Knisel, 1980), the SWRRB (Simulator for Water Resources in Rural Basins) model (Arnold et al., 1989), the SNOW-17 routine of the National Weather Service River Forecast System (NWSRFS) Snow Accumulation and Ablation Model (Anderson, 1973), and the WGEN synthetic weather generator (Richardson and Wright, 1984).

HELP Version 1 (Schroeder et al., 1984a and 1984b) represented a major advance beyond the HSSWDS program (Perrier and Gibson, 1980; Schroeder and Gibson, 1982), which was also developed at WES. The HSSWDS model simulated only the cover system, did not model lateral flow through drainage layers, and handled vertical drainage only in a rudimentary manner. The infiltration, percolation and evapotranspiration routines were almost identical to those used in the Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model, which was developed by Knisel (1980) for the U.S. Department of Agriculture (USDA). The runoff and infiltration

routines relied heavily on the Hydrology Section of the National Engineering Handbook (USDA, Soil Conservation Service, 1985). Version 1 of the HELP model incorporated a lateral subsurface drainage model and improved unsaturated drainage and liner leakage models into the HSSWDS model. In addition, the HELP model provided simulation of the entire landfill including leachate collection and liner systems.

Version 1 of the HELP program was tested extensively using both field and laboratory data. HELP Version 1 simulation results were compared to field data for 20 landfill cells from seven sites (Schroeder and Peyton, 1987a). The lateral drainage component of HELP Version 1 was tested against experimental results from two large--scale physical models of landfill liner/drain systems (Schroeder and Peyton, 1987b). The results of these tests provided motivation for some of the improvements incorporated into HELP Version 2.

Version 2 (Schroeder et al., 1988a and 1988b) presented a great enhancement of the capabilities of the HELP model. The WGEN synthetic weather generator developed by the USDA Agricultural Research Service (ARS) (Richardson and Wright, 1984) was added to the model to yield daily values of precipitation, temperature and solar radiation. This replaced the use of normal mean monthly temperature and solar radiation values and improved the modeling of snow and evapotranspiration. Also, a vegetative growth model from the Simulator for Water Resources in Rural Basins (SWRRB) model developed by the ARS (Arnold et al., 1989) was merged into the HELP model to calculate daily leaf area indices. Modeling of unsaturated hydraulic conductivity and flow and lateral drainage computations were improved. Default soil data were improved, and the model permitted use of more layers and initialization of soil moisture content.

In Version 3, the HELP model has been greatly enhanced beyond Version 2. The number of layers that can be modeled has been increased. The default soil/material texture list has been expanded to contain additional waste materials, geomembranes, geosynthetic drainage nets and compacted soils. The model also permits the use of a user-built library of soil textures. Computations of leachate recirculation and groundwater drainage into the landfill have been added. Moreover, HELP Version 3 accounts for leakage through geomembranes due to manufacturing defects (pinholes) and installation defects (punctures, tears and seaming flaws) and by vapor diffusion through the liner based on the equations compiled by Giroud et al. (1989, 1992). The estimation of runoff from the surface of the landfill has been improved to account for large landfill surface slopes and slope lengths. The snowmelt model has been replaced with an energy-based model; the Priestly-Taylor potential evapotranspiration model has been replaced with a Penman method, incorporating wind and humidity effects as well as long wave radiation losses (heat loss at night). A frozen soil model has been added to improve infiltration and runoff predictions in cold regions. The unsaturated vertical drainage model has also been improved to aid in storage computations. Input and editing have been further simplified with interactive, full-screen, menu-driven input techniques.

The HELP model requires daily climatologic data, soil characteristics, and design

specifications to perform the analysis. Daily rainfall data may be input by the user, generated stochastically, or taken from the model's historical data base. The model contains parameters for generating synthetic precipitation for 139 U.S. cities. The historical data base contains five years of daily precipitation data for 102 U.S. cities. Daily temperature and solar radiation data are generated stochastically or may be input by the user. Necessary soil data include porosity, field capacity, wilting point, saturated hydraulic conductivity, and Soil Conservation Service (SCS) runoff curve number for antecedent moisture condition II. The model contains default soil characteristics for 42 material types for use when measurements or site-specific estimates are not available. Design specifications include such things as the slope and maximum drainage distance for lateral drainage layers, layer thicknesses, leachate recirculation procedure, surface cover characteristics and information on any geomembranes.

Figure 1 is a definition sketch for a somewhat typical closed hazardous waste landfill profile. The top portion of the profile (layers 1 through 4) is the cap or cover. The bottom portion of the landfill is a double liner system (layers 6 through 11), in this case composed of a geomembrane liner and a composite liner. Immediately above the bottom composite liner is a leakage detection drainage layer to collect leakage from the primary liner, in this case, a geomembrane. Above the primary liner are a geosynthetic drainage net and a sand layer that serve as drainage layers for leachate collection. The drain layers composed of sand are typically at least 1-ft thick and have suitably spaced perforated or open joint drain pipe embedded below the surface of the liner. The leachate collection drainage layer serves to collect any leachate that may percolate through the waste layers. In this case where the liner is solely a geomembrane, a drainage net may be used to rapidly drain leachate from the liner, avoiding a significant buildup of head and limiting leakage. The liners are sloped to prevent ponding by encouraging leachate to flow toward the drains. The net effects are that very little leachate should leak through the primary liner and virtually no migration of leachate through the bottom composite liner to the natural formations below. Taken as a whole, the drainage layers, geomembrane liners, and barrier soil liners may be referred to as the leachate collection and removal system (drain/liner system) and more specifically a double liner system.

Figure 1 shows eleven layers--four in the cover or cap, one as the waste layers, three in the primary leachate collection and removal system (drain/liner system) and three in the secondary leachate collection and removal system (leakage detection). These eleven layers comprise three subprofiles or modeling units. A subprofile consists of all layers between (and including) the landfill surface and the bottom of the top liner system, between the bottom of one liner system and the bottom of the next lower liner system, or between the bottom of the lowest liner system and the bottom of the lowest soil layer modeled. In the sketch, the top subprofile contains the cover layers, the middle subprofile contains the waste, drain and liner system for leachate collection, and the bottom subprofile contains the drain and liner system for leakage detection. Six subprofiles in a single landfill profile may be simulated by the model.

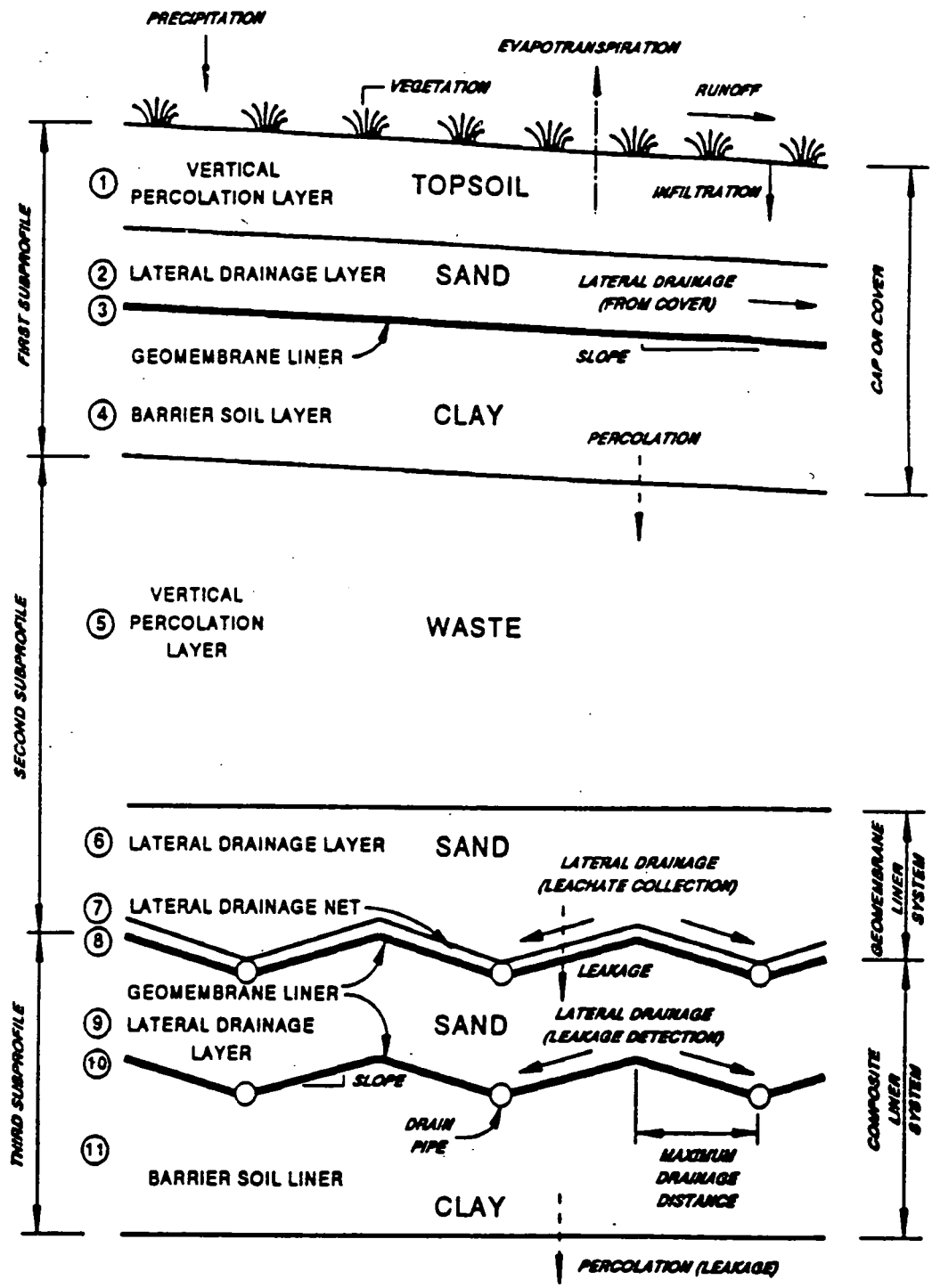


Figure 1. Schematic Profile View of a Typical Hazardous Waste Landfill

The layers in the landfill are typed by the hydraulic function that they perform. Four types are of layers are available: vertical percolation layers, lateral drainage layers, barrier soil liners and geomembrane liners. These layer types are illustrated in Figure 1. The topsoil and waste layers are generally vertical percolation layers. Sand layers above liners are typically lateral drainage layers; compacted clay layers are typically barrier soil liners. Geomembranes are typed as geomembrane liners. Composite liners are modeled as two layers. Geotextiles are not considered as layers unless they perform a unique hydraulic function.

Flow in a vertical percolation layer (e.g., layers 1 and 5 in Figure 1) is either downward due to gravity drainage or extracted by evapotranspiration. Unsaturated vertical drainage is assumed to occur by gravity drainage whenever the soil moisture is greater than the field capacity (greater than the wilting point for soils in the evaporative zone) or when the soil suction of the layer below the vertical percolation layer is greater than the soil suction in the vertical percolation layer. The rate of gravity drainage (percolation) in a vertical percolation layer is assumed to be a function of the soil moisture storage and largely independent of conditions in adjacent layers. The rate can be restricted when the layer below is saturated and drains slower than the vertical percolation layer. Layers, whose primary hydraulic function is to provide storage of moisture and detention of drainage, should normally be designated as vertical percolation layers. Waste layers and layers designed to support vegetation should be designated as vertical percolation layers, unless the layers provide lateral drainage to collection systems.

Lateral drainage layers (e.g., layers 2, 6, 7 and 9 in Figure 1) are layers that promote lateral drainage to collection systems at or below the surface of liner systems. Vertical drainage in a lateral drainage layer is modeled in the same manner as for a vertical percolation layer, but saturated lateral drainage is allowed. The saturated hydraulic conductivity of a lateral drainage layer generally should be greater than 1×10^{-3} cm/sec for significant lateral drainage to occur. A lateral drainage layer may be underlain by only a liner or another lateral drainage layer. The slope of the bottom of the layer may vary from 0 to 40 percent.

Barrier soil liners (e.g., layers 4 and 11 in Figure 1) are intended to restrict vertical flow. These layers should have hydraulic conductivities substantially lower than those of the other types of layers, typically below 1×10^{-6} cm/sec. The program allows only downward flow in barrier soil liners. Thus, any water moving into a liner will eventually percolate through it. The leakage (percolation) rate depends upon the depth of water-saturated soil (head) above the base of the layer, the thickness of the liner and the saturated hydraulic conductivity of the barrier soil. Leakage occurs whenever the moisture content of the layer above the liner is greater than the field capacity of the layer. The program assumes that barrier soil liner is permanently saturated and that its properties do not change with time.

Geomembrane liners (e.g., layers 3, 8 and 10 in Figure 1) are layers of nearly

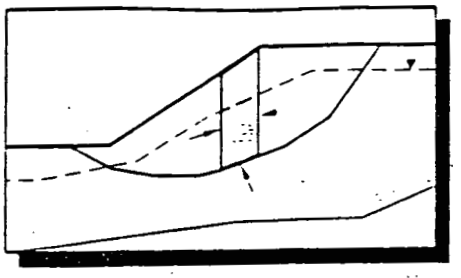
impermeable material that restricts significant leakage to small areas around defects. Leakage (percolation) is computed to be the result from three sources: vapor diffusion, manufacturing flaws (pinholes) and installation defects (punctures, cracks, tears and bad seams). Leakage by vapor diffusion is computed to occur across the entire area of the liner as a function of the head on the surface of the liner, the thickness of the geomembrane and its vapor diffusivity. Leakage through pinholes and installation defects is computed in two steps. First, the area of soil or material contributing to leakage is computed as a function of head on the liner, size of hole and the saturated hydraulic conductivity of the soils or materials adjacent to the geomembrane liner. Second, the rate of leakage in the wetted area is computed as a function of the head, thickness of soil and membrane and the saturated hydraulic conductivity of the soils or materials adjacent to the geomembrane liner.

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.



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.

The licensed software is provided for your personal business, professional and educational use and may be installed on more than one computer or a single network. However, **XSTABL** may *NOT* be operated on more than one personal computer at the same time. One back-up copy of the original **XSTABL** disk(s) is permitted to safeguard against disk failure.

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 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.

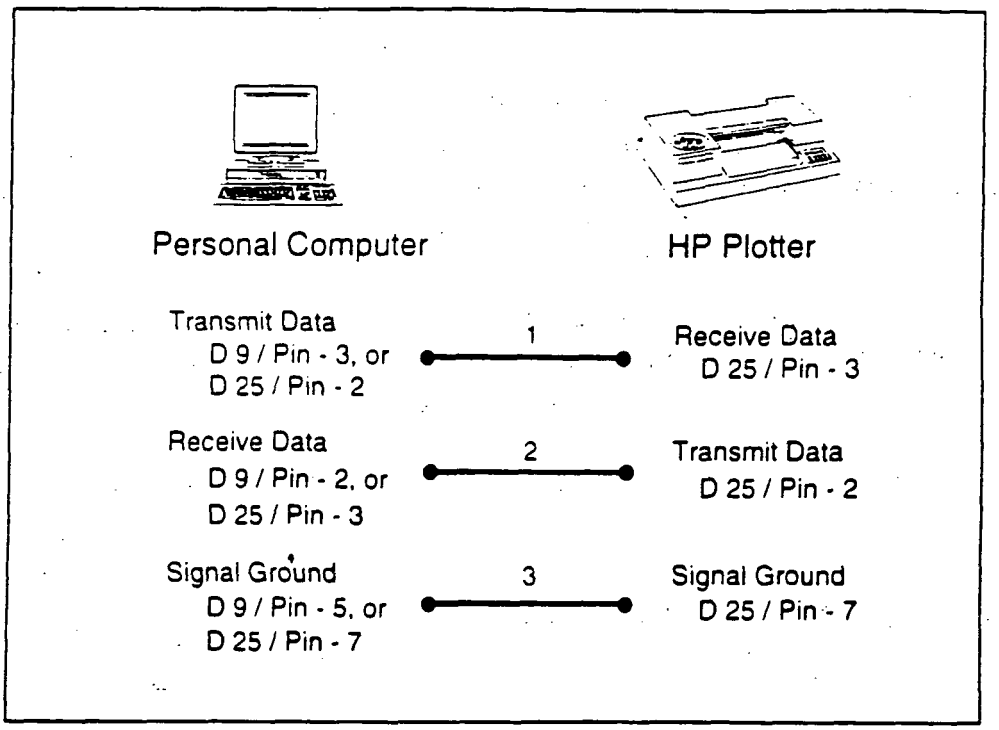

Fig. 1.1. Wire connections for PC - HP plotter cable

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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.

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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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Fig. B-7 -- Calculated Amplification Spectra for Sample Problem Using Diamond Heights Record as Input Motion

Fig. B-8 -- Time Histories of Shear Strains and Stresses Calculated at Depths of 20 and 60 ft for Sample Problem Using Diamond Heights Record as Input Motion

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

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 ~~11~~ 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.

Option 3 -- Input (Object) Motion

- 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

Corrected in the program w/ v. v.

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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)

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 & 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)

start at 1st col. fourth line: name of file to read periods from 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

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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.

Mr. Peter Dirrim, formerly with Caltrans in Sacramento, provided valuable input during the early stages of the modifications and the writers are grateful for this assistance.

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REFERENCES

Cooley, J. W. and Tukey, J. W. (1965) "An Algorithm for the Machine Calculations of Complex Fourier Series," Mathematics of Computation, Vol. 19, No. 90.

Dickenson, S. E. and Seed, R. B. (1991) "Correlations of Shear Wave Velocity and Engineering Properties for Soft Soil Deposits in the San Francisco Bay Region", Report No. UCB/EERC - 91, Earthquake Engineering Research Center, University of California, Berkeley, 110p.

Dickenson, S. E., Seed, R. B., Lysmer, J and Mok, C. M. (1991) "Response of Soft Soils during the 1989 Loma Prieta Earthquake and Implications for Seismic Design Criteria", Proceedings, Pacific Conference on Earthquake Engineering, Auckland, New Zealand, November.

Hardin, B. O. and Drnevich, V. P. (1970) "Shear Modulus and Damping in Soils: I. Measurement and Parameter Effects, II. Design Equations and Curves," Technical Reports UKY 27-70-CE 2 and 3, College of Engineering, University of Kentucky, Lexington, Kentucky, July. [These reports were later published in the Journal of Soil Mechanics and Foundation Division, ASCE, Vol. 98, No. 6, pp 603-624 and No. 7, pp 667-691, in June and July, 1972].

Idriss, I. M. (1990) "Response of Soft Soil Sites during Earthquakes", Proceedings, Memorial Symposium to honor Professor Harry Bolton Seed, Berkeley, California, Vol. II, May.

Idriss, I. M. (1991) "Earthquake Ground Motions at Soft Soil Sites", proceedings, Second International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, St. Louis, Missouri, Vol. III, March.

Idriss, I. M. and Seed, H. Bolton (1968) "Seismic Response of Horizontal Soil Layers," Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 94, No. SM4, July.

Kanai, K. (1951) "Relation Between the Nature of Surface Layer and the Amplitude of Earthquake Motions," Bulletin, Tokyo Earthquake Research Institute.

Lysmer, J., Seed, H. Bolton and Schnabel, P. B. (1971) "Influence of Base -Rock Characteristics on Ground Response," Bulletin of the Seismological Society of America, Vol. 61, No. 5, October, pp 1213-1232.

Matthiesen, R. B., Duke, C. M., Leeds, D. J. and Fraser, J. C. (1964) "Site Characteristics of Southern California Strong-Motion Earthquake Stations, Part Two," Report No. 64-15, Department of Engineering, University of California, Los Angeles, August.

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Roesset, J. M. and Whitman, R. V. (1969) "Theoretical Background for Amplification Studies," Research Report No. R69-15, Soils Publications No. 231, Massachusetts Institute of Technology, Cambridge.

Rollins, K. M., Hryciw, R. D., McHood, M., Homolka, M. and Shewbridge, S. E. (1992) "Soil Amplification at Treasure Island during the Loma Prieta Earthquake," Paper prepared for Inclusion in the NEHRP Report to Congress on the Loma Prieta Earthquake.

Schnabel, P. B., Lysmer, J. and Seed, H. Bolton (1972) "SHAKE: A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites", Report No. UCB/EERC-72/12, Earthquake Engineering Research Center, University of California, Berkeley, December, 102p.

Seed, H. Bolton and Idriss, I. M. (1970) "Soil Moduli and Damping Factors for Dynamic Response Analysis", Report No. UCB/EERC-70/10, Earthquake Engineering Research Center, University of California, Berkeley, December, 48p.

H. Bolton Seed, Wong, R. T., Idriss, I. M. and Tokimatsu, K. (1986) "Moduli and Damping factors for Dynamic Analyses of Cohesionless Soils," Journal of the Geotechnical Engineering Division, ASCE, Vol. 112, No. GT11, November, pp 1016-1032.

Sun, J. I., Golesorkhi, R. and Seed, H. Bolton (1988) "Dynamic Moduli and Damping Ratios for Cohesive Soils," Report No. UCB/EERC-88/15, Earthquake Engineering Research Center, University of California, Berkeley, 42p.

Yokel, F. Y. (1992) " Effects of Subsurface Conditions on earthquake Ground Motions", Report No. NISTIR 4769, Building and Fire Research Laboratory, National Institute of Standards and Technology, Gaithersburg, Maryland, 85p .

Vucetic, M. and Dobry, R. (1991) "Effect of Soil Plasticity on Cyclic Response," Journal of the Geotechnical Engineering Division, ASCE, Vol. 111, No. 1, January, pp 89-107.

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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 N.M. 10-17-95 A19/20

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
```

MHG 20 Oct 95

N.M. 10-17-95

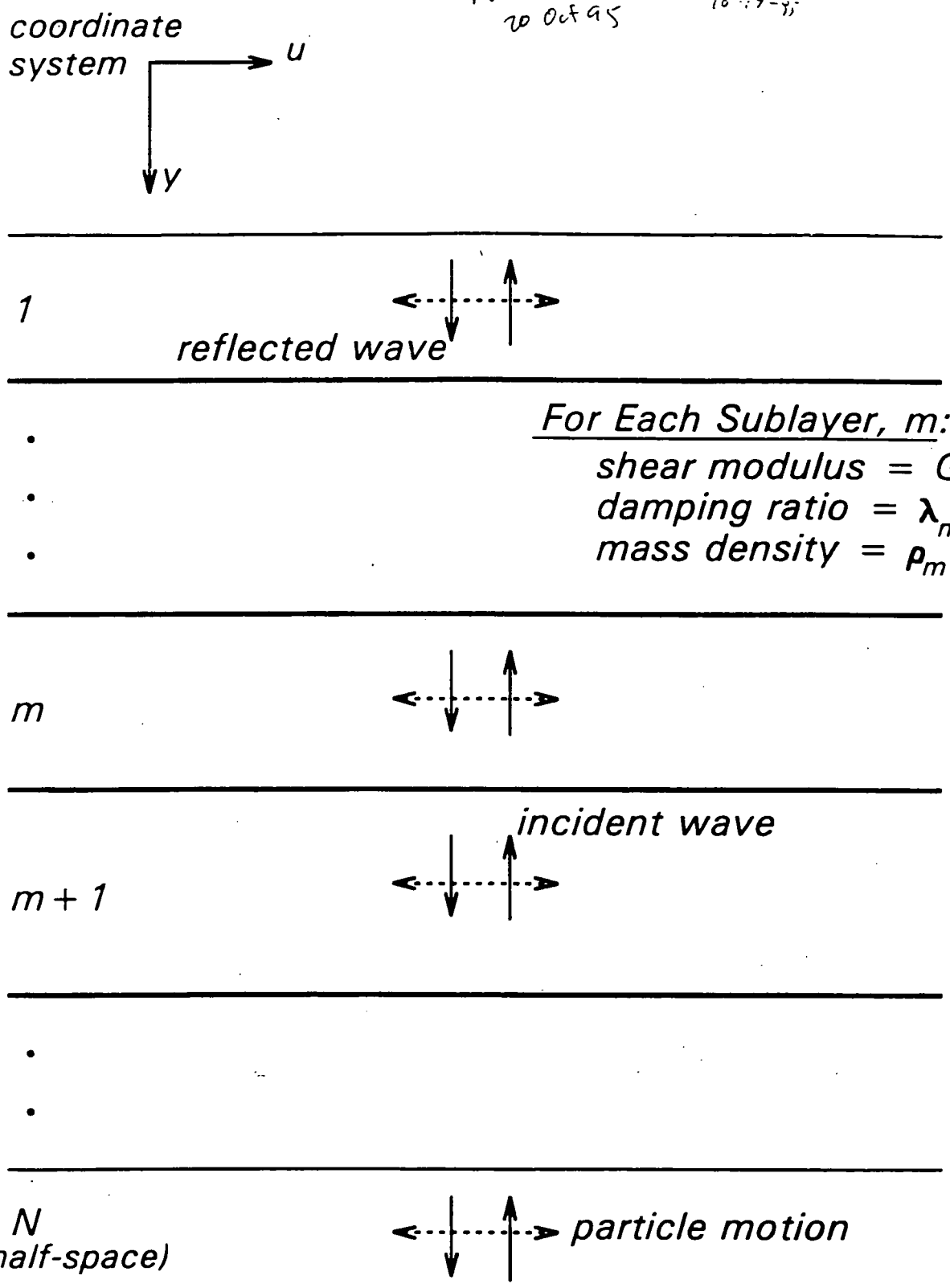

Fig. 1 One-Dimensional Idealization of a Horizontally-Layered Soil Deposit Over a Uniform Half-Space

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

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

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 95

B4/4

```
**********************************************
**                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 !

APPENDIX A

COMPUTER SOFTWARE USED TO PREPARE CALCULATION PACKAGE RADIATION ATTENUATION EFFECTIVENESS AND COVER OPTIMIZATION WITH MOISTURE EFFECTS (RAECOM)

NRC, "*Radon Attenuation Effectiveness and Cover Optimization with Moisture Effects (RAECOM)*", Computer Program prepared by Rogers and Associates Engineering, Salt Lake City, Utah, for the U.S. Nuclear Regulatory Commission, Washington, D.C., 1984.

RADIATION ATTENUATION EFFECTIVENESS AND COVER OPTIMIZATION WITH MOISTURE EFFECTS

THE RAECOM CODE

The one-dimensional, steady-state radon diffusion code, RAECO,[48] has been modified and updated. The updated code, RAECOM, is a FORTRAN program which determines the radon fluxes and concentrations in multilayer uranium tailings and cover systems using the mathematical formulation given in Appendix A, and then optimizes the cover thickness to satisfy a given flux constraint. The numerical method of solution in RAECOM is identical to that in RAECO.

In proceeding through a calculation, first, the D's are calculated from a correlation if they are not input directly. Then the migration of radon is determined for the specified cover characteristics and the radon concentrations (C) and the radon fluxes (J) are calculated. The cover optimization is performed yielding adjusted values (t) for the layer thicknesses. The radon migration calculations are then repeated for each J and C with the adjusted cover layer thicknesses, and the resulting surface flux, J_c, is tested against the specified criterion, J_{crit}. If this criterion is satisfied, the code proceeds to final output. If the flux criterion is not satisfied, appropriate layer thicknesses are adjusted within the specified constraints, radon migration calculations are repeated, and the surface radon flux is again tested against the flux criterion. This process is repeated until all criteria are satisfied. The code then outputs all radon attenuation data. If additional cover systems are to be evaluated, the RAECOM code will re-initialize and perform the complete analysis for the subsequent cover systems. Any number of cover systems can be analyzed by stacking data sets.

B.1 MODIFICATIONS

Modifications to RAECO that are incorporated in RAECOM include:

1. Soil moistures (dry weight percent) are read in to calculate the D of any layer not input, using Equation 12.

2. The radon concentration interface condition includes the effects of soil moisture (Appendix A).

3. The diffusion coefficient of the pore space, D, and the pore space radon source term, $Q = R\rho E\lambda/P$, are read in directly instead of the bulk parameters $D_e = pD$ and $Q_e = pQ$.

4. The optimization routine does not depend upon cost parameters.

5. If desired, the program will estimate the entrance radon flux into layer 1, assuming an infinitely thick subsoil underneath layer 1.

B.2 INPUT DATA FORMAT FOR RAECOM

All input data is free format. The following input is needed for program operation.

Card Set Number	Card Description
1	Site Designation Card - One card with up to 80 characters which designates the tailings cover system and run identification.
2	Boundary Conditions and Cost Control Parameters - One card containing six parameter values, each separated by commas in the following order: (1) N, Number of distinct tailings cover layers: positive integer, presently limited to 99. (2) F01, Entrance radon flux to layer 1, pCi/m^{2}s. If F01 equals -1., then F01 is computed internally for an infinitely thick subsoil. (3) CN1, Surface radon concentration at top of system, pCi/l. (4) ICOST, Integer Cover Optimization Flag, ICOST = 0 if no optimization is to be performed, otherwise, ICOST equals the layer number to be optimized. ICOST cannot equal 1. (5) CRITJ, Surface Flux Constraint for optimization, pCi/m^{2}s, CRITJ = 0 for no constraint. (6) ACC, Surface Flux Convergence Criterion, fraction.
3, 1-N	Individual Cover Layer Data Cards - One card for each tailings or cover layer. Each card is composed of four parameters: (1) DX, The layer thickness in cm.

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(2) D, Layer radon diffusion coefficient, $cm^2\ s^{-1}$.

(3) p, Layer porosity.

(4) Q, Layer radon source term in $pCi\ cm^{-3}s^{-1}$.

(5) M, Moisture content as dry wt percent.

B.4 SAMPLE PROBLEM

The output and input for the example problem described in Table 2 of the Handbook is given below:

RAECOM CALCULATION OF MULTIREGION EXAMPLE

```
RAECOM CALCULATION OF MULTIREGION EXAMPLE

********** I N P U T   P A R A M E T E R S **********

NUMBER OF LAYERS :                    3
RADON FLUX INTO LAYER 1 :             0.000     pCi/m2/sec
SURFACE RADON CONCENTRATION :         0.000     pCi/liter

LAYER 3 ADJUSTED TO MEET Jcrit :       20.0    +/-  0.100E-02 pCi/m2/sec

BARE SOURCE FLUX (Jo) FROM LAYER 1 :  198.4     pCi/m2/sec
```

LAYER	THICKNESS (cm)	DIFF COEFF (cm2/sec)	POROSITY	SOURCE (pCi/cm3/sec)	MOISTURE (dry wt. percent)
1	500.	1.3000E-02	0.4400	5.7300E-04	11.70
2	50.	7.8000E-03	0.3000	0.0000E-01	6.30
3	100.	2.2000E-02	0.3700	0.0000E-01	5.40

```
***** R E S U L T S   O F   R A D O N   D I F F U S I O N   C A L C U L A T I O N *****
```

LAYER	THICKNESS (cm)	EXIT FLUX (pCi/m2/sec)	EXIT CONC. (pCi/liter)	MIC
1	500.	7.6937E+01	1.6701E+05	0.7025
2	50.	4.5285E+01	4.4198E+04	0.7063
3	149.	2.0011E+01	0.0000E-01	0.8163

```
RAECOM CALCULATION OF MULTIREGION EXAMPLE
3, 0   0., 3, 20., .001
500., .013, .44, .000573, 11.7
50., .0078, .30, .0,      6.3
100., .022, .37, .0,      5.4
```

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```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
C THE RAECOM PROGRAM IS A SHORTENED AND UPDATED VERSION OF THE
C
C ORIGINAL RAECO PROGRAM (V.C. ROGERS ET.AL., UMTRA-DOE/ALO-165, JUNE
C
C 1981).  THE COST CALCULATION SEGMENT OF IHE ORIGINAL PROGRAM HAS
C
C BEEN REMOVED. MODIFIED INPUT INCLUDES DIFFUSION COEFFICIENTS AND
C
C SOURCE TERMS FOR THE PORE SPACE, AND SOIL MOISTURES.  THE PROGRAM
C
C ALSO CAN ESTIMATE DIFFUSION COEFFICIENTS FROM MOISTURES (V.C. ROGERS
C
C ET.AL., UMTRA-DOE/ALO-193, NOV. 1982).  INTEREACE CONDITIONS HAVE
C
C BEEN UPDATED (V.C. ROGERS ET.AL., FT. COLLINS: URANIUM MILL TAILINGS
C
C MANAGEMENT - 5, P. 369-382, 1982).  THE MODIFICATIONS IN RAECOM, THE
C
C INPUT FORMAT, AND A SAMPLE PROBLEM ARE GIVEN IN NUREG/CR-3533 (1984).C
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCDEC-1983CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

      PROGRAM RAECOM
C
C DEFINE & INITIALIZE ARRAYS
C
      IMPLICIT REAL*8 (A-H,O-Z)
      CHARACTER*80 H
      DIMENSION ALP(50),AIP1MI(50),R(50),A(245),B(99),G(245),BU(99),
     &AS(50),BS(50),Q(50),D(50),P(50),T(50),U(50),RR(50),DDX(50),
     &X(50),RF(50),RC(50),DX(50),RHO(50),XM(99),A4(50),XMS(99)
      DATA RHO/50*0.0D0/,
     &NSAVE,XL/0.2,1D-6/
      OPEN (UNIT=6,FILE='RAECOM.OUT',FORM='FORMATTED')
C       CALL ASSIGN(6,'LA:')
```

```
C
C READ RADON DIFFUSION DATA
C
      OPEN(UNIT=5,FILE='RAECOM.INP')
      READ(5,882) H
  882 FORMAT(A80)
      READ(5,1) N,F01,CN1,ICOST,CRITJ1,ACC
      READ(5,2) (DX(I),D(I),P(I),Q(I),XM(I),I=1,N)
    1 FORMAT(I3,2F8.0,I3,2F8.0)
    2 FORMAT(5F10.0)
      NO3 = 0
      IF (ICOST.GT.0) NO3 = ICOST
      IF (ICOST.GT.0) ICOST = 1
      ITHK = 0
      NO2 = NO3 - 1
      NO1 = NO2 - 1
      NO4 = NO3 + 1
      F0 = F01/10000.
      CN = CN1/1000.
      CRITJ = CRITJ1/10000.
      WRITE(6,2222) H
 2222 FORMAT(/////' ',A80)
      WRITE(6,888) N,F01,CN1
  888 FORMAT(/,'  ********** I N P U T  P A R A M E T E R S
     &**********',//,' NUMBER OF LAYERS :',19X,I2,
     &/,' RADON FLUX INTO LAYER 1 :',12X,G10.3,' pCi/m2/sec',/,
     &' SURFACE RADON CONCENTRATION :',8X,G10.3,' pCi/liter')
      IF (ICOST.EQ.0) GO TO 676
      WRITE(6,675) NO3,CRITJ1,ACC
  675 FORMAT(/,' LAYER',I2,' ADJUSTED TO MEET Jcrit :',5X,G10.3,
     &  '+/- ',G10.3,' pCi/m2/sec',/)
  676 CONTINUE
      DO 100,I=1,N
     XM(I) = XM(I)*.01
     RHO(I) = 2.7D0*(1.D0-P(I))
     XMS(I) = RHO(I)*XM(I)/P(I)
     IF (XMS(I).LE..99) GO TO 678
       T8 = XM(I)
       XMS(I) = .99
```

```
      XM(I) = XMS(I)*P(I)/RHO(I)
      WRITE(6,679) I,T8,XM(I)
679     FORMAT(/,' LAYER',I2,' EXCEEDS SATURATION.  MOISTURE ',
     &    'CHANGED FROM',F7.3,' TO',F7.3,//)
678   CONTINUE
     IF(D(I).EQ.0.)D(I)=.07*DEXP(-4.*(XMS(I)*(1.-P(I)**2)+
     &  XMS(I)**5))
100 A4(I) = 1. - .74*XMS(I)
      AB = DSQRT(XL/D(1))
      RF(1) = (Q(1)*P(1)/AB)*TANH(AB*DX(1))
      IF (F01.EQ.-1.) RF(1) = RF(1)/(1.+(.5*TANH(AB*DX(1)))/
     & 0.5/(DEXP(AB*DX(1))+DEXP(-AB*DX(1))))
      IF (F01.EQ.-1.) F0 = -.5*RF(1)*TANH(AB*DX(1))
      DDX(1) = DX(1)
      RC(1) = CN/A4(1)
      WRITE(6,341) RF(1)*10000.
341 FORMAT(' BARE SOURCE FLUX (Jo) FROM LAYER 1 :',G11.4,
     &' pCi/m2/sec',//)
      WRITE(6,887)
      WRITE(6,850) (I,DX(I),D(I),P(I),Q(I),100.*XM(I),I=1,N)
850 FORMAT(50(/,2X,I2,5X,F6.0,8X,1PE11.4,7X,0PF7.4,7X,1PE11.4,7X,
     &0PF7.2))
      WRITE(6,886)
886 FORMAT(//,' *****  R E S U L T S   O F   R A D O N   D I F F U S
I
     & O N   C A L C U L A T I O N *****',/)
887 FORMAT(' LAYER',2X,'THICKNESS',7X,'DIFF COEFF',7X,
     &'POROSITY',9X,'SOURCE',9X,'MOISTURE',/,11X,'(cm)',9X,
     &'(cm2/sec)',21X,'(pCi/cm3/sec)',1X,'(dry wt. percent)')
      DO 101 I=1,N
     Q(I) = Q(I)*P(I)
     P(I) = P(I)*A4(I)
     D(I) = D(I)*P(I)
101 CONTINUE
      IF (N.EQ.1) GO TO 110
      NM1 = N - 1
      NM2 = N - 2
      JTST = 1
      DDX(1) = DX(1)
```

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```
      ALP(1) = DSQRT(XL*P(1)/D(1))
   99 CONTINUE
      DO 58 I=2,N
   58 DDX(I) = DX(I)
C
C  MODIFY PARAMETERS FOR CODE LIMITS
C
      SUMX = 0.
      SUMA = 0.
      SUMAX = 0.
      XRED = 0.
      XCHG = 0.
      X(1) = 0.
      X0 = 0.
      SUMMAX = ALP(1)*DX(1)
      IF (SUMMAX.LE.4.61) GO TO 60
     XRED = 4.61/ALP(1)
     F0 = F0 * DEXP(4.61 - SUMMAX)
      SUMMAX = ALP(1) * (DX(1) - XRED)
   60 CONTINUE
      IF (XRED.GT.0.) XCHG=DX(1)-XRED
      DO 345 I=1,N
     ALPI = DSQRT(XL*P(I)/D(I))
     SUMX = SUMX + DX(I)
     X(I+1) = SUMX - XCHG
     SUMA = SUMA + ALPI
     ALSUM = ALPI * X(I+1)
     IF (ALSUM.GE.SUMMAX)  SUMMAX = ALSUM
     SUMAX = SUMAX + ALSUM
  345   ALP(I) = ALPI
      IF (SUMMAX.GT.174.) WRITE(6,321)
  321 FORMAT(' LAYER THICKNESS OR DIFFUSION COEFFICIENT EXCEEDS LIMITS')
      IF (SUMMAX.LE.87.) GO TO 500
     X0 = SUMAX/SUMA
     DO 456 I=0,N
     X(I+1) = X(I+1) -X0
  456   CONTINUE
  500 CONTINUE
C
```

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```
C  CALCULATE PARAMETERS FOR MATRIX
C
      DO 10 I=1,NM1
     RDUM = DSQRT(P(I+1)*D(I+1)/(P(I)*D(I)))
     R(I) = -.5*(1.-RDUM)
     RR(I) = -.5*(1.+RDUM)
     QP = (Q(I+1)/P(I+1)-Q(I)/P(I))/XL
     T(I) = QP*DEXP(-ALP(I)*X(I+1))
     U(I) = QP*.5*DEXP(ALP(I)*X(I+1))
10   AIP1MI(I)=DSQRT(XL)*(DSQRT(P(I+1)/D(I+1))-DSQRT(P(I)/D(I)))
      ALP(N) = DSQRT(XL*P(N)/D(N))
C
C  SPECIFY MATRIX ELEMENTS AND SOLVE
C
      DO 20 I=1,NM1
     J = 5*I-4
     K = 2*I-1
     A(J) = DEXP(-2.*ALP(I)*X(I+1))
     A(J+1) = -DEXP(AIP1MI(I)*X(I+1))
     A(J+2) = -DEXP(-(ALP(I+1)+ALP(I))*X(I+1))
     A(J+3) = R(I)*DEXP((ALP(I+1)+ALP(I))*X(I+1))
     A(J+4) = RR(I)*DEXP(-AIP1MI(I)*X(I+1))
     B(K) = T(I)
20   B(K+1) = U(I)
      N5M4 = 5*N-4
      A(N5M4) = DEXP(-2.*ALP(N)*X(N+1))
      N2M1 = 2*N-1
      B(N2M1) = (CN-Q(N)/(P(N)*XL))*DEXP(-ALP(N)*X(N+1))
C
C  UPPER TRIANGULARIZE MATRIX
C
      G(1) = A(1)+DEXP(-2.*ALP(1)*X(1))
      G(2) = A(2)/G(1)
      G(3) = A(3)/G(1)
      BU(1) = (B(1)+F0*DEXP(-ALP(1)*X(1))/(D(1)*ALP(1)))/G(1)
      DO 30 I=1,NM2
     J = 5*I-1
     K = 2*I
     G(J) = A(J)-G(J-2)
```

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```
      G(J+1) = (A(J+1)-G(J-1))/G(J)
      BU(K) = (B(K)-BU(K-1))/G(J)
      G(J+2) = A(J+2)-G(J+1)
      G(J+3) = A(J+3)/G(J+2)
      G(J+4) = A(J+4)/G(J+2)
   30   BU(K+1) = (B(K+1)-BU(K))/G(J+2)
       N5M6 = 5*N-6
       G(N5M6) = A(N5M6)-G(N5M6-2)
       G(N5M6+1) = (A(N5M6+1)-G(N5M6-1))/G(N5M6)
       N2M2 = 2*N-2
       BU(N2M2) = (B(N2M2)-BU(N2M2-1))/G(N5M6)
       G(N5M6+2) = A(N5M6+2)-G(N5M6+1)
       BS(N) = (B(N2M1)-BU(N2M1-1))/G(N5M6+2)
       AS(N) = BU(N2M1-1)-G(N5M6+1)*BS(N)
       DO 40 I=1,NM2
      J = 5*(N-I)-3
      K = 2*(N-I)-1
      L = N-I
      BS(L) = BU(K)-G(J)*AS(L+1)-G(J+1)*BS(L+1)
   40   AS(L) = BU(K-1)-G(J-2)*BS(L)
      BS(1) = BU(1)-G(2)*AS(2)-G(3)*BS(2)
      AS(1) = (BS(1)*DEXP(-ALP(1)*X(1))-F0/(ALP(1)*D(1)))
      &  *DEXP(-ALP(1)*X(1))
C
C  MATRIX SOLUTION COMPLETE
C
       DO 147 I=1,N
      ALPI = ALP(I)*X(I+1)
      ASI = AS(I)*DEXP(ALPI)
      BSI = BS(I)*DEXP(-ALPI)
      RC(I) = ASI+BSI+Q(I)/(P(I)*XL)
  147   RF(I) = -D(I)*ALP(I)*(ASI-BSI)
       RC(N) = CN
       IF (ICOST.EQ.0) GO TO 45
       F0P = F0
       IF (F0.LT.1) F0P=1.
       IF (RF(1).LE.0.D0) RF(1)=1.D0
C   ***** BEGIN COST OPTIMIZATION
       IF (JTST.EQ.0) GO TO 44
```

DMD
JM 05/04/96

```
      IF (CRITJ.GT.99.) GO TO 45
      IF (CRITJ.LE.0.) GO TO 45
      T7 = (RF(N)-CRITJ)/CRITJ
      ABT7 = DABS(T7)
      IF (ABT7.LE.ACC) GO TO 45
      NTST = NO3
      IIJ  = NO2
      IF (NTST.EQ.NSAVE) GO TO 190
     DXMAX = 0.
     DXMIN = 0.
     RFMAX = 0.
     RFMIN = 0.
     NSAVE = NTST
  190 CONTINUE
C
C  SET LIMITS (DXMAX &DXMIN) AND DO REGULA EALSI SEARCH FOR DX
C
      IF (T7) 200,45,201
  200 DXMAX = DX(NTST)
      RFMIN = RF(N)
      GO TO 202
  201 DXMIN = DX(NTST)
      RFMAX = RF(N)
      IF (DXMAX) 202,203,202
  202 DX(NTST) = DXMIN+(DXMAX-DXMIN)*(RFMAX-CRITJ)/(RFMAX-RFMIN)
      GO TO 204
  203 DX(NTST) = DX(NTST)*(1.+0.5*T7)
  204 CONTINUE
      IF (RFMAX.EQ.0.) DX(NTST)=0.5*DXMAX
      IF (DX(NTST).LE.1.) DX(NTST)=0.
      IF (DX(NTST).LE.1.) JTST=0
      IF (ITHK.EQ.0) GO TO 99
      T2T = 0.
      IF(NO4.GT.N) GO TO 55
      DO 46 IJ = NO4,N
   46 T2T = T2T+DX(IJ)
   55 IF(NO1.LT.2) GO TO 47
      DO 56 IJ = 2,NO1
   56 T2T = T2T+DX(IJ)
```

```
   47 CONTINUE
      T23 = DX(NTST)
      T2T = T2T+DX(NTST)
C      IF (NMIN.EQ.NTST) T2T=T2T+DX(IIJ)-DX(NTST)
C      IF (NMIN.NE.0) DX(NMIN)=X(N+1)-X(2)-T2T
C      IF (DX(NMIN).GE.0.) GO TO 48
C        DX(NMIN) = 0.  I
C        DX(NTST) = 0.5*(DX(NTST)+DDX(NTST))
C        GO TO 99
   48 CONTINUE
      IF (DX(NTST).NE.T23) CRITJ=-1.
      GO TO 99
   44 CONTINUE
   45 CONTINUE
C
C  OUTPUT RESULTS
C
  110 WRITE(6,881)
  881 FORMAT(6X,' LAYER',3X,'THICKNESS',7X,'EXIT FLUX',10X,
     &'EXIT CONC.',8X,'MIC',/,18X,'(cm)',7X,'(pCi/m2/sec)',
     &8X,'(pCi/liter)',/)
      DO 884 I=1,N
      RXYZ = RF(I)*10000.
      CXYZ = RC(I)*1000.*A4(I)
  884   WRITE(6,883) I,DDX(I),RXYZ,CXYZ,A4(I)
  883   FORMAT(8X,I2,6X,F6.0,6X,1PE12.4,7X,E12.4,6X,0PF7.4)
      CLOSE(UNIT=5)
      CLOSE(UNIT=6)
      END
```

GEOSYNTEC CONSULTANTS

Written by: _____ Date: ___/___/___ Reviewed by: _____ Date: ___/___/___

Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 10.2

OSDF METHANE GENERATION

APPENDIX A

Landfill Air Emissions Estimation Model Documentation

GE3900-10.2/Methane.cal

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April 1991

LANDFILL AIR EMISSIONS ESTIMATION MODEL VERSION 1.1

USER'S MANUAL

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ABSTRACT

This document is a user's guide for a computer program entitled, "Landfill Air Emissions Estimation Model, Version 1.1." This manual provides step-by-step guidance for using this program to estimate landfill air emissions. The purpose of this program is to aid local and state agencies in estimating landfill air emission rates for nonmethane organic compounds and individual air toxics. This program will also be helpful to landfill owners and operators affected by the upcoming New Source Performance Standard and Emission Guidelines for Municipal Solid Waste Landfill Air Emissions.

The model is based on the Scholl Canyon Gas Generation Model, which was used in the development of the soon-to-be proposed regulation for landfill air emissions. The Scholl Canyon Model is a first order decay equation that uses site specific characteristics for estimating the gas generation rate. In the absence of site-specific data, the program provides conservative default values taken from the soon-to-be proposed NSPS for new landfills and emission guidelines for existing landfills. These default values may be revised based upon any future information collected by the Agency.

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1.3 Select Technical References

Reference: "*Report of Workshop on Geosynthetic Clay Liners*", United States Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, Ohio, August 1995, in press.

EVALUATION OF VARIOUS ASPECTS OF GCL PERFORMANCE

by

R. Bonaparte[1], M.A. Othman[1], N.R. Rad[1], R.H. Swan[1], and D.L. Vander Linde[1]

INTRODUCTION

The purpose of this paper is to briefly present the results of various activities that have recently been undertaken by the authors on the subject of geosynthetic clay liner (GCL) testing and performance evaluation. The subjects that are addressed are:

- field hydraulic performance of composite liners containing GCLs;
- drained shear strength of hydrated GCLs at high normal stress;
- interface shear strength between unhydrated GCLs and textured geomembranes at high normal stress;
- hydration of GCLs adjacent to soil layers; and
- causes of failure of a landfill cover system containing a GCL.

FIELD PERFORMANCE OF COMPOSITE LINERS CONTAINING GCLs

Sources of Flow in LDS of Double-Liner System

A double liner system consists of top and bottom liners with a leakage detection system (LDS) between the two liners. If the double-liner system is used in a landfill, it will also contain a leachate collection and removal system (LCRS) above the top liner. As part of an ongoing research investigation for the United States Environmental Protection Agency (USEPA), the authors have collected data

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on the rates of liquid flow into the sumps of LCRSs and LDSs for a wide variety of double-lined waste management units located throughout the United States. Comparison of the rates of flow into the LCRS and LDS of a unit can be used to quantify the performance of the top liner (in terms of the ability to impede advective transport of liquid through the liner). In essence, the LDS serves as a large lysimeter (i.e., collection pan) below the top liner.

To make the evaluation, consideration must be given to the potential sources of liquid in the LDS. Gross et al. [1990] described the potential sources of LDS flow, which are (Figure 1): (i) leakage through the top liner; (ii) drainage of water (mostly rainwater) that infiltrates the leakage detection layer during construction but does not drain to the LDS sump until after start of facility operation ("construction water"); (iii) water expelled from the LDS layer as a result of compression under the weight of the waste ("compression water"); (iv) water expelled from any clay component of the top liner as a result of clay consolidation under the weight of the waste ("consolidation water"); and (v) for a waste management unit with its base located below the water table, groundwater infiltration through the bottom liner ("infiltration water").

Gross et al. [1990] and Bonaparte and Gross [1990] presented the following five-step approach for evaluating the sources of LDS liquid at a specific waste management unit.

- Identify the potential sources of flow for the unit based on double-liner system design, climatic and hydrogeologic setting, and unit operating history.
- Calculate flow rates from each potential source.
- Calculate the time frame for flow from each potential source.
- Evaluate the potential sources of flow by comparing measured flow rates to calculated flow rates at specific points in time.
- Compare LCRS and LDS chemical constituent data to further establish the likely source(s) of liquid.

Bonaparte and Gross [1990, 1993] used this five-step approach to evaluate the sources of LDS flow for 93 waste management units. Under a contract to the USEPA Risk Reduction Research Laboratory, the authors are currently performing this evaluation using new data from the facilities in the Bonaparte and Gross studies, as well as data from a significant number of additional waste management units not included in the original studies. Preliminary results for waste management units with composite top liners containing GCLs are presented below.

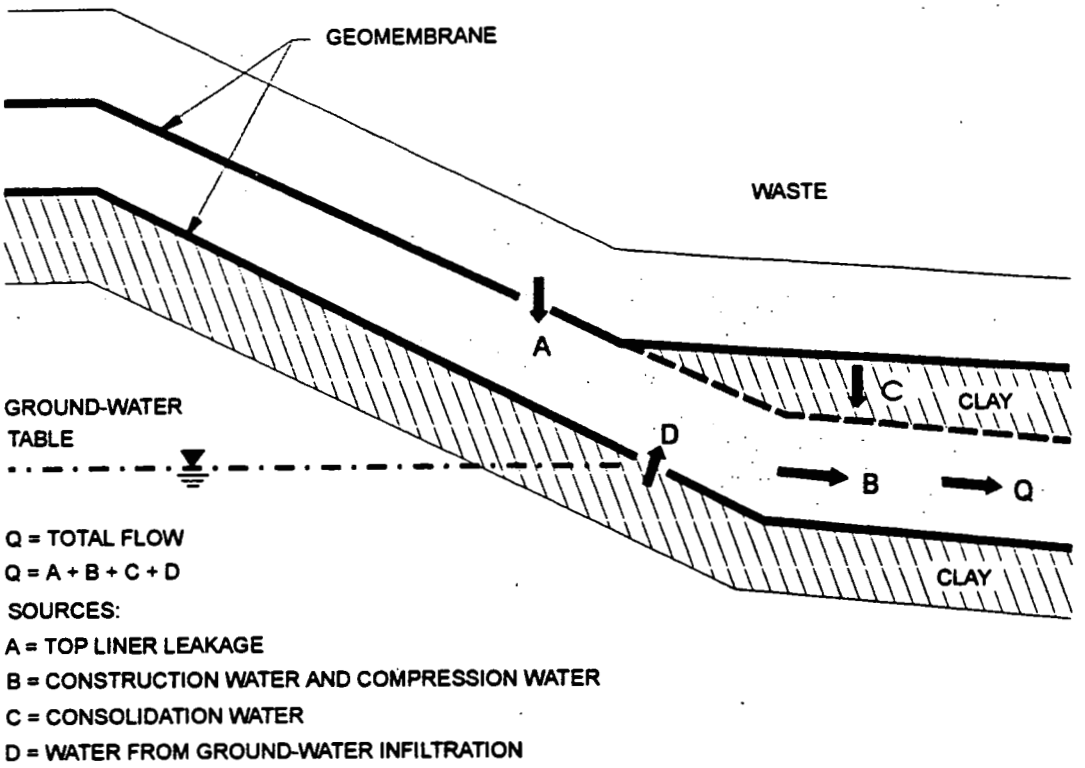

Figure 1. Sources of flow from leak detection layers.

LCRS and LDS Flow Data

Flow rate data have been collected for 26 waste management units containing composite top liners consisting of a geomembrane overlying a GCL. The 26 units are located at six different landfill sites. Descriptions of the components of the liner systems used at these facilities are presented in Table 1 and flow rate data for the LCRSs and LDSs in the units are presented in Table 2. Average daily flow rates were calculated for both systems on a monthly basis by dividing the total amount of liquid extracted from the system during the month by the number of days in the month and the area of the waste management unit. Flow rates are reported in units of liter/hectare/day (lphd). The volume of flow used in the calculation was typically obtained from the landfill operator, with flow measurements most often measured using accumulating flow meters. The reported flow volumes should be considered approximate.

Table 1. Description of landfill liner system components.

Landfill Identification	LCRS		Composite Top Liner		LDS		Bottom Liner		
	Material	Thickness (mm)	HDPE Geomembrane Thickness (mm)	GCL Thickness (mm)	Material	Thickness (mm)	HDPE Geomembrane Thickness (mm)	Layer 2	
								Material	Thickness (mm)
A	Sand	600	1.5	13	Sand	300	1.5	Clay	200
B	Sand	600	2.0	13	Sand	450	2.0	Clay	300
C	Sand	450	1.5	13	Sand	300	1.5	GCL	13
D	Sand	600	1.5	13	GT/GN[1]	5	1.5	N/A	N/A
E	Sand	600	1.5	13	GT/GN	5	1.5	Clay	900
F	GN	5	1.5	13	GT/GN	5	1.0	GCL	13

Notes: [1] GT= Geotextile, GN= Geonet.
[2] All material thicknesses are nominal values.

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Table 2. Summary of flow data for the LCRS and LDS of units with composite top liners containing GCLs.

Cell No.	Cell Area	End of Cell Const.	Start of Waste Placem.	End of Final Closure	Initial Period of Operation[1]					Active Period of Operation[2]					Post Closure Period[3]				
					Time Period	LCRS Flow[4]		LDS Flow		Time Period	LCRS Flow		LDS Flow		Time Period	LCRS Flow		LDS Flow	
						Avg.	Peak	Avg.	Peak		Avg.	Peak	Avg.	Peak		Avg.	Peak	Avg.	Peak
	(hectare)	(month-year)	(month-year)	(month-year)	(months)	(lphd)	(lphd)	(lphd)	(lphd)	(months)	(lphd)	(lphd)	(lphd)	(lphd)	(months)	(lphd)	(lphd)	(lphd)	(lphd)
A1	2.0	7-88	7-88	2-91	1-2	16,718	19,738	0.0	0.0	3-32	561	2,384	0.0	0.0	33-83	65	103	0.0	0.0
A2	2.0	7-88	7-88	2-91	1-5	15,521	58,671	15.0	44.9	6-32	281	570	1.9	20.6	33-83	178	421	0.0	0.0
A3	1.7	8-88	9-88	4-93	1-5	3,366	7,985	34.6	150.5	6-56	290	1,075	3.7	46.8	57-81	206	458	0.9	9.4
A4	1.7	8-88	9-88	4-93	1-12	2,534	12,688	101.0	860.2	13-56	75	187	0.9	13.1	57-81	47	84	0.0	0.0
A5	2.8	9-88	10-88		1-11	1,384	3,394	37.4	91.6	12-80	56	187	1.9	37.4					
A6	3.9	11-88	12-88		1-9	3,759	7,171	53.3	92.6	10-80	168	655	0.0	0.0					
A7	2.6	1-89	2-89		1-10	5,376	12,155	33.7	46.8	11-76	234	851	1.9	9.4					
A8	3.8	7-89	7-89		1-14	4,881	21,038	47.7	188.9	15-71	439	1,384	0.0	0.0					
A9	3.3	12-89	12-89		1-9	1,047	3,478	0.9	7.5	10-65	37	159	0.0	0.0					
A10	3.9	2-90	7-90		1-7	2,786	13,698	0.0	0.0	8-59	374	645	0.0	0.0					
A11	3.0	2-90	2-90		1-16	4,675	14,586	0.0	0.0	17-64	150	337	0.0	0.0					
A12	4.0	10-90	10-90		1-18	2,945	8,836	0.0	0.0	19-56	655	1,505	0.0	0.0					
A13	3.0	1-91	1-91		1-32	3,740	14,343	0.0	0.0	33-53	281	486	0.0	0.0					
A14	2.8	4-91	4-91		1-11	2,777	6,582	0.0	0.0	12-38	281	449	0.0	0.0					
A15	2.8	5-92	5-92		1-12	5,573	11,809	0.0	0.0	13-37	299	561	0.0	0.0					
A16	4.5	1-93	1-93		1-22	4,675	17,756	0.0	0.0	23-29	206	393	0.0	0.0					
B1	3.6	5-93	8-93		1-10	3,273	12,155	177.7	822.8	11-17	393	1,403	2.8	15.0					
C1	2.4	4-93	5-93		1-12	6,358	20,570	130.9	523.6										
C2	2.4	7-93	8-93		1-10	3,553	7,480	289.9	514.3										
D1	4.0	12-90	2-91		1-23			11.2	24.3	24-47			0.9	3.7					
D2	2.4	12-92	1-93		1-24	4,208	11,688	0.9	14.0										
D3	2.8	12-92	1-93		1-13	3,179	8,228	0.0	0.0	14-24	187	309	0.0	0.9					
E1	3.8	9-92	12-92		3-23	3,890		1.9	22.4										
F1	1.3	7-94	10-94		1-9	6,330	12,052	0.0	0.0										
F2	1.0	7-94	8-94		1-11	9,967	21,729	4.7											
F3	1.0	7-94	8-94		1-11	11,248	31,313	11.2											

Notes:

(1) "Initial Period of Operation" represents period after waste placement has started and only a few lifts of waste and daily cover have been placed in the cell (i.e., no intermediate cover).

(2) "Active Period of Operation" represents period when waste thickness in cell is significant and/or an effective intermediate cover is placed on the waste.

(3) "Post Closure Period" represents period after final cover system has been placed on the entire cell.

(4) Flow rates are given in liter/hectare/day.

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Figure 2 shows LCRS and LDS average daily flow rate data for a municipal solid waste management unit, located in Pennsylvania, that was active for 56 months. Subsequently, a final cover system containing a geomembrane was placed over the entire unit. Flow data for the 56-month operational period and a 25-month post closure period were obtained and analyzed. As Figure 2 shows, flow rates in both systems were highest immediately after the start of waste placement and thereafter decreased with time. During the first twelve months of operation, the average rate of flow into the LCRS sump decreased from 12,700 to 180 lphd. After that time, the LCRS flow rate stabilized and during the following 44 months, the rate of flow into the LCRS sump varied between 10 and 170 lphd. After final closure, the flow rate decreased even further, to between 10 and 80 lphd.

As illustrated in Figure 2, waste management unit development can be divided into three distinct periods. During the first period, herein referred to as the "initial period of operation", LCRS flow rates may be relatively high. High flows during this period are attributed to the occurrence of rainfall into a unit that initially contains little waste. To the extent rainfall occurs during this period, it will find its way rapidly into the LCRS. Obviously, the amount of LCRS flow during this period is highly dependent on climate. A lag exists between the time liquid first enters the LCRS and when it flows into the LCRS sump. The magnitude of the lag is largely dependent on the hydraulic characteristics (i.e., the length and slope of the LCRS and the hydraulic conductivity of the LCRS drainage material). Most available data indicate a decreasing LCRS flow rate with time during the initial period of operation. During the second period, referred to herein as the "active period of operation", the rate of flow into the LCRS continues to decreases and eventually stabilizes. This occurs as the amount of waste in the unit increases and as daily and intermediate layers of cover soil are placed. This trend in flow rates is also dependent on the type of waste but is likely representative of the trends observed at most new landfills, excluding those that accept sludges or other high moisture content wastes. During the "post closure period", the final cover system further reduces infiltration of rainwater into the waste, resulting in a further reduction in LCRS flow. Final covers containing geomembranes can, if functioning properly, virtually eliminate rainwater infiltration.

LDS flow rates for the waste management unit in Figure 2 were highest (860 lphd) at the beginning of operations and decreased in the following few months, becoming very low (i.e., less than 10 lphd) within approximately 15 months after the start of unit operation. The decrease in LDS flow with time is expected because: (i) flow rates in the LCRS during this time period decreased, and therefore, the potential for leakage through the top liner also decreased; (ii) most construction water initially present in the LDS flowed to the LDS sump in the first few weeks to months of unit operation; and (iii) the volume of compression and consolidation water for this waste management unit should be very small.

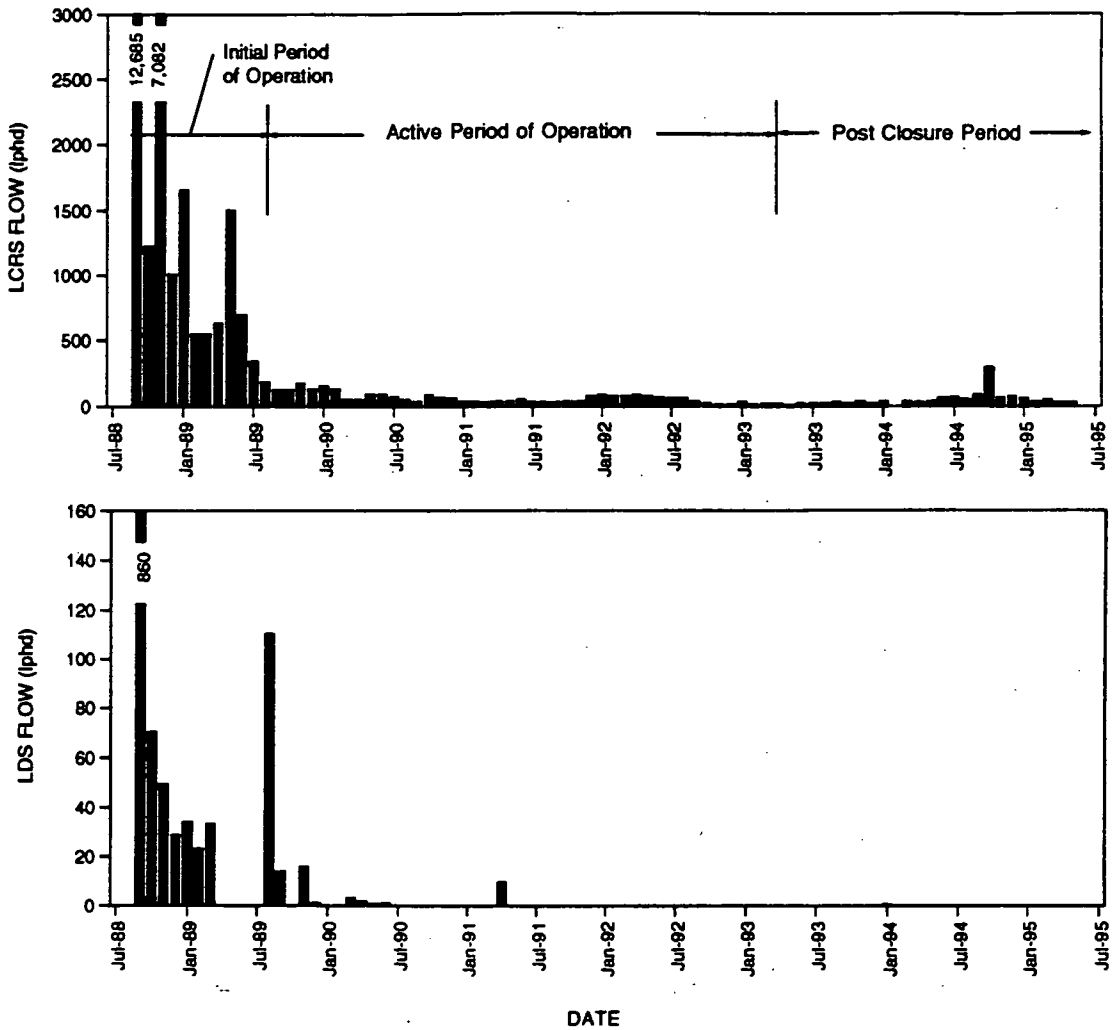

Figure 2. LCRS and LDS flow rates at a modern MSW landfill in Pennsylvania.

Table 2 summarizes LCRS and LDS flow data for the 26 waste management units containing GCLs in their composite top liners. Average and peak flow rates are reported for the three time periods described above. Table 2 shows that between the initial and active periods of operation, LCRS flow rates decreased one to two orders of magnitude and LDS flow rates decreased one to three orders of magnitude. Reported peak LCRS flow rates were up to 5 times the average, while peak LDS flow rates were up to 20 times the average. Table 3 presents the mean values of average and peak flows for the database.

Table 3. Mean values of flow for the data in Table 2 (Note: m = mean value; σ = standard deviation; values are in liter/hectare/day).

LCRS	Number of Units	Average Flow Rate		Peak Flow Rate	
		m	σ	m	σ
Initial Period of Operation	25	5,350	3,968	14,964	11,342
Active Period of Operation	18	276	165	752	590
Post-Closure Period	4	124	-	266	-

LDS	Number of Units	Average Flow Rate		Peak Flow Rate	
		m	σ	m	σ
Initial Period of Operation	26	36.6	68.5	141.8	259.9
Active Period of Operation	19	0.7	1.1	7.7	13.7
Post-Closure Period	4	0.2	-	2.3	-

Top Liner Hydraulic Efficiency

Table 4 summarizes calculated "apparent" efficiencies for the composite top liners of the 26 waste management units presented in Table 2. Liner apparent efficiency, AE, is calculated using the following equation:

AE (%) = (1 - LDS Flow Rate / LCRS Flow Rate) x 100 (Equation 1)

Table 4. "Apparent" efficiencies of composite liners containing GCLs[1].

Cells with Sand LDS				Cells with GT/GN LDS	
Cell No.	Initial Period of Operation (%)	Active Period of Operation (%)	Post-Closure Period (%)	Cell No.	Initial Period of Operation (%)
A1	100.00	100.00	100.00	D1	99.98
A2	99.90	99.33	100.00	D2	100.00
A3	98.97	98.71	99.55	E1	99.95
A4	96.01	98.75	100.00	F1	100.00
A5	97.23	97.50		F2	99.95
A6	98.58	100.00		F3	99.90
A7	99.37	99.20			
A8	99.02	100.00			
A9	99.91	100.00			
A10	100.00	100.00			
A11	100.00	100.00			
A12	100.00	100.00			
A13	100.00	100.00			
A14	100.00	100.00			
A15	100.00	100.00			
A16	100.00	100.00			
B1	94.57	99.29			
C1	97.94				
C2	91.84				
Number	19	17	4	Number	6
Range	91.84 - 100.00	97.5 - 100.00	99.55 - 100.00	Range	99.90 - 100.00
Mean	98.60	99.58	99.89	Mean	99.96
Median	99.90	100.00	100.00	Median	99.97

Notes: [1] Apparent Efficiency = (1 - LDS Flow / LCRS Flow) x 100 %

This liner efficiency is referred to as "apparent" because, as described above, flow into the LDS sump may be attributed to sources other than top liner leakage (Figure 1). If the only source of flow into the LDS sump is top liner leakage, then Equation 1 provides the "true" liner efficiency. Liner efficiency provides a measure of the effectiveness of a particular liner in limiting or preventing advective transport across the liner.

Table 4 presents calculated AE values for waste management units with sand LDSs (Landfills A, B, and C). For these units, the apparent efficiency is lowest during the initial period of operation (AE_m = 98.6 percent; where AE_m = mean apparent efficiency) and increases significantly thereafter (AE_m = 99.58 percent during the active period of operation and AE_m = 99.96 percent during the post closure period). The lower AE_m during the initial period of operation can be attributed to LDS flow from construction water. For units A, B, and C, calculated AE values during the active period of operation and the post-closure period may provide a reasonably accurate indication of true liner efficiency for the conditions at these units during the monitoring periods. It should be noted, however, that the true efficiency of a liner is not constant but rather a function of the hydraulic head in the LCRS and size of the area over which LCRS flow is occurring (the area is larger at high flow rates compared to low flow rates).

Table 4 also presents calculated AE values for waste management units with geonet LDSs (Landfills D, E, and F). The available data are limited to the initial period of unit operation. As shown in Table 4, AE_m for the six units with geonet LDSs is 99.96 percent. This value is much higher than the AE_m of liners of cells with sand LDSs for the same facility operational period (i.e., 98.60 percent). This higher efficiency can be attributed to the differences in liquid storage capacity and hydraulic transmissivity between sand and geonet drainage materials. A granular drainage layer can store a much larger volume of construction water and releases this water more slowly during the initial period of operation than does a geonet drainage layer. This suggests that, during the initial period of operation, the main source of flow in a sand LDS underlying a composite top liner containing a GCL is construction water.

Conclusions on Field Performance of Composite Liners Containing GCLs

From Table 2, LDS flows attributable to top liner leakage very from 0 to 50 lphd, with most values being less than about 2 lphd. These flow rates are very low. The data shown in Table 4 suggest that the true hydraulic efficiency of a composite liner incorporating a GCL may be greater than 99.90 percent. A liner with this efficiency, when appropriately used as part of an overall liner system, can provide a very high degree of liquid containment capability.

SHEAR STRENGTH OF HYDRATED GCLs

Overview

For a recent project, the authors were concerned with the long-term drained shear strength of hydrated GCLs at normal stresses in the range of 240 to 720 kPa. Drained shear strengths are applicable to long-term design and the range of considered normal stresses is applicable to conditions in a liner system at the base of a landfill. A testing program to evaluate the long-term drained shear strength of GCLs was undertaken and this program is ongoing. To develop interim values for preliminary design, the authors reviewed and analyzed available data from the technical literature on the consolidated-drained (CD) shear strength of GCLs. The findings of this review are presented below.

Required Deformation Rates to Achieve CD Conditions

To achieve consolidated drained (CD) test conditions, direct shear tests must be carried out at a very slow rate of shear displacement. The required displacement rate can be estimated using the well-known time-to-failure equation specified in American Society of Testing and Materials (ASTM) standard test method D 3080:

$$t_f = 50\ t_{50} \qquad \text{(Equation 2)}$$

where: t_f = total elapsed time to failure(s); and t_{50} = time required for the test specimen to achieve 50 percent primary consolidation under the specified normal stress, or increment(s) thereof. Using t_f from consolidation tests and an estimated failure displacement δ_t, the required shear displacement rate, d_r, can be calculated using the equation:

$$d_r = \delta_t / t_f \qquad \text{(Equation 3)}$$

Shan [1993] performed one-dimensional consolidation tests on the GCL products Claymax®, Gundseal®, Bentomat®, and Bentofix®. He evaluated t_f values for each product. The results of his evaluation are provided in Figure 3. With reference to this figure, at normal stresses in the range of 240 to 720 kPa, t_f values are in the range of about 100 to 400 hours. If it is assumed that a displacement of 25 mm is needed to achieve peak shear stress conditions, a required shear displacement rate of 0.05 to 0.25 mm/s is calculated. Only test results conducted at shear displacement rates that satisfy Equations 2 and 3 and the data from Shan [1993] should be considered to represent CD conditions. Test results at faster rates will yield lower shear strengths as a result of positive pore pressure development during the shearing phase of the test.

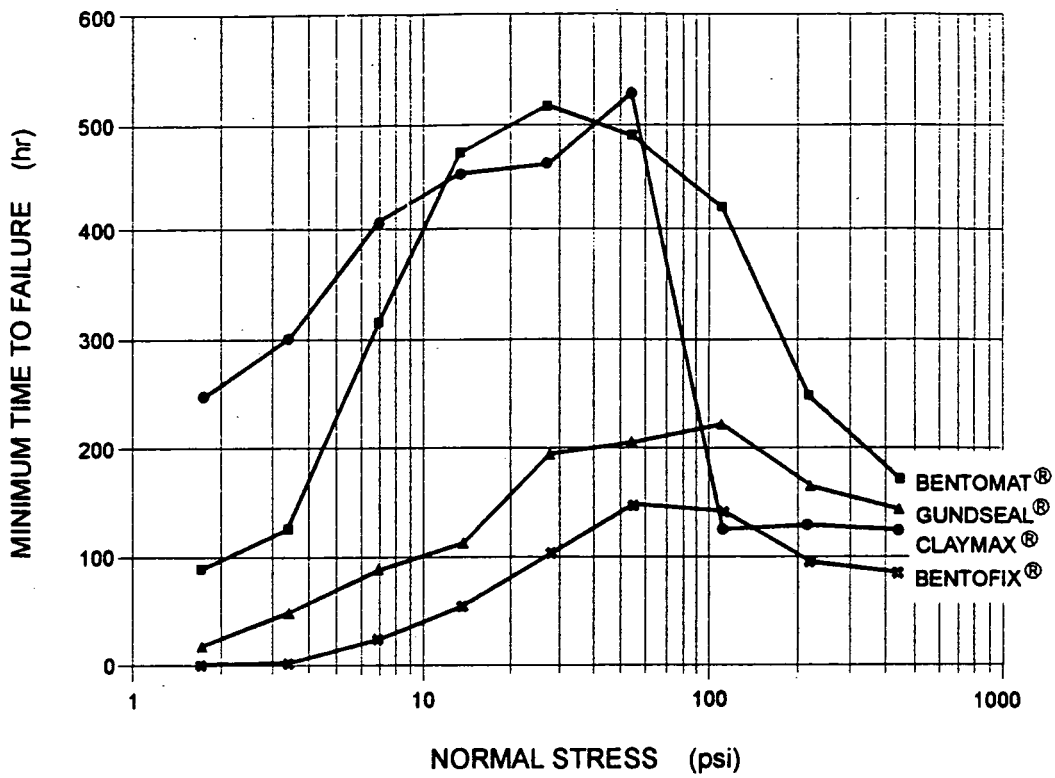

Figure 3. Relationship between time to failure of GCLs in direct shear tests and normal stress (from Shan, 1993; Note: 1 psi = 6.9 kPa).

It is noted that direct shear tests on GCLs are often performed in general accordance with the standard test method ASTM D 5321 ("*Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method*"). This method provides the following guidelines for selecting shear displacement rates for tests involving soils:

> "*11.6 Apply the shear force using a constant rate of displacement that is slow enough to dissipate soil pore pressures, as described in Method D 3080 (Note 9). If excess pore pressures are not anticipated, and in the absence of a material specification, apply the shear force at a rate of 1 mm/min (0.04 in./min).*"

The foregoing requirement calls for performing direct shear tests involving soils at a shear displacement rate in conformance with ASTM D 3080 if pore pressures are anticipated. For the soil component of GCLs (i.e., sodium montmorillonite), significant pore pressures will certainly be generated if the GCL is sheared at rates faster than those satisfying Equations 2 and 3. Interestingly, however, most test data available in the published literature were generated at the default shear displacement rate of 0.017 mm/s. Data generated at the default shear displacement rate are considered to reflect "undrained" or "partially-drained," and not "fully-drained," conditions.

Review of Available Information for Unreinforced GCLs

For purposes of shear strength characterization, two different categories of GCL can be considered: GCLs that do not contain internal reinforcement (hereafter referred to as unreinforced GCLs) and those that do (hereafter referred to as reinforced GCLs). Published information relevant to the CD shear strengths of unreinforced GCLs is very limited. The available information is summarized below.

- Daniel and Shan [1991] and Shan and Daniel [1991] reported CD direct shear test results for the GCL product Claymax®. Tests were performed using 60-mm diameter specimens and a shear deformation rate of 5 x 10^{-6} mm/s. Test results have been interpreted herein in terms of "peak (p)" and "large-displacement (ld)" normalized shear strengths. Peak displacements in these tests were 0.5 to 5 mm with the largest displacement corresponding to the lowest normal stress; the reported "ld" shear strengths correspond to shear displacements of approximately 6 to 9 mm. Results from the tests are as follows:

σ_n (kPa)	$(\tau/\sigma_n)_p$	ϕ_p	$(\tau/\sigma_n)_{ld}$	ϕ_{ld}
34	0.236	13.3°	0.236	13.3°
69	0.238	13.4°	0.209	11.8°
100	0.194	11.0°	0.165	9.4°
140	0.178	10.1°	0.137	7.8°

where: σ_n = normal stress on the shear plane at failure (kPa); τ = shear stress on the shear plane at failure (kPa); and ϕ = secant friction angle (dimensionless), calculated as the inverse tangent of τ/σ_n. It is noted that ϕ should also be interpreted as a measure of normalized shear strength and not as a "true" indication of internal friction. This data interpretation is illustrated in Figures 4 and 5.

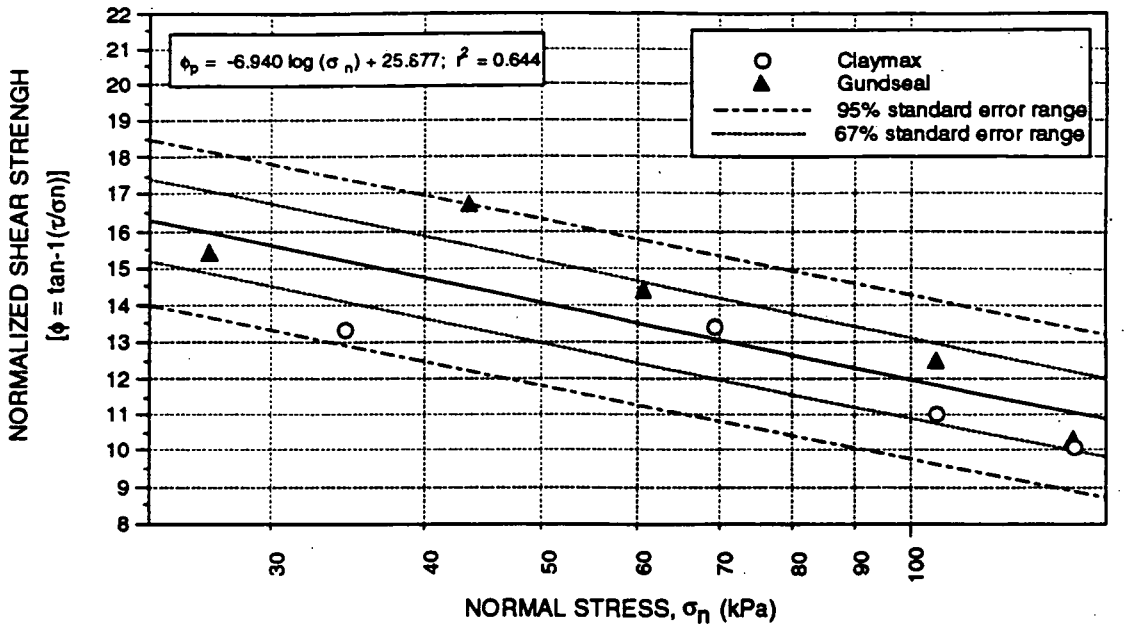

Figure 4. Log-linear regression analysis for peak CD conditions.

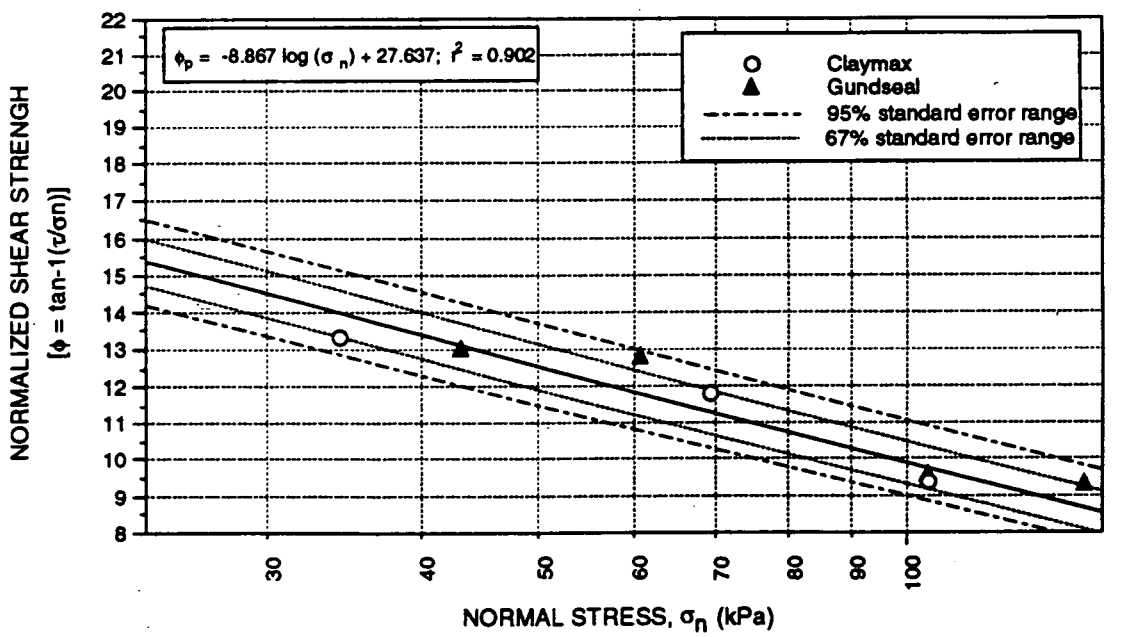

Figure 5. Log-linear regression analysis for large-displacement CD conditions.

- Daniel and Shan [1991], Daniel et al. [1993], and Shan [1993] reported direct shear CD test results for the GCL product Gundseal®. Tests were performed using 60-mm diameter specimens and a shear deformation rate of 5 x 10^{-6} mm/s. Test results have been interpreted herein in terms of peak and large-displacement normalized shear strengths. Typical peak displacements in these tests were 2 to 4 mm with the largest displacement corresponding to the lowest normal stress; the reported "ld" shear strengths correspond to shear displacements of approximately 9 to 12 mm. Results from the tests are as follows:

σ_n (kPa)	$(\tau/\sigma_n)_p$	ϕ_p	$(\tau/\sigma_n)_{ld}$	ϕ_{ld}
27	0.275	15.4°	-	-
44	0.300	16.7°	0.231	13.0°
61	0.256	14.4°	0.227	12.8°
100	0.223	12.6°	0.169	9.6°
140	0.181	10.3°	0.164	9.3°

The direct shear test results from Daniel and Shan are plotted in Figures 4 and 5 for "peak" and "large displacement" shearing conditions, respectively. Regression equations were developed to describe the test results. It is interesting to note the lesser amount of scatter in the results for the large-displacement shearing conditions compared to the peak shearing conditions.

The test results in Figures 4 and 5 only cover the stress range between 24 and 144 kPa. Even at these relatively low normal stresses, GCL CD shear strengths exhibit significant normal stress dependency. A basis is needed for extrapolating this stress dependency to higher normal stress. This basis was derived from published information from the soil mechanics literature on the shear strength of sodium montmorillonite. This information is summarized below.

- Mesri and Olson [1970] and Olson [1974] reported the results of constant rate-of-strain CD and consolidated-undrained (with pore pressure measurement) triaxial compression tests on homionic sodium montmorillonite consolidated from a slurry (Figure 6); approximate effective-stress normalized shear strengths and secant friction angles derived from the tests are as follows:

σ_n (kPa)	(τ/σ_n)	ϕ
72	0.21	12°
170	0.14	8°
340	0.10	6°
530	0.07	4°

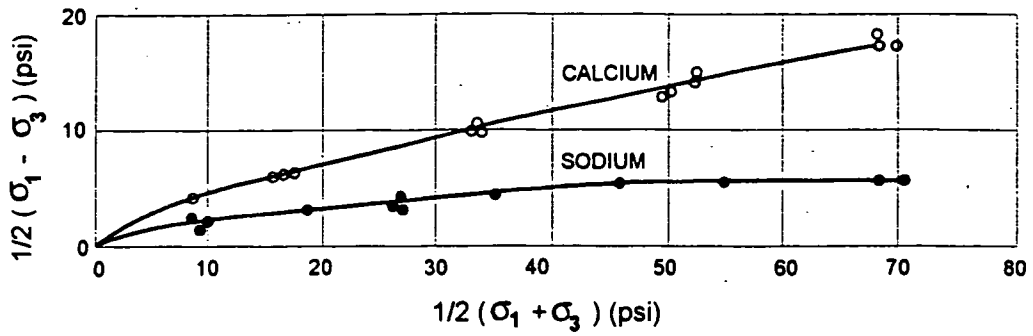

Figure 6. Effective-stress failure envelopes for calcium and sodium montmorillonite from CD and CU triaxial tests (from Mesri and Olson, 1970; Note: 1 psi = 6.9 kPa).

- Mitchell [1993] presented residual shear strength data for montmorillonite from Kenney [1967] and Chattopadhyay [1972]. Inspection of the residual shear strength data shown in Figure 7 reveals several significant points:

  - the residual friction angle exhibits significant stress dependency over a wide range of normal stress; stated differently the residual failure envelope is curved over a wide range of normal stress;

  - there may exist a normal stress above which the residual friction angle is independent of normal stress; based on Figure 7, this normal stress may be on the order of 480 kPa for sodium montmorillonite; and

  - the residual friction angle of montmorillonite is dependent on the dominant exchangeable cation and the soil pore chemistry; the smallest measured residual friction angle given in Figure 7 is 3° for homionic sodium montmorillonite in distilled water.

The GCL regression lines from Figures 4 and 5 are plotted along with the Mesri and Olson [1970] data in Figure 8. Reasonable agreement is observed between the Mesri and Olson data and the extrapolated regression lines for the unreinforced GCL. Also shown on this figure are the residual shear strengths for sodium montmorillonite developed by Kenney [1967] and Chattopadhyay [1972] as reported by Mitchell [1993]. These latter results further support the extrapolations presented in Figure 8.

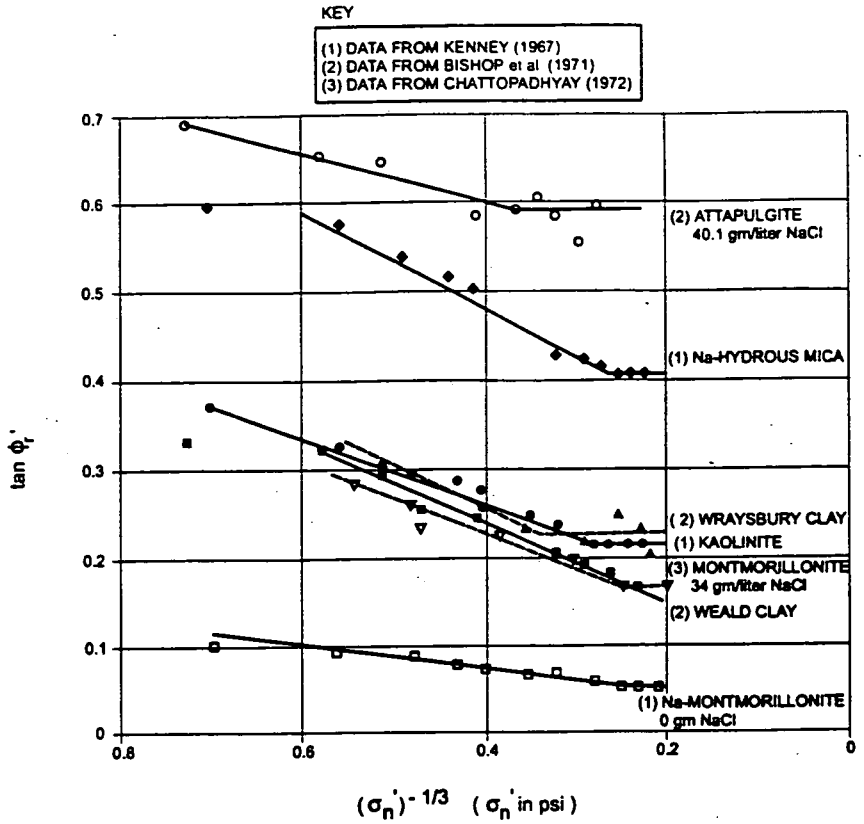

Figure 7. Residual effective-stress friction angles for clay minerals (from Mitchell, 1993; Note: 1 psi = 6.9 kPa).

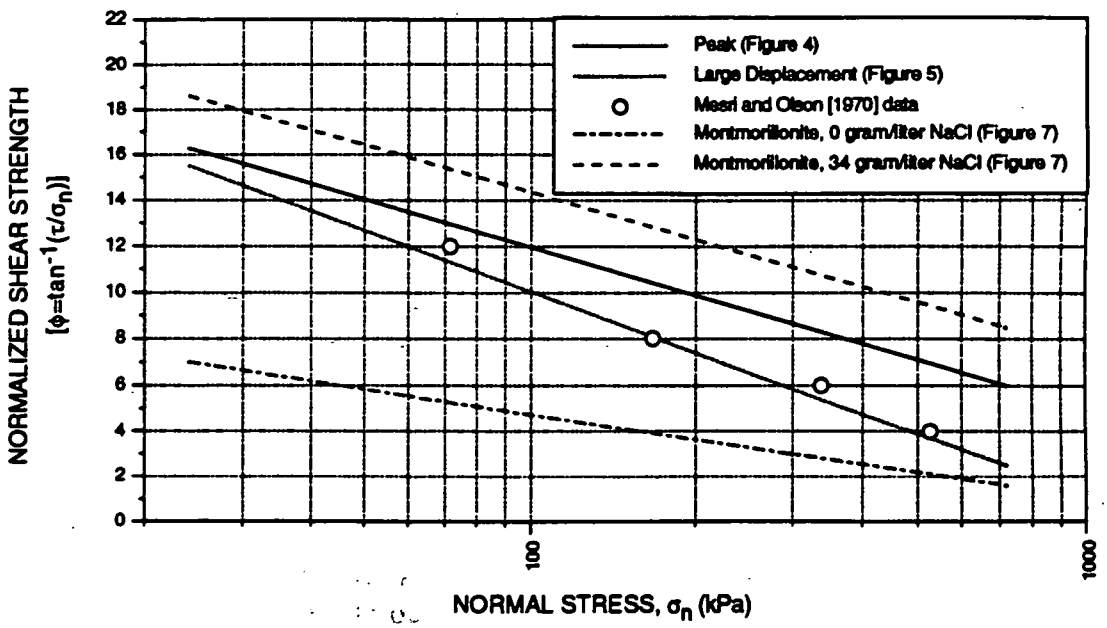

Figure 8. Comparison on montmorillonite shear strength data and GCL log-linear regression lines.

Review of Available Information for Reinforced GCLs

The authors were unable to find any information in the published technical literature on the CD shear strengths of reinforced GCLs at high normal stress. A few CD tests performed at low normal stress have been reported by Daniel and Shan [1991] for the product Bentomat®. These results cannot be extrapolated to higher normal stress, however, due to the current limited understanding of the effect of reinforcing fibers on the shear displacement-shear resistance-normal stress relationship for this type of material.

The authors have performed a limited number of consolidated-quick (CQ) direct shear tests on reinforced GCLs at normal stresses in the range of interest. Quick tests were performed at a displacement rate of 0.016 mm/s. While not "truly undrained" due to the lack of boundary drainage control in the direct shear test, the specimens in these tests will only undergo very limited pore pressure dissipation during the shear phase of the test due to the high rate of shear displacement. Due to these pore pressures, CQ tests at a given consolidation stress will result in lower GCL shear strengths than obtained from true CD tests at the same normal stress. CQ tests may therefore be considered to provide a lower bound of the CD shear strength of reinforced GCLs.

The results of the CQ direct shear tests on reinforced GCLs indicate relatively high peak shear strengths followed by a significant degree of shear softening (i.e., post peak decrease in shearing resistance). A typical test result is illustrated in Figure 9. Normalized peak and large displacement shear strengths, and the ratio of the two (ψ) for a normal stress of 480 kPa are given below:

	ϕ_p	ϕ_{ld}	τ_{ld}/τ_p
Bentomat®	29°	10°(↓)	0.32
Bentofix®	31°	16°(↓)	0.48
Claymax® 500SP	13°	6°(↓)	0.45

In the above table the downward arrow (↓) indicates that the GCL shearing resistance was decreasing at the end of the test (i.e., at a shear displacement of 40 to 50 mm). The ψ values reported above are low, generally in the range of 0.3 to 0.5. In contrast, ψ values for the CD direct shear tests on unreinforced GCLs were higher, typically in the range of 0.7 to 1.0. The ϕ_{ld} values reported above are somewhat larger than those obtained for the unreinforced GCLs. However, as noted above, observation of the shear force-displacement plots for the tests indicates that the shear stresses applied to the sample were decreasing at the ends of the tests, which typically occurred at a displacement of 40 to 50 mm. This observation, coupled with observations of the tested samples, that the GCL reinforcing fibers and stitching were still partially intact at the time the test was terminated, suggests that residual CD and CQ shear strengths of reinforced

GCLs may not be much larger than those of unreinforced GCLs. Clearly, testing is required to establish the large-displacement, high normal stress behavior of these materials, and to identify differences in product behavior based on differences in montmorillonite properties and reinforcing characteristics.

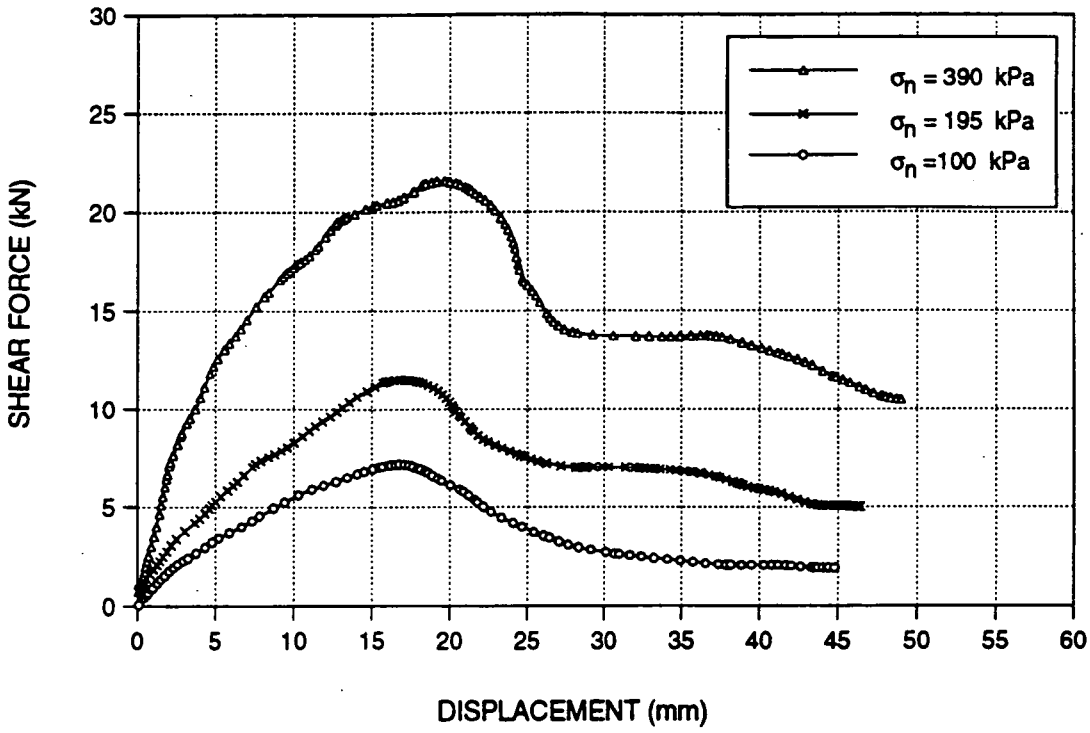

Figure 9. Results of CQ direct shear tests on reinforced Bentofix GCL.

Interim Design Values

Unreinforced GCLs: Based on the information presented in Figure 8, the authors used the following interim guidelines for performing liner system stability analyses for long-term drained conditions, for potential slip surfaces that involve internal shearing of unreinforced GCLs. These guidelines further assume that the GCL will hydrate through adsorption of water from an adjacent subgrade soil layer.

- Slope stability analyses are performed using: (i) peak internal GCL shear strengths and a minimum slope-stability factor of safety of 1.5; and (ii) large-displacement internal GCL shear strengths and a minimum slope-stability factor of safety of 1.15.

- Using the regression equation presented in Figure 4, peak normalized shear strengths are:

σ_n (kPa)	$(\tau/\sigma_n)_p$	ϕ_p
96	0.214	12.1°
240	0.157	8.9°
480	0.114	6.5°
720	0.106	6.1°

- Using the regression equation presented in Figure 5, large-displacement normalized shear strengths are:

σ_n (kPa)	$(\tau/\sigma_n)_{ld}$	ϕ_{ld}
96	0.178	10.1°
240	0.116	6.6°
480	0.070	4.0°
720	0.052	3.0°

For the large displacement strengths, a minimum friction angle cutoff of 3° was assumed based on the test results reported by Mitchell [1993], presented in Figure 7.

The normalized shear strengths given above are relatively low, and their use may be viewed by some as overconservative. This view should be tempered with the realization that the large-displacement GCL shear strengths reported in the technical literature do not represent true residual minimums (due to the limited displacement of the direct shear apparatus) and no allowance has been made for the possible effects of drained creep of the GCL under working stress conditions. Furthermore, the available CD direct shear test results for unreinforced GCLs correlate well with the triaxial compression test results for sodium montmorillonite from Mesri and Olson [1970] and Olson [1974] (Figure 6). Finally, it is noted that the foregoing approach, which utilizes a smaller slope stability factor of safety with the large displacement shear strengths than the factor of safety used with the peak shear strengths, is similar to the approaches advocated by Byrne [1994] and Stark and Poeppel [1994].

Reinforced GCLs: Recognizing the lack of data on the CD strength of reinforced GCLs at high normal stress, the complex behavior and high degree of shear-softening exhibited by these products, the authors utilized the same factors of safety and GCL long-term shear strengths for reinforced GCLs as for unreinforced GCLs. It is recognized that this assumption is conservative. However, given the limitations with respect to the available reinforced GCL test data (e.g., the technical literature does not contain any "true" CD direct shear test

results for reinforced GCLs at high normal stress) and the other factors discussed above, the authors believe the assumption was prudent.

SHEAR STRENGTH OF GCL-GEOMEMBRANE INTERFACES

Direct Shear Testing Program

For a project located in the desert of southeastern California, the authors performed 14 interface direct shear tests on unhydrated GCL-textured HDPE geomembrane interfaces. The tests were performed in a 300 mm x 300 mm shear box following procedures in general accordance with ASTM D 5321. Three different GCLs were tested. The geomembrane used in the tests was from a single roll of material and samples were selected based on visual observation of a consistent degree of texturing. The tests were carried out in a manner that allowed shearing either at the GCL interface or internally within the GCL bentonite layer. Tests were carried out at normal stresses ranging between approximately 350 and 1,920 kPa. Sliding in the tests consistently occurred at the interface and not within the GCL. Thus, the test results correlate to interface failures and at the same time provide conservative lower bound unhydrated shear strengths for the tested GCLs under the project testing conditions.

Typical test results are presented in Figure 10 and summarized in Table 5. The tests correspond to two shearing rates, namely 0.016 mm/s and 0.0007 mm/s. Interface friction angles obtained from the tests at the slower shearing rate are 1° to 2° lower than interface friction angles obtained from tests at the higher shearing rate. The test results also reveal an interface shear strength stress-dependency with secant interface friction angles 5° to 10° lower at 1,920 kPa than at 350 kPa. The interfaces exhibited only minor amounts of shear softening (typically less than 1 to 2°) at test displacements of up to about 50 mm.

Comment on Results

The foregoing interface direct shear test results illustrate the ranges of shear strengths obtained and several of the factors that affect this strength including normal stress, displacement rate, and magnitude of displacement.

The authors note that they have observed relatively wide variances in the degree of texturing of geomembranes, even from a given manufacturer. The degree of texturing significantly influences the interface shear strength. Thus, the strength values reported above should not be considered appropriate for design. Interface shear strengths for design should be established on a project-specific basis and construction-phase quality control testing should be used to establish that materials delivered to the construction site can achieve the interface strengths established during design.

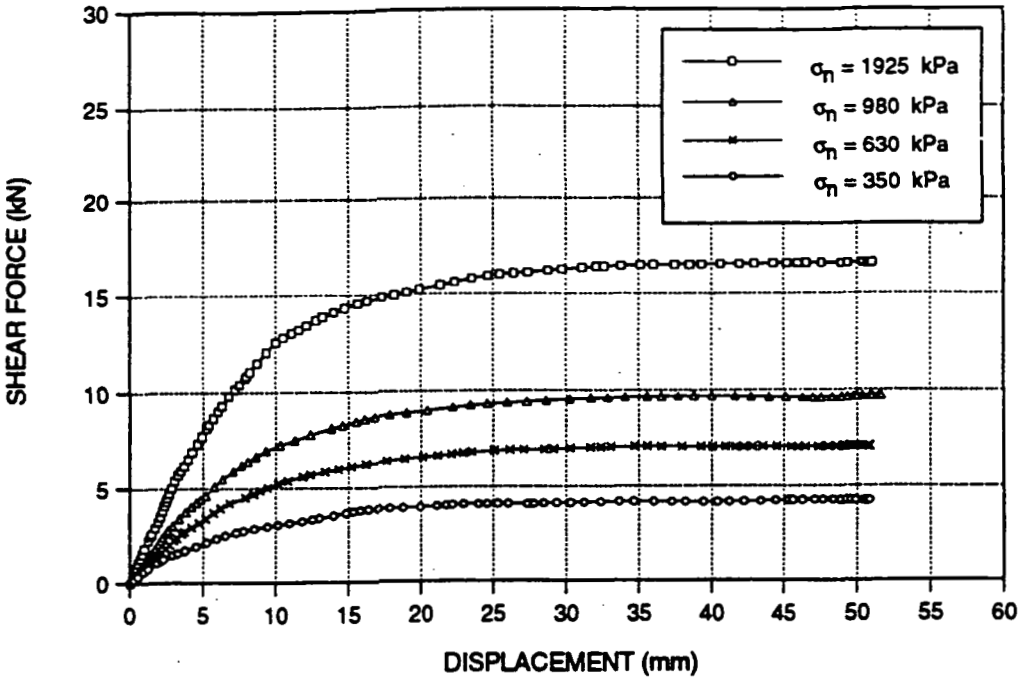

Figure 10. Results of direct shear tests on unhydrated Bentofix GCL-textured HDPE geomembrane interface.

HYDRATION OF GCLs ADJACENT TO SOIL LAYERS

Overview of Testing Program

The authors conducted an extensive laboratory testing program to evaluate the potential for hydration of GCLs placed against a compacted subgrade soil layer. Hydration tests were performed on three different GCL products to evaluate the effects of: (i) test duration (i.e., hydration time); (ii) soil initial water content; (iii) thickness of soil layer; and (iv) overburden pressure. Three commercially-available GCL products, namely, Claymax®, Bentomat®, and Bentofix® were used in the testing program. The soil used in the testing program was obtained from the USEPA GCL Field Test Site at the ELDA-RDF facility in Cincinnati, Ohio. This material is classified as low plasticity clay (CL) based on the Unified Soil Classification System (USCS). Tests were performed on two different soil samples and consistent results were obtained between samples. The results reported herein were obtained from tests on a sample with 99 percent of the soil passing the U.S. No. 200 standard sieve and 33 percent smaller than 2 μm (clay fraction). The liquid limit of the soil is 41 and the plasticity index is 19. The soil has an optimum moisture content (OMC) of 20 percent and a maximum dry unit weight of 16.7 kN/m^3 based on the standard Proctor compaction method (ASTM D 698).

Table 5. Direct shear test results of textured 80-mil HDPE geomembrane/unhydrated GCL interfaces[1].

Test Number	Type of GCL	Normal Stress (kPa)	Displacement Rate (mm/s)	Large Displacement Secant Friction Angle[2] (ϕ_{ld}°)
1	Bentomat GCL (nonwoven side)	350	0.016	24°
2	Bentomat GCL (nonwoven side)	620	0.016	24°
3	Bentomat GCL (nonwoven side)	960	0.016	23°
4	Bentomat GCL (nonwoven side)	960	0.0007	22°
5	Bentomat GCL (nonwoven side)	1,920	0.016	19°
6	Bentomat GCL (nonwoven side)	1,920	0.0007	17°
7	Bentofix GCL (nonwoven side)	350	0.016	28°
8	Bentofix GCL (nonwoven side)	620	0.016	26°
9	Bentofix GCL (nonwoven side)	960	0.016	23°
10	Bentofix GCL (nonwoven side)	1,920	0.016	21°
11	Gundseal GCL (bentonite granules side)	350	0.016	34°
12	Gundseal GCL (bentonite granules side)	620	0.016	29°
13	Gundseal GCL (bentonite granules side)	960	0.016	27°
14	Gundseal GCL (bentonite granules side)	1,920	0.016	24°

Notes:
(1) The tests were performed using unhydrated GCLs and in a manner that allowed shearing at the geomembrane/GCL interface, as well as within the GCL bentonite layer.
(2) Final displacements in the tests were in the range of 25 to 50 mm.

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Testing Apparatus and Procedure

Figure 11 shows the apparatus specially designed to conduct the GCL hydration tests. The apparatus consists of a polypropylene mold 75 mm in diameter and 150 mm in height. A geomembrane/GCL/soil composite specimen is placed in the mold and covered with two layers of a thin vapor barrier. A loading platen is placed on the specimen for application of overburden pressure.

To process the soil, it was first passed through a U.S. No. 4 standard sieve. The soil was then moisture conditioned to achieve the desired moisture content. The moist soil was placed in the mold in a loose condition and statically compressed to 50-mm thick lifts. The soil was compacted to a dry unit weight equal to approximately 90 percent of the maximum dry unit weight based on the standard Proctor method (ASTM D 698). Two soil lifts were used giving a total thickness of 100 mm. The GCL and geomembrane specimens were carefully trimmed from the same sheets. The initial moisture content of the GCL was measured by taking a small sample from the same GCL sheet and measuring its weight before and after oven drying. The initial moisture content of the GCLs varied between 15 and 20 percent.

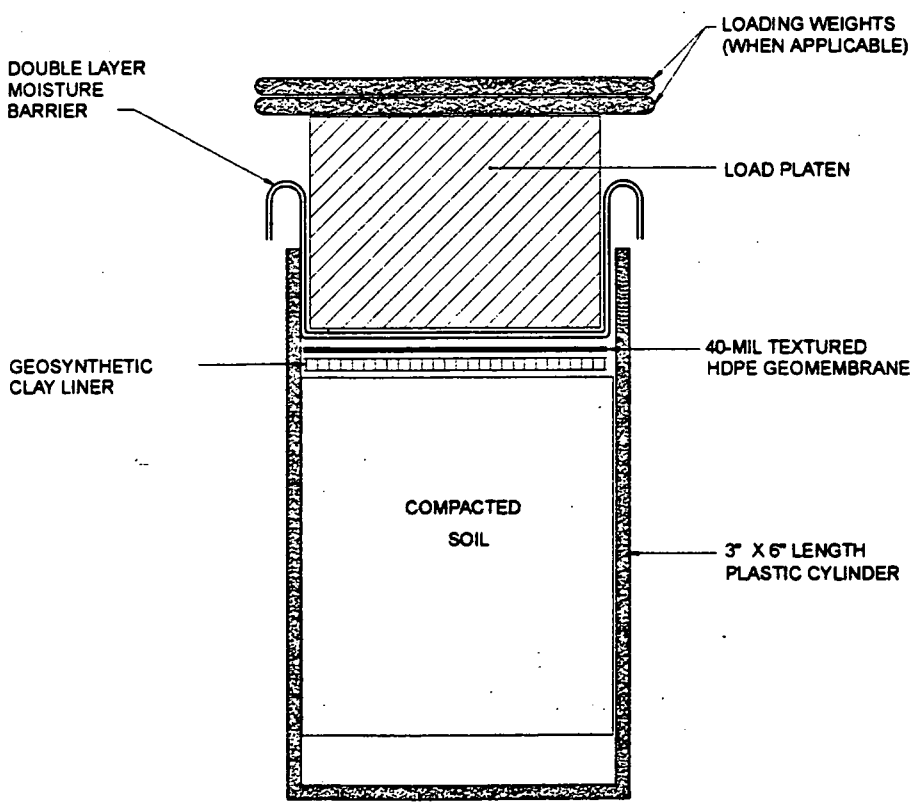

Figure 11. Simplified diagram of GCL hydration test set-up.

The GCL and geomembrane were placed on the soil and covered with the vapor barrier. The side of the GCL placed against the soil was woven in the case of Claymax® and nonwoven for Bentomat® and Bentofix®. Overburden pressure of 10 kPa was applied on the composite specimen utilizing standard weights which were placed on the loading platen. The entire apparatus was then placed in a temperature and humidity controlled room for the desired hydration time period. At the end of the hydration period, the test specimen was removed and the water content of the GCL and soil were measured. The final moisture content of the GCL was measured by weighing the entire GCL specimen before and after oven drying. The final moisture content of the soil was measured as the average water content of three samples obtained from the top, middle, and bottom of the soil specimen.

Testing Conditions and Results

As previously described, test conditions were varied to evaluate the effects of several factors on the hydration of GCLs. To evaluate the effect of test duration, tests were performed where the GCL was in contact with the soil for 5, 25, and 75 days. Soil specimens were compacted to initial moisture contents equal to OMC, 4 percentage points dry of OMC, and 4 percentage points wet of OMC to evaluate the effect of soil initial moisture content on GCL hydration.

Figures 12, 13, and 14 present the results of the hydration tests for the GCL products Claymax®, Bentomat®, and Bentofix®, respectively. These figures show that the moisture content of all three GCLs increased significantly as a result of contact with compacted subgrade soil. The increase in GCL water content was significant after only five days of hydration. With increasing time, GCL water content continued to increase at a decreasing rate. For most tests, GCL water content reached a maximum value after about 25 days of soil contact and for some of the tests water content continued to increase even after 75 days of hydration. It is interesting to note that all three GCL products showed relatively similar behavior. Increases in water content were comparable for the three GCL products despite differences in GCL fabric (i.e., woven vs. nonwoven) and types of bentonite clay used to manufacture the GCLs.

Figures 12, 13, and 14 illustrate the influence of soil subgrade initial moisture content on the hydration of GCLs. From these figures, it is evident that the moisture content of the GCL for any particular hydration time increases as the initial moisture content of the soil increases. These figures also show that a small increase in soil initial moisture content can have a significant impact on GCL moisture content. For example, after 75 days of hydration, the moisture content of Claymax® was approximately 16 percent higher when the initial moisture content of the soil was equal to OMC than when it was 4 percentage points drier than OMC. This behavior is expected because more water is available in the soil for the GCL to hydrate.

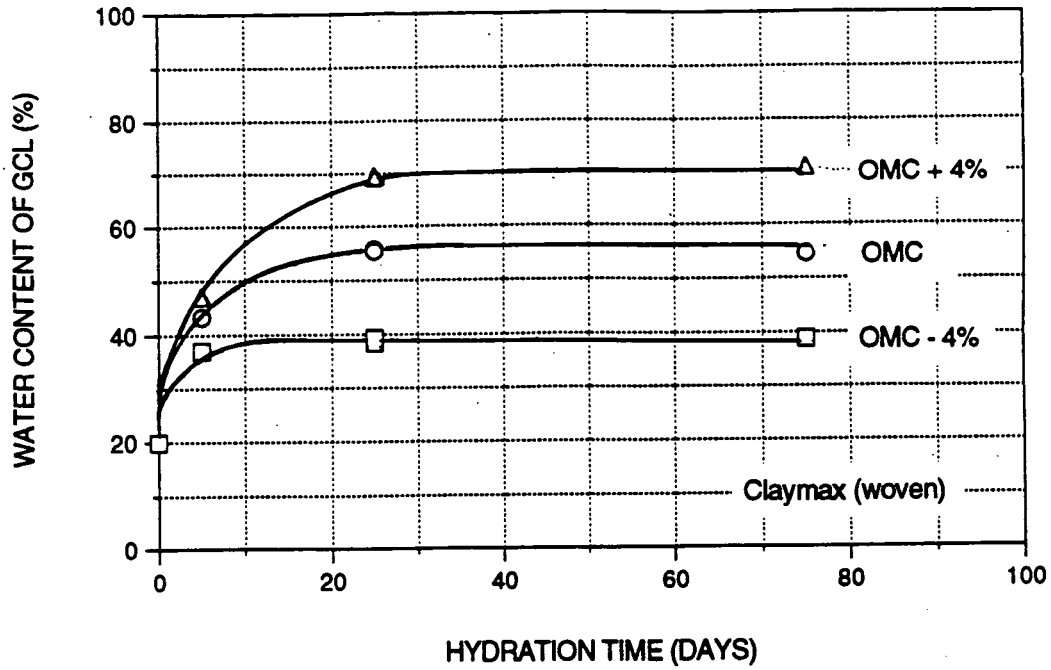

Figure 12. Increase in GCL moisture content due to contact with compacted subgrade soil: Claymax® with woven geotextile against soil.

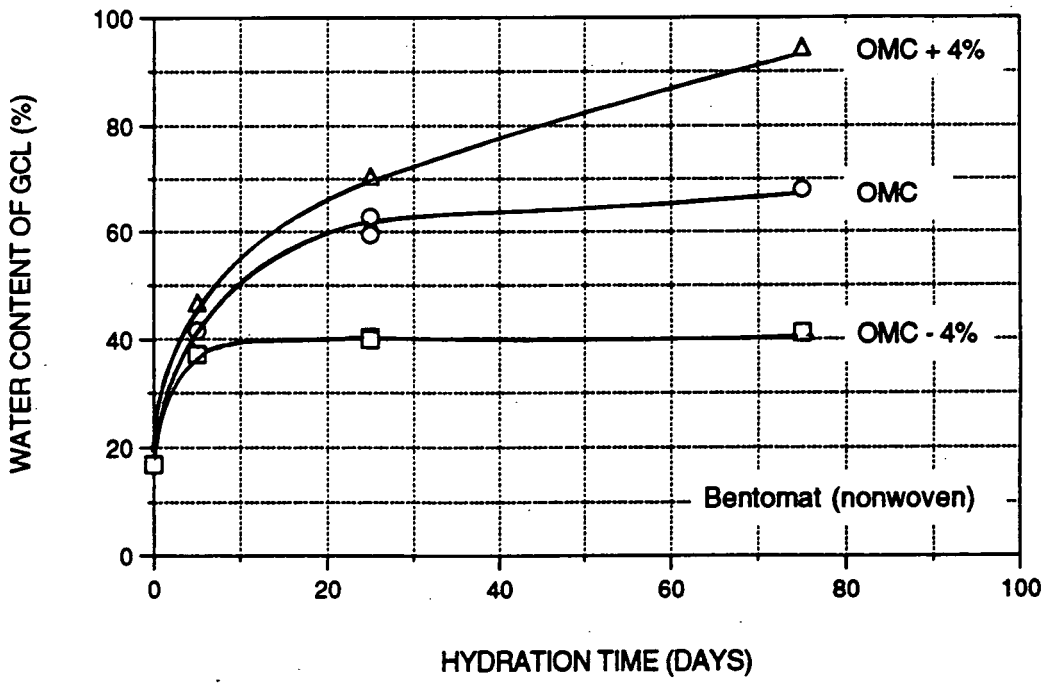

Figure 13. Increase in GCL moisture content due to contact with compacted subgrade soil: Bentomat® with nonwoven geotextile against soil.

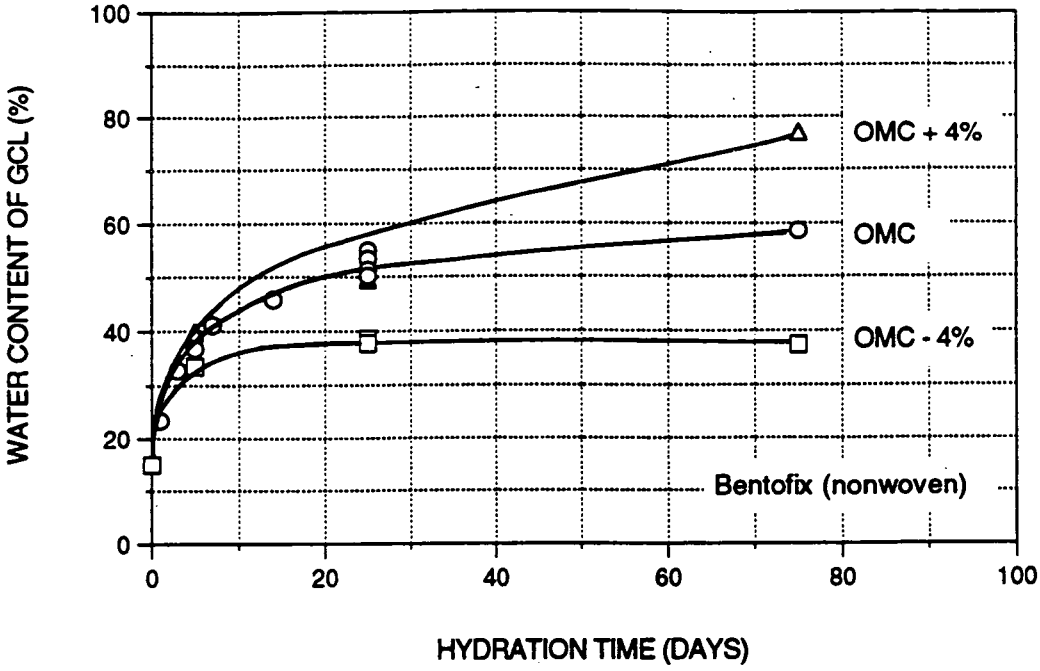

Figure 14. Increase in GCL moisture content due to contact with compacted subgrade soil: Bentofix® with nonwoven geotextile against soil.

The examination of the curves shown in Figures 12, 13, and 14 shows that the time required for the GCL to reach its final moisture content is less in the case of a dry soil than in the case of a wet soil. At the lowest soil initial moisture content tested, GCL moisture content ceased to increase after about 5 to 25 days. At the highest initial moisture content tested, the Bentomat® and Bentofix® GCLs continued to increase in moisture content after 75 days of hydration.

To evaluate the effect of soil layer thickness, specimens were prepared using 50, 100, 150, and 200 mm of soil thickness. Soil initial moisture content was 20 percent and dry unit weight was 14.9 kN/m^3 for all specimens. Figure 15 shows the results of hydration tests for the Bentofix® GCL after 25 days of hydration. The GCL moisture content increased with the increase of the soil layer thickness. However, it appears that only a small change in moisture content increase occurs for thicknesses greater than 100 mm.

The effect of overburden pressure on GCL hydration is illustrated in Figure 16 for the Bentofix® GCL. As shown in this figure, overburden pressure in the range of 5 to 390 kPa did not significantly affect the rate of GCL hydration during the 25-day test duration.

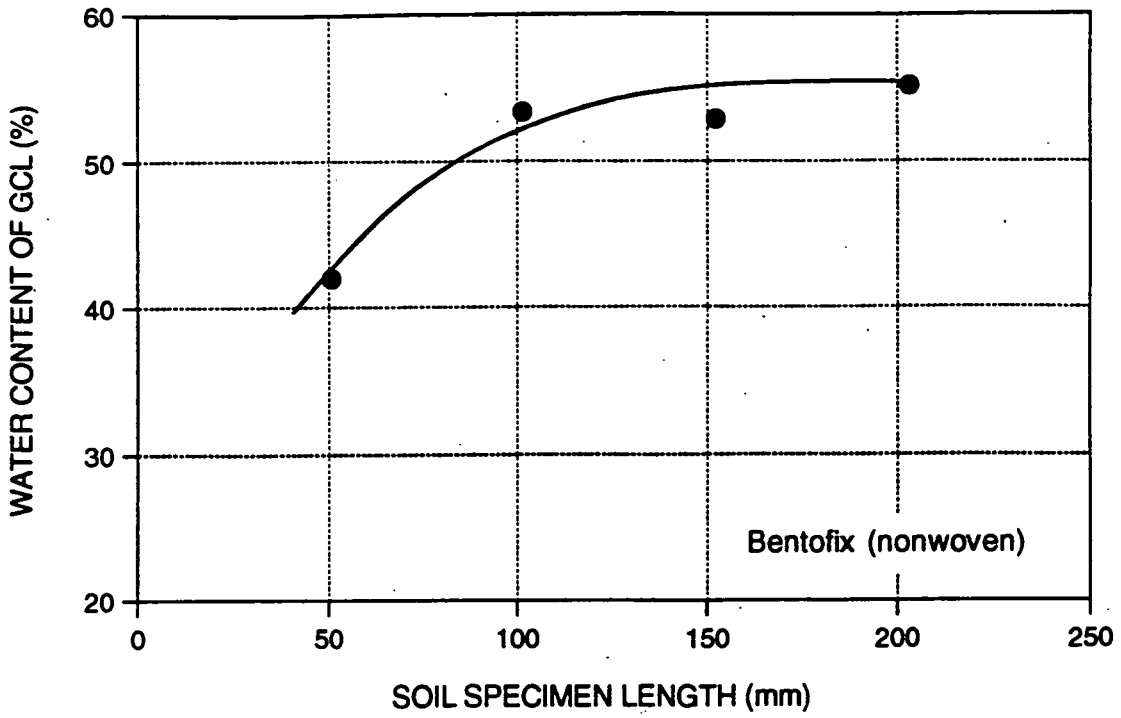

Figure 15. Influence of subgrade soil layer thickness on GCL moisture content.

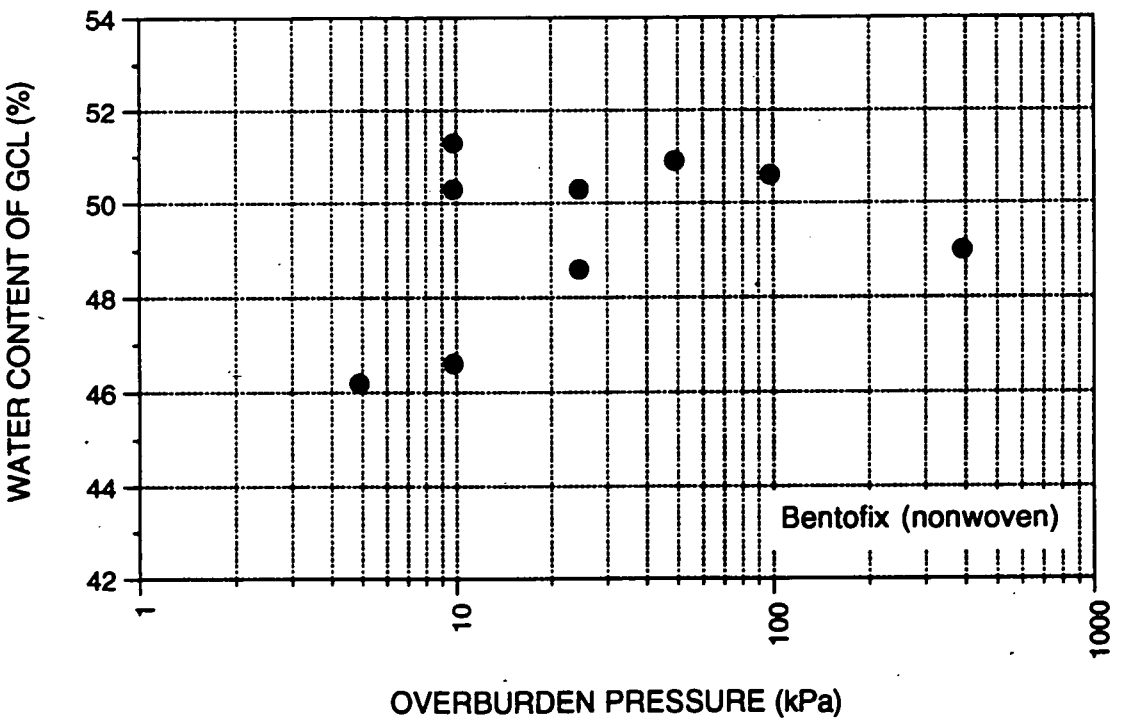

Figure 16. Influence of overburden pressure on the increase in GCL moisture content.

Summary

From the testing program results described above, the following can be concluded:

- GCLs will hydrate when placed in contact with subgrade soils compacted within the range of moisture contents typically found in earthwork construction specifications; this conclusion is consistent with data provided by Daniel et al. [1993]; even for the driest soil (compacted 4 percentage points dry of OMC), GCL moisture contents consistently increased from an initial value in the range of 15 to 20 percent up to about 40 percent within a 100-day period; it should thus be anticipated that GCLs placed even against relatively dry compacted subgrades will undergo substantial hydration;

- given that Daniel et al. [1993] have shown that long-term GCL shear strengths are insensitive to water content for water contents above about 50 percent, stability analyses involving GCLs placed in contact with compacted subgrade soils should be based on hydrated GCL shear strengths;

- significant increases in GCL moisture contents may occur within a few days of GCL contact with a moist soil; the rate of GCL hydration is initially highest and then decreases with increasing time;

- within the range of conditions tested a higher soil moisture content results in a higher GCL moisture content;

- larger soil layer thickness results in a larger increase in GCL moisture content, however, for soil layer thicknesses greater than 100 mm only insignificant increases were observed with increasing soil layer thickness;

- overburden pressure within the range tested (i.e., 5 to 390 kPa) did not influence the hydration process; and

- differences between GCL products tested (i.e., type of bentonite clay and fabric) did not seem to significantly affect the test results.

FAILURE OF LANDFILL COVER SYSTEM CONTAINING A GCL

Description of Cover System

The authors recently investigated the failure of a cover system for a municipal solid waste landfill near Atlanta, Georgia. The failure is described in more detail by Vander Linde et al. [1995]. The cover system was constructed in the fall of 1994 on 3H:1V (horizontal:vertical) side slopes to a maximum height above surrounding ground of approximately 18 m. The cover system consisted of, from top to bottom:

- 300-mm thick layer of final cover soil which is classified as silty sand containing approximately 40 percent fines based on ASTM D 2487, and which has a hydraulic conductivity in the range of 10^{-4} to 10^{-3} cm/s;
- stitch-bonded reinforced GCL; and
- 150- to 300-mm thick layer of intermediate cover soil which served as a foundation for the overlying final cover components.

Failure of System

During the winter of 1995, the cover system experienced several episodes of downslope movement. The first major episode occurred approximately one month after the completion of construction; the movement occurred after a three-day period in which 58 mm of rain fell at the site. The next major episode occurred six weeks later, after two days of inclement weather generated about 41 mm of rainfall at the site. Total downslope movements exceeded 1 m at some locations. The observed failure mechanism was sliding of the final cover soil on top of the GCL.

Analysis of Failure

The episodes of downslope movement both followed periods of extended rainfall at the site. A slope stability back-analysis of the cover system was performed which accounted for the influence of rainfall-induced seepage forces on cover system factor of safety against downslope sliding. The back-analysis involved two steps:

- estimating seepage forces within the cover soil using several different calculation methods and parameter values; and
- calculating the resulting slope stability factors of safety for the range of estimated seepage forces.

The evaluation of seepage forces involved calculating the water build-up (i.e., hydraulic head) within the final cover soil on top of the GCL. Head was calculated using a methodology developed by Giroud and Houlihan [1995] and checked using the United States Environmental Protection Agency (USEPA) Hydrologic Evaluation of Landfill Performance (HELP) computer program Version 3.03 [USEPA, 1994a, 1994b]. The values of head calculated using these approaches ranged from 150 mm to the full thickness of the cover soil layer, 300 mm.

Calculations to obtain slope stability factors of safety were performed using the equations presented by Giroud et al. [1995a, 1995b]. An important input to the equations is the shear strength of the interface between the cover soil and GCL. Tests to evaluate the shear strength of this interface had not been carried out as part of the original design. For the back-analysis of the failure, a range of friction angles (20° to 26°) was considered for the cover soil-GCL interface; this range likely brackets the actual interface strength and includes the value of 24° originally assumed by the design engineer. Calculations were performed and the following results were obtained:

Interface Friction Angle (degrees)	Factor of Safety (FS) vs. Hydraulic Head 0 mm	100 mm	200 mm
20°	1.09	0.84	0.60
24°	1.35	1.04	0.73
26°	1.47	1.13	0.80

These calculation results demonstrate the significant impact of seepage forces on the stability of the final cover soil. Even with the largest assumed interface strength, only 140 mm of head buildup is required to decrease the slope stability factor of safety to less than 1.0. Interface shear strength tests performed after the completion of the back analyses resulted in peak and large-displacement secant friction angles for the GCL-cover soil interface, at the applicable normal stress, of 23° and 21°, respectively.

Summary

The primary factor contributing to the observed final cover soil movements was the build-up of seepage forces in the final cover soil during periods of heavy rain. Seepage forces were not accounted for in the design. If seepage forces had been accounted for, the potential for instability likely would have been identified during preparation of the design. The development of seepage forces in cover soils is typically minimized by the inclusion of a drainage layer above the low-permeability barrier component of the cover (in this case, the GCL). A secondary factor contributing to the movements was a final cover soil-GCL interface shear strength lower than assumed in the design. An interface friction

angle of 24° was assumed by the design engineer, based on information provided by the GCL manufacturer. The actual project-specific interface shear strength was closer to 21°. This result highlights the fact that actual interface strengths can only be assessed by project-specific testing; such testing was not performed for the project.

ACKNOWLEDGEMENTS

The authors would like to thank Mr. Robert R. Landreth and Mr. David A. Carson of the U.S. Environmental Protection Agency, Risk Reduction Research Laboratory for their support in the evaluation of double-liner system performance.

REFERENCES

Bonaparte, R. and Gross, B.A., "Field Behavior of Double-Liner Systems" *Proceedings of the Symposium on Waste Containment Systems, ASCE Geotechnical Special Publication No. 26*, San Francisco, CA, 1990, pp. 52-83.

Bonaparte, R. and Gross, B.A., "LDCRS Flow from Double-Lined Landfills and Surface Impoundments", *EPA/600/SR-93/070*, U.S. Environmental Protection Agency, Risk Reduction Research Laboratory, Cincinnati, OH, 1993, 65 p.

Byrne, J., "Design Issues with Strain-Softening Interfaces in Landfill Liners", *Proceedings, Waste Tech '94*, National Waste Management Association, Charleston, SC, Jan 1994, 26 p.

Chattopadhyay, P.K., "*Residual Shear Strength of Pure Clay Minerals*", Ph.D. Dissertation, University of Alberta, Edmonton, Canada, 1972.

Daniel, D.E. and Shan, H-Y., "*Results of Direct Shear Tests on Hydrated Bentonitic Blankets*", University of Texas, Geotechnical Engineering Center, 1991, 13 p.

Daniel, D.E., Shan, H-Y., and Anderson, J.D., "Effects of Partial Wetting on the Performance of the Bentonite Component of a Geosynthetic Clay Liner, *Proceedings, Geosynthetics '93 Conference*, Vol. 3, Vancouver, Feb 1993, pp. 1483-1496.

Giroud, J.P. and Houlihan, M.F., "Design of Leachate Collection Layers", *Proceedings of the Fifth International Landfill Symposium*, Vol. 2, Sardinia, Oct 1995, pp. 613-640.

Giroud, J.P., Williams, N.D., and Pelte, T., "Stability of Geosynthetic-Soil Layered Systems on Slopes", *Geosynthetics International*, Vol. 2, No. 6, 1995a, pp. 1115-1148.

Giroud, J.P., Bachus, R.C., and Bonaparte, R., "Influence of Water Flow on the Stability of Geosynthetic-Soil Layered Systems on Slopes", *Geosynthetics International*, Vol. 2, No. 6, 1995b, pp. 1149-1180.

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*, Vol. 2, The Hague, Jun 1990, pp. 481-486.

Kenney, T.C., "The Influence of Mineralogic Composition on the Residual Shear Strength of Natural Soils", *Proceedings of the Oslo Geotechnical Conference on the Shear Strength Properties of Natural Soils and Rocks*, Vol. 1, 1967, pp. 123-129.

Mesri, G. and Olson, R.E., "Shear Strength of Montmorillonite", *Geotechnique*, Vol. 20, No. 3, 1970, pp. 261-270.

Mitchell, J.K., "*Fundamentals of Soil Behavior*", 2nd Edition, John Wiley & Sons, Inc., New York, NY, 1993, 437 p.

Olson, R.E., "Shearing Strengths of Kaolinite, Illite, and Montmorillonite", *Journal of the Geotechnical Engineering Division*, ASCE, Vol. 100, No. GT11, 1974, pp. 1215-1229.

Shan, H-Y, "*Stability of Final Covers Placed on Slopes Containing Geosynthetic Clay Liners*", Ph.D. Dissertation, University of Texas, Austin, TX, 1993, 296 p.

Shan, H-Y. and Daniel, D.E., "Results of Laboratory Tests on a Geotextile/Bentonite Liner Material", Vol. 2, *Proceedings, Geosynthetics '91 Conference*, Atlanta, GA, Feb 1991, pp. 517-535.

Stark, T.D. and Poeppel, A.R., "Landfill Liner Interface Strengths from Torsional-Ring-Shear Tests", *Journal of Geotechnical Engineering*, ASCE, Vol. 120, No. 3, 1994, pp. 597-615.

USEPA, "*The Hydrologic Evaluation of Landfill Performance (HELP) Model, User's Guide for Version 3*", EPA/600/R-94/168a, U.S. Environmental Protection Agency, Washington D.C., December 1994a.

USEPA, "*The Hydrologic Evaluation of Landfill Performance (HELP) Model, Engineering Documentation for Version 3*", EPA/600/R-94/168b, U.S. Environmental Protection Agency, Washington D.C., December 1994b.

Vander Linde, D.L., Luettich, S.M., and Bonaparte, R., "Lessons Learned for Failures of a Landfill Cover System", *Geosynthetics: Lessons Learned from Failures*, J.P. Giroud and K.L. Soderman, Eds., International Geosynthetics Society, 1995, in press.

2. OSDF LAYOUT

2.1 Required Volume
2.2 Capacity Verification
2.3 Earthwork Required Volume

2.1 Required Volume

COMPUTATION COVER SHEET

SUBJECT OF CALCULATION: OSDF REQUIRED VOLUME

Computations By: (Cognizant Engineer)
Signature: Rudolph Bonaparte — Date: 29 March 96
Printed Name and Title: Rudolph Bonaparte, PRINCIPAL

Assumptions and Procedures Checked by: (Checker)
Signature: [signature] — Date: 29 Mar 96
Printed Name and Title: Kenneth W Cargill, Associate

Computations Checked by:
Signature: [signature] — Date: 29 Mar 96
Printed Name and Title: Kenneth W Cargill, Associate

Computations Backchecked by: (Cognizant Engineer)
Signature: Rudolph Bonaparte — Date: 29 March 96
Printed Name and Title: Rudolph Bonaparte, PRINCIPAL

Approved by: (PDP)
Signature: [signature] — Date: 29 Mar 96
Printed Name and Title: Kenneth W Cargill, Associate

Approved by: (DTL and TETL)
Signature: [signature] — Date: 29 Mar 96
Printed Name and Title: Kenneth W Cargill, Associate

Record of Revision (Number and initial all revisions)

Rev. No.	Reason	Date	By	Checked	Approval
D	Intermediate Design Submittal to EPA	29 Mar 96	—	—	[initials]

OSDF REQUIRED VOLUME

EXECUTIVE SUMMARY

Purpose

Calculate the required volume of the OSDF considering the design requirement of 2,500,000 yd^3 of "bank/unbulked" materials to be disposed and taking into account: (i) impacted material bulking; (ii) post-placement material settlement; and (iii) placement of seasonal (winter) closure cover soils.

Contents

- Calculation Procedure
- Data Verification Package
- Calculation Results

Findings

The required OSDF volume is 2,750,000 yd^3 assuming compaction of impacted soils to 90% relative compaction based on standard Proctor compaction procedures. The required volume is 2,880,000 yd^3 if 85% relative compaction is assumed.

Recommendations

- Design of OSDF for a volume of 2,880,000 yd^3
- Consider providing a contingency volume equal to about 10% of the required volume to account for:
  - additional volume resulting from confirmatory sampling
  - minor overexcavation
  - unanticipated seasonal (winter) or partial closure activities

Written by: R. Bonapark Date: 3/29/96 Reviewed by: Date:

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 8.12

FC 29 Mar 96

OSDF REQUIRED VOLUME

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2.	Data Verification	5/15
3.	Calculation Results	15/15
	3.1 Assuming 90% Relative Compaction	15/15
	3.2 Assuming 85% Relative Compaction	15/15

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Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 8.12

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CALCULATION

OSDF REQUIRED VOLUME

PROCEDURE

1. This document describes the procedure for estimating the required gross volume of the Fernald On-Site Disposal Facility (OSDF). The OSDF will accept certain wastes from remediation of five operable units at the Fernald Environmental Management Project (FEMP).

2. The required gross volume is the volume of OSDF airspace required to contain all of the impacted materials destined for the OSDF. The required volume must consider bulking, shrinkage, and settlement of impacted material from its "bank/unbulked" condition in-situ at the operable units to its compacted and compressed condition in the OSDF. The required volume must exist in the OSDF above the top of the leachate collection system and below the bottom of the compacted clay cap.

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Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 8.12

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3. The required gross volume of airspace depends on the following parameters, with the symbol for each parameter in parenthesis.

- total bank/unbulked volume of impacted material (V_T)
- composition of impacted material reported as a volumetric fraction of the total volume:
  - soil (F_1)
  - concrete/asphalt (F_2)
  - solid waste (F_3)
  - flyash (F_4)
  - sludge (F_5)
  - building materials (F_6)
- bank/unbulked volume of each material identified above (V_i)
  - $V_1 = F_1 V_T$
  - $V_2 = F_2 V_T$
  - $V_3 = F_3 V_T$
  - $V_4 = F_4 V_T$
  - $V_5 = F_5 V_T$
  - $V_6 = F_6 V_T$

which, in general terms, may be expressed by

$$V_i = F_i V_T$$

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- shrink/swell/settlement factor for each material (S_i) calculated using the following equation

$$S_i = \frac{(\gamma_{dbui})}{(\gamma_{dci})} \times (1 - \varepsilon_{zi}) = S_{\gamma i} \, S_{\varepsilon i}$$

where γ_{dbui} = the average dry density of material i in the bank/unbulked condition

γ_{dci} = the average dry density of material i in the OSDF compacted condition

ε_{zi} = the average vertical compression of material i between the time it is placed and the time overlying material is placed to the final grade of the facility (assumed on average to be 4 months)

S_γ, S_ε = shrink/swell and settlement factors, respectively

- estimated volume of seasonal (winter) closure material (V_c), where V_c may be calculated by

$$V_c = \sum_{i=1}^{N} A_i d_i$$

where: N = number of seasonal closures, A_i = area of seasonal closure i, and d_i = thickness of unrecoverable seasonal closure soil for

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[illegible] 17 Oct 95

seasonal closure i.

4. Using the parameters defined above, the required gross volume of airspace is obtained using the equations

$$V_R = \left(\sum_{i=1}^{6} V_i S_{fi} S_{\varepsilon i} \right) + V_c$$

$$= \left(\sum_{i=1}^{6} V_T F_i \left(\frac{\gamma_{dbui}}{\gamma_{dci}} \right) \left(1 - \varepsilon_{zi} \right) \right) + \left(\sum_{i=1}^{N} A_i d_i \right)$$

where V_r = total required volume

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CALCULATION

OSDF REQUIRED VOLUME

DATA VERIFICATION

Data inputs must be established for each of the parameters identified in the calculation procedure

1. Total volume (V_T) bank/unbulked

   - Based on the FERMCO Statement-of-Work (SOW)

$$V_T = 2,500,000 \text{ yd}^3$$

2. Composition fraction (F_i)

   - Utilize information in Appendix C of the SOW. This information comes from Table 7-3 of the Feasibility Study (draft) for Operable Unit 5.

   - The impacted-material composition (F_1 through F_6) is indicated for each material on Table 7-3:

$F_1 = 0.7708$

$F_2 = 0.0704$

$F_3 = 0.0074$

$F_4 = 0.0779$

$F_5 = 0.0198$

$F_6 = 0.0536$

Total = 1.0002

R. Bonaparte 95/10/17
FERMCO OSDF

TABLE 7-3

MATERIAL ASSUMED TO MEET WASTE ACCEPTANCE CRITERIA FOR ON-PROPERTY DISPOSAL
(Assumed for CRARE Analysis)

Source	Material	Quantity (cubic yards)
OU2	F_3 Solid waste landfill material	18,000
	F_1 South Field material	120,000
	F_5 Lime sludge ponds material	18,000
	F_4 Active fly ash pile material	80,000
	F_4 Inactive fly ash pile material	109,000
	Subtotal	345,000
OU3	F_6 Windows, wood, insulation	58,571
	F_2 Asphalt and concrete	167,797
	F_6 Structural steel	2274
	F_6 Equipment, conduit/wire, piping	64,485
	F_6 Painted light gauge metals	224
	F_6 Brick	766
	F_6 Transite, floor tile, fire brick	3843
	Subtotal	297,960
OU4	F_2 Concrete	3000
	Subtotal	3000
OU5	F_1 Soil	1,750,000
	F_5 Sludge - groundwater/wastewater treatment facilities	30,000
	Subtotal	1,780,000
	TOTAL	2,425,960

7.1.3 Off-Property Disposal

This section provides information on the material assumed, as part of the adopted criteria remedy, to be disposed of off-property. Table 7-4 lists these wastes. Assumed quantities given are in-place cubic yards and no allowances have been made for volumes following excavation, treatment, and/or containerization.

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3. Estimate shrink/swell factors ($S_{\gamma i}$)

3.1 Soil Materials

The shrink/swell factors for soil materials are dependent on the depth from which material is excavated and the density to which it is compacted in the OSDF. The depth of excavation of OU5 soil (which is about 93.6% of the total soil removal based on Table 7-3) destined for on-site disposal is given below.

Depth Interval (ft)	% of Total Volume
0 to 0.5	17
0.5 to 1.5	17
1.5 to 2.5	7
2.5 to 5.5	18
5.5 to 10.5	21
10.5 to 15.5	14
15.5 to 20.5	6
	100%

Note: These factors estimated using the drawing "Alternatives 3A and 3D - On-Property Undeveloped Park @ 1×10^{-6} BASE + LEVEL 1 + Level 2 + ALARA" which shows OU5 excavation contours.

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To estimate the shrink/swell factor, the ratio of the undisturbed dry density (γ_{du}) must be compared to the OSDF compacted dry density (γ_{dc}). This is accomplished using Figures 1 and 2 which were obtained from the Sept 1995 Parsons report "Geotechnical Investigation Report, On-Site Disposal Facility". Figure 1 presents undisturbed dry density and Figure 2 presents maximum compaction dry density based on standard Proctor compaction. To obtain the OSDF compacted dry density, the maximum dry density in Figure 2 must be multiplied by the relative compaction. Two values of relative compaction will be considered 85% and 90%. Using these values, the following shrink/swell factors are obtained for 90% and 85% relative compaction:

Depth	(γ_{du})	90% (γ_{dc})	$S_{\gamma 1}$	85% γ_{dc}	$S_{\gamma 1}$
0 to 0.5	109	94.5	1.15	89.2	1.22
0.5 to 1.5	109.5	95.0	1.15	89.7	1.22
1.5 to 2.5	110.3	96.5	1.14	91.1	1.21
2.5 to 5.5	112.8	101.2	1.11	95.6	1.18
5.5 to 10.5	118.0	108.5	1.09	102.5	1.15
10.5 to 15.5	123.5	110.7	1.12	104.5	1.18
15.5 to 20.5	125±	110.7	1.13	104.5	1.20

Written by: VANDER LINDE Date: 95/10/7 (YY MM DD) Reviewed by: K. Olson Date: 95/10/7 (YY MM DD)

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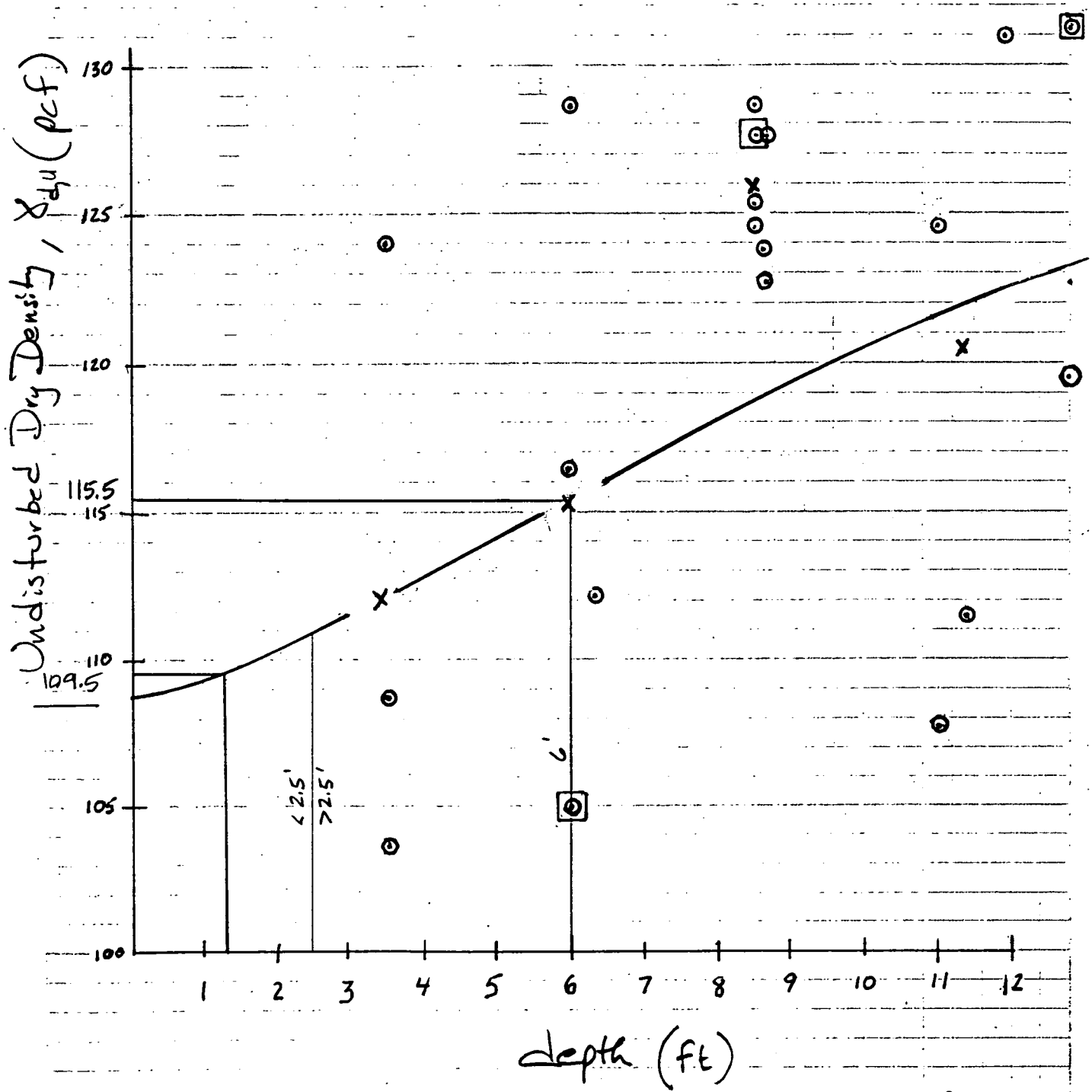
RB 95/10/17
KO 17 Oct 95



Ref.: Geotechnical Investigation Report, OSDF, Sept 1995, Table G-2

FIGURE 1

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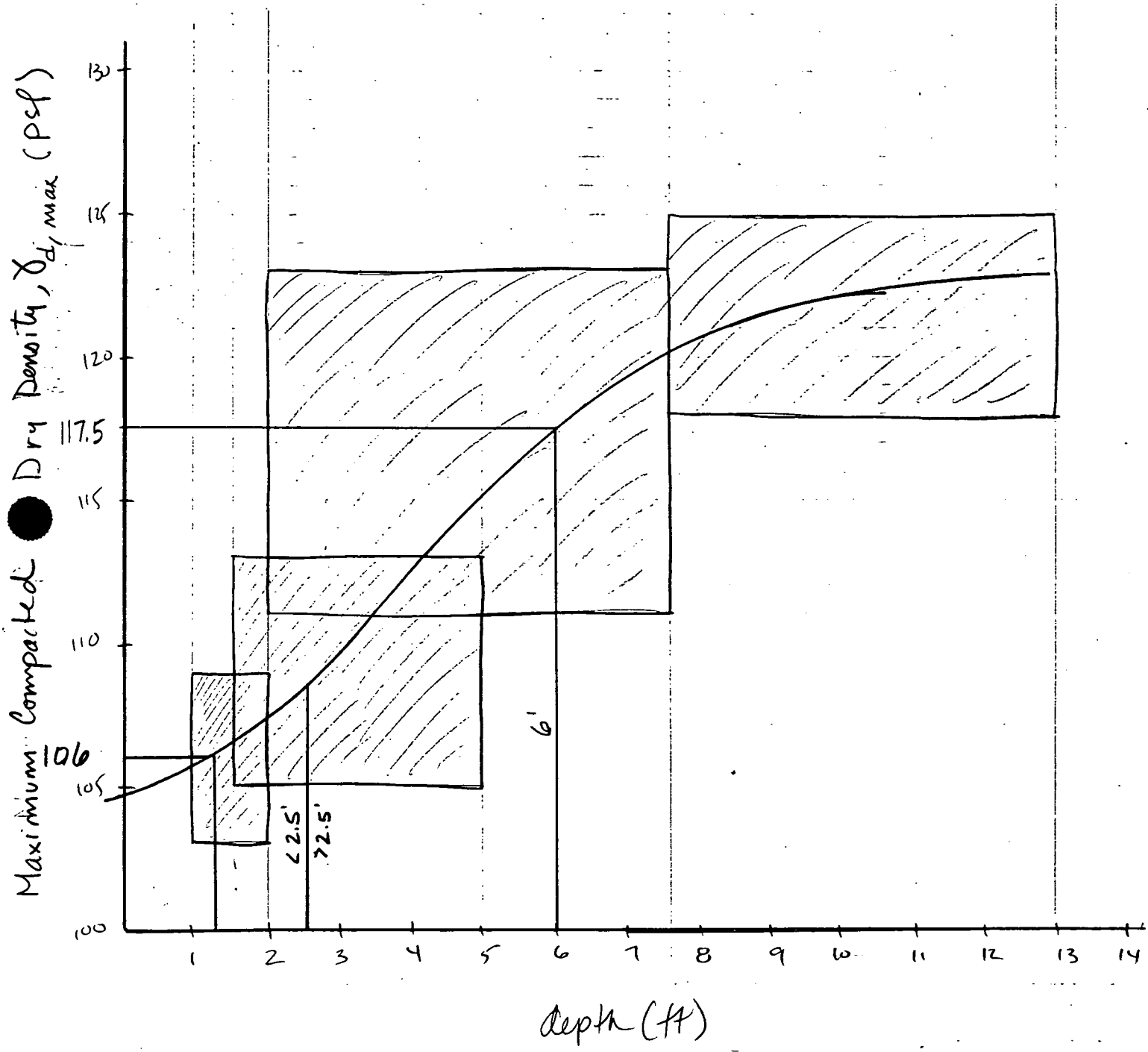

Ref.: Geotechnical Investigation Report, OSDF, Sept 1995, pg 4-13 to 4-16 and Appendix I

FIGURE 2

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The weighted average value of $S_{\gamma 1}$ for the OU5 soils at a relative compaction of 90% is 1.12. The weighted average value of $S_{\gamma 1}$ for the OU5 soils for 85% compaction is 1.059 times larger than the value for 90% compaction; for 85% compaction, $S_{\gamma 1}$ for the OU5 soils is 1.19.

Information for making a detailed estimate of $S_{\gamma 1}$ for the soil in the South field area is unavailable at this time. Therefore, the values derived for OU5 soils will be used for OU2 soils.

3.2 Concrete

Bank/unbulked concrete will bulk considerably when it is broken up and placed in the OSDF. A value of $S_{\gamma 2} = 1.3$ is assumed. See the attached page 11(a) for a discussion of this factor. RB 29 March 96

3.3 Solid Waste Landfill Material

The volume of solid waste is small, a value of $S_{\gamma 3} = 1.0$ is assumed for simplicity.

3.4 Flyash

The flyash was placed in a loose state, but has probably densified slightly over time due to gravity loads and environmental factors. A value of $S_{\gamma 4} = 1.0$ is assumed.

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Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 8.12

SELECTION OF CONCRETE SHRINK/SWELL FACTOR

The selected shrink/swell factor of 1.3 for concrete was chosen based on a number of factors and assumptions. These are: (i) concrete will consist of (on an unbulked volume basis) 75 percent broken-up concrete pieces (including concrete rubble and masonry) placed in lifts and 25 percent individual concrete pieces (including columns and footings); and (ii) the bulking factors for these pieces are 1.4 for the broken-up concrete and 1.0 for the individual concrete pieces. Thee average bulking factor of 1.4 is based on an assumed broken-up concrete porosity of 35 percent, which is a typical porosity for a granular material. (Note, bulked volume = unbulked volume divided by (1-porosity)). The bulking factor for individual concrete pieces recognizes the fact that these pieces will be placed intact in the OSDF and soil will be placed and compacted around the pieces.

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3.5 Sludge

Some of the sludge is desiccated, while some is wet. Sludge will likely be mixed with soil during disposal. The volume of sludge is small. For simplicity, $S_{\gamma 5} = 1.0$ is assumed.

3.6 Building Materials

It is assumed that due to packaging at demolition and/or placement in the OSDF, building materials, on average, do not shrink or swell, Thus, $S_{\gamma 5} = 1.0$.

4. Estimate of Settlement Factors

4.1 Soil

Soil in the OSDF will settle under the weight of overlying layers. Calculations currently being performed for the "Impacted Material Settlement" calculation package indicate average impacted soil material settlements of 3% during filling of each OSDF cell. Thus, $S_{\varepsilon 1} = 0.97$

4.2 Concrete

Concrete rubble has very little compressibility. $S_{\varepsilon 2} = 1.0$ is assumed for simplicity.

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Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 8.12

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4.3 Solid Waste Landfill Material

Solid waste is compressible. However, since the bulking factor was taken as 1.0 in Section 3.3 (i.e., it was assumed that no bulking occurred), the settlement factor is taken as 1.0.

4.4 Flyash

The flyash will likely settle in a manner similar to soil. A value of $S_{\varepsilon 4} = 0.97$ is assumed.

4.5 Sludge

The volume of sludge is small. Consistent with the assumption $S_{\gamma 5} = 1.0$, a value of $S_{\varepsilon 5}$ is also assumed.

4.6 Building Materials

The building materials are assumed to be incompressible. Thus, $S_{\varepsilon 6} = 1.0$

5. Seasonal (Winter) Closure Area (A_i)

The value of A_i is assumed to correspond to cover 2.5 acres (108,900 ft^2)

6. Seasonal (Winter) Closure soil thickness (d_i)

The assumed average soil thickness is 1 ft

Written by: R. Bonaparte Date: 95/10/17 (YY/MM/DD) Reviewed by: FC Date: 95/10/17 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: 6639 00 Task No.: 8.12

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7. Number of Seasonal Closures

The active life of the OSDF may range from 7 to 25 years. For planning purposes, a 10 year life is assumed, with 9 seasonal closures. Therefore, N=9.

Written by: R. Bonaparte Date: 95/10/17 (YY MM DD) Reviewed by: [illegible] Date: 95/10/17 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 8.12

CALCULATION

OSDF REQUIRED VOLUME

From the calculation procedure, for a relative compaction of 90%,

$$V_r(90\%) = V_T \sum_{i=1}^{6} F_i S_{\gamma i} S_{\varepsilon i} + \sum_{i=1}^{9} A_i d_i$$ ✓

$$= 2.5 \times 10^6 \, yd^3 (0.7708 \times 1.12 \times 0.97$$
$$+ 0.0704 \times 1.30 \times 1.0$$
$$+ 0.0074 \times 1.0 \times 1.0$$
$$+ 0.0779 \times 1.0 \times 0.97$$
$$+ 0.0198 \times 1.0 \times 1.0$$
$$+ 0.0536 \times 1.0 \times 1.0)$$
$$+ 9 \times 108{,}900 \, ft^2 \times 1 \, ft \div 27$$

$$= 2.5 \times 10^6 \, yd^3 (1.085) +$$ ✓

$$= 2{,}713{,}200 \, yd^3 + 36{,}000 \, yd^3$$ ✓

$$= 2{,}749{,}500 \, yd^3 \simeq 2{,}750{,}000 \, yd^3$$ ✓

Repeating the same calculation for 85% compaction using $S_{\gamma 1} = 1.19$ results in:

$$V_r(85\%) = 2{,}880{,}000 \, yd^3$$ ✓

2.2 Capacity Verification

COMPUTATION COVER SHEET

SUBJECT OF CALCULATION: OSDF CAPACITY VERIFICATION

Computations By: (Cognizant Engineer)
Signature Robert A. Morgan III — Date 13 OCT 1995
Printed Name and Title ROBERT A. MORGAN III, STAFF ENGINEER

Assumptions and Procedures Checked by: (Checker)
Signature Daniel B. Wisialowski — Date 16 OCT 95
Printed Name and Title DANIEL B. WISIALOWSKI, ASSISTANT PROJECT ENGINEER

Computations Checked by:
Checked by:
Signature [illegible] — Date 16 Oct. 1995
Printed Name and Title RON CZ, Asst. Proj. Engineer.

Computations Backchecked by: (Cognizant Engineer)
Signature Robert A. Morgan III — Date 16 OCT 1995
Printed Name and Title ROBERT A. MORGAN III, STAFF ENGINEER

Approved by: (PDP)
Signature Dennis L. VanderLinde — Date 17 OCTOBER 1995
Printed Name and Title DENNIS L. VANDER LINDE, ASSISTANT PROJECT ENGINEER

Approved by: (DTL and TETL)
Signature [illegible] — Date 17 Oct 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	Draft submittal to FERMCO	17 Oct 95	NA	NA	NA
Ø	30% Submittal	NA	NA	NA	NA
B	Preliminary Design - EPA Submittal	15 Dec 95	[illegible]		
C	Intermediate Design, Fig 3&4 changed	10 FEB 96	RNM	DBW	[illegible] 16 Feb 96
D	Intermediate Design - EPA Submittal	3 Apr 96	[illegible]		

Written By: RAM Date: 12 DEC 95 Reviewed by: DBW Date: 13 DEC 95

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE3900 Task No.: 11.1

OSDF CAPACITY VERIFICATION

EXECUTIVE SUMMARY

PURPOSE OF ANALYSIS

The purpose of this package is to present the OSDF capacity verification summary. Results are given for the volume of a 9 cell OSDF (ninth cell is a contingency cell) and an 8 cell OSDF.

METHOD OF ANALYSIS

The OSDF capacity (for a nine cell OSDF) was calculated using two methods: (1) hand calculated using the average end area method for the midsection (see Figure 1) and approximating the ends as a pyramid; and (2) using the Earthworks volume calculation package developed by SOFTDESK for AUTOCAD®. The OSDF capacity was also calculated by hand for an eight cell OSDF by subtracting one cell from the midsection (see Figure 1).

CONCLUSIONS

	9-CELL OSDF	8-CELL OSDF
HAND	3,118,801.48 cyd	2,753,689.11 cyd
AUTOCAD®	3,275,394.24 cyd	2,898,035.08 cyd
% DIFFERENCE	4.80%	4.98%

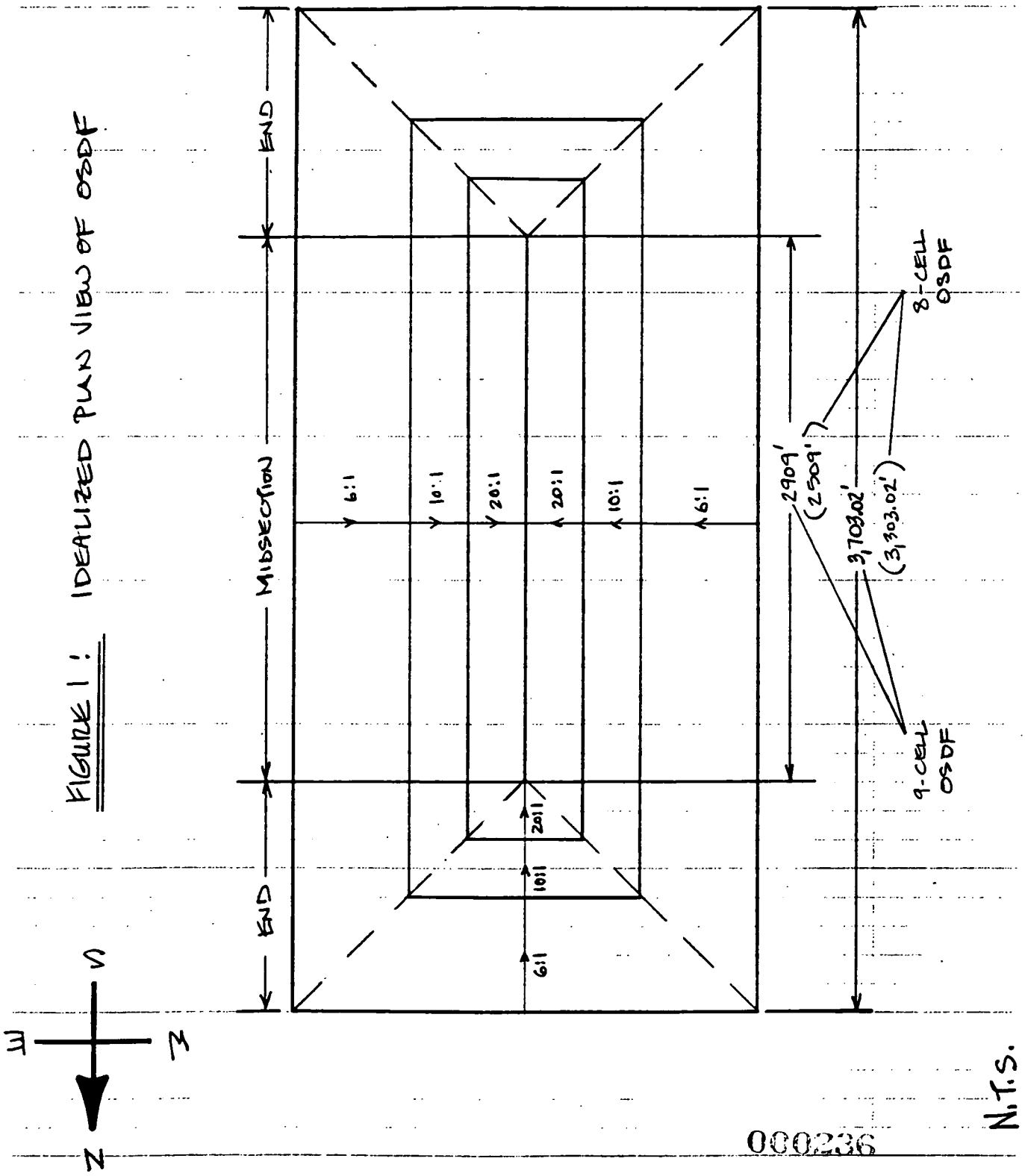
GEOSYNTEC CONSULTANTS

Written by: RATM Date: 95/10/12 (YY/MM/DD) Reviewed by: DBW Date: 95/10/16 (YY/MM/DD)

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE3900 Task No.: 11.1

file 170c+25

FIGURE 1: IDEALIZED PLAN VIEW OF OSDF



N.T.S.

Written by: _____ Date: _____ Reviewed by: _____ Date: _____

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 11.1

CAPACITY VERIFICATION

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Written by: RAM Date: 95/10/11 (YY MM DD) Reviewed by: DBW Date: 95/10/16 (YY MM DD)

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE3900 Task No.: 11.1

Rev 17 Oct 95

OSDF CAPACITY VERIFICATION

CALCULATION PROCEDURES

Written by: RAM Date: 95/10/11 (YY/MM/DD) Reviewed by: DBW Date: 95/10/16 (YY/MM/DD)

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE3900 Task No.: 11.1

17 Oct 95

INTRODUCTION:

THE PURPOSE OF THIS PACKAGE IS TO PRESENT THE CALCULATION PROCEDURES FOR VOLUME VERIFICATION OF THE OSDF CAPACITY CALCULATED USING AUTOCAD®.

METHOD OF ANALYSIS:

STEP 1: DETERMINE THE GROSS AREA OF THE E-W CROSS-SECTION. THE CROSS-SECTION SHOWN IN FIGURE 1 & 2 REPRESENTS AN AVERAGE CROSS-SECTION BETWEEN THE INTERCELL BERM AND THE DRAINAGE CORRIDOR OF A CELL IN THE OSDF.

RAM 95/10/12 DBW 95/10/16
FERMCO FERNALD OSDF GE 3900 11.1

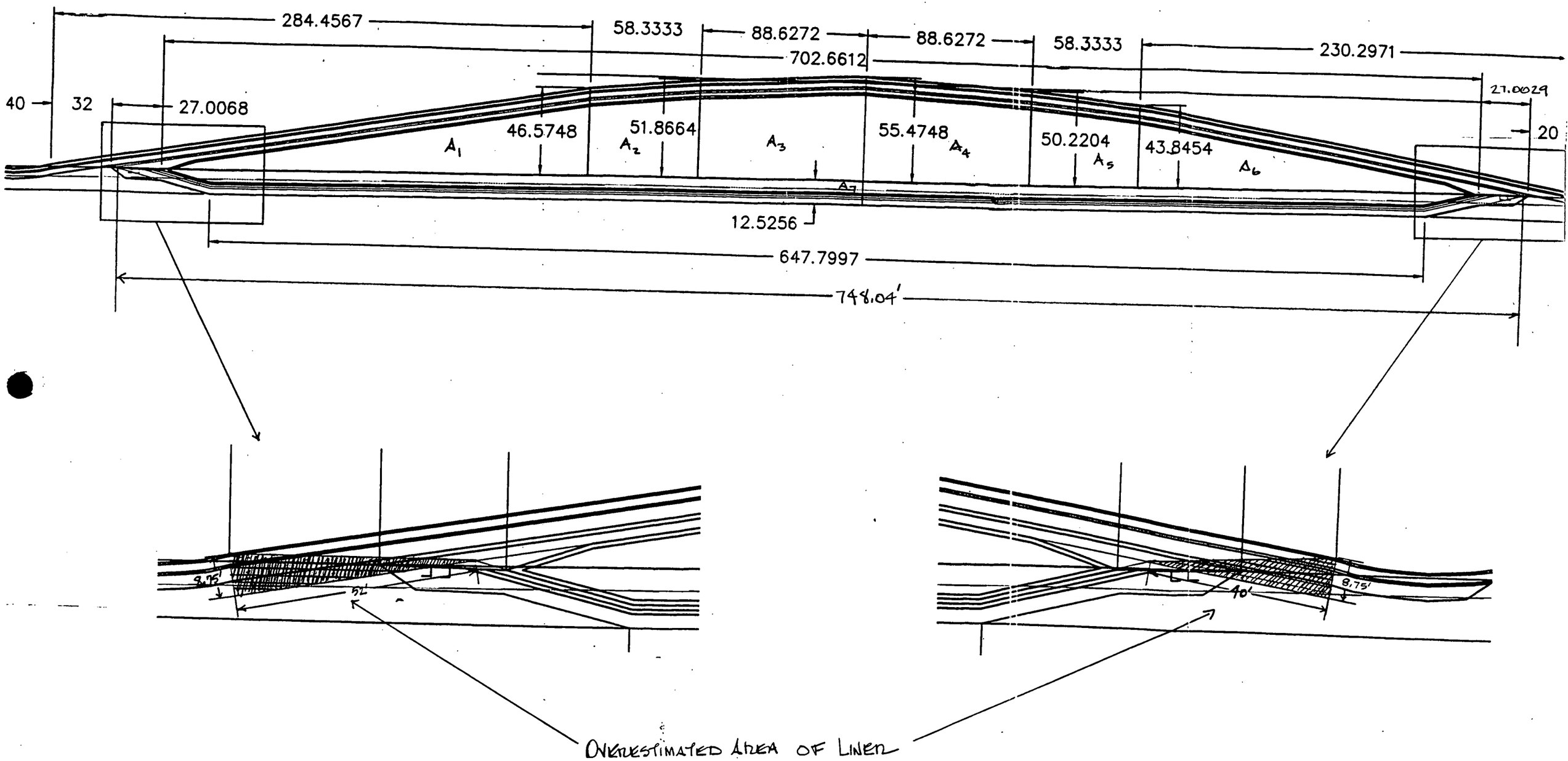

FIGURE 1:

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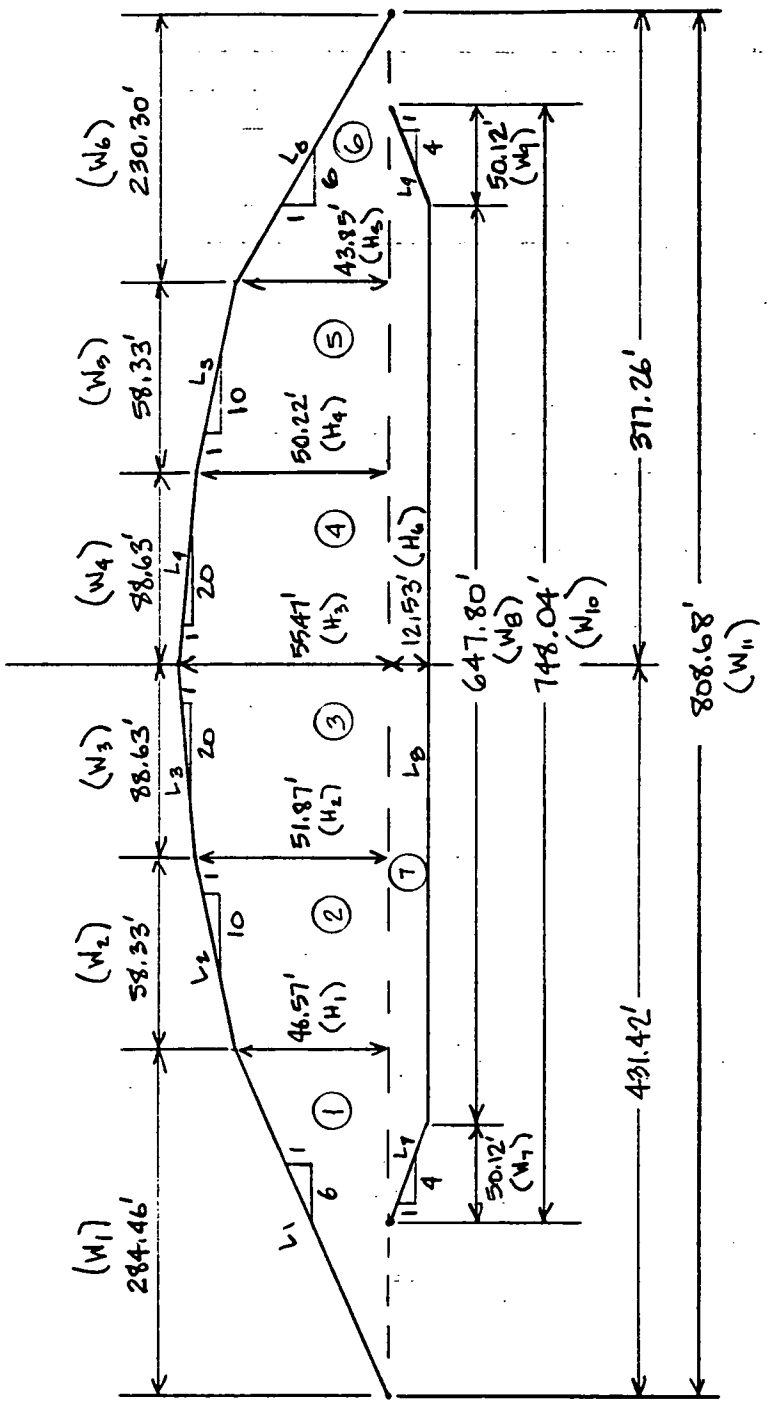
FIGURE 2 : E-W CROSS-SECTION



NTS

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- EQUATIONS FOR VARIOUS DIMENSIONS (SEE FIGURE 2)

- $L_1 = \sqrt{H_1^2 + W_1^2}$ ✓
- $L_2 = \sqrt{(H_2 - H_1)^2 + W_2^2}$ ✓
- $L_3 = \sqrt{(H_3 - H_2)^2 + W_3^2}$ ✓
- $L_4 = \sqrt{(H_3 - H_4)^2 + W_4^2}$ ✓
- $L_5 = \sqrt{(H_4 - H_5)^2 + W_5^2}$ ✓
- $L_6 = \sqrt{H_5^2 + W_6^2}$ ✓
- $L_7 = \sqrt{H_6^2 + W_7^2}$ ✓
- $L_8 = W_8$ ✓
- $L_9 = \sqrt{H_6^2 + W_9^2}$ ✓

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- EQUATIONS FOR AREA OF E-W CROSS-SECTION

- $A_1 = \frac{1}{2}(W_1)(H_1)$ ✓
- $A_2 = \left(\frac{H_1 + H_2}{2}\right)(W_2)$ ✓
- $A_3 = \left(\frac{H_2 + H_3}{2}\right)(W_3)$ ✓
- $A_4 = \left(\frac{H_3 + H_4}{2}\right)(W_4)$ ✓
- $A_5 = \left(\frac{H_4 + H_5}{2}\right)(W_5)$ ✓
- $A_6 = \frac{1}{2}(W_6)(H_5)$ ✓
- $A_7 = (W_8)(H_6) + 2\left[\frac{1}{2}(H_6)(W_7)\right]$ ✓

- GROSS AREA OF E-W CROSS-SECTION

$$A_G = A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 \checkmark$$

Written by: RAM Date: 95/10/12 (YY MM DD) Reviewed by: DBW Date: 95/10/16 (YY MM DD)

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE 3900 Task No.: 11.1

17 of 95

STEP 2: CALCULATE THE CROSS-SECTIONAL AREA OF COVER AND LINER. (SEE FIGURE 3 AND 4)

- $A_c = 8.75' (L_1 + L_2 + L_3 + L_4 + L_5 + L_6)$ ✓

- $A_L = 5.0' (L_7 + L_8 + L_9)$ ✓

- OVER ESTIMATED AREA OF COVER (SEE FIGURE 1) $= A_o$

$A_o = \frac{1}{2}(40')(8.75') + \frac{1}{2}(52')(8.75') = 402.50\ SL^2$ ✓

- GROSS AREA OF LINER + COVER $= A_c + A_L - A_o$ ✓

STEP 3: CALCULATE THE NET AREA (i.e., AREA OF IMPACTED MATERIAL) OF THE E-W CROSS-SECTION.

- $A_N = A_G - (A_c + A_L - A_o)$ ✓

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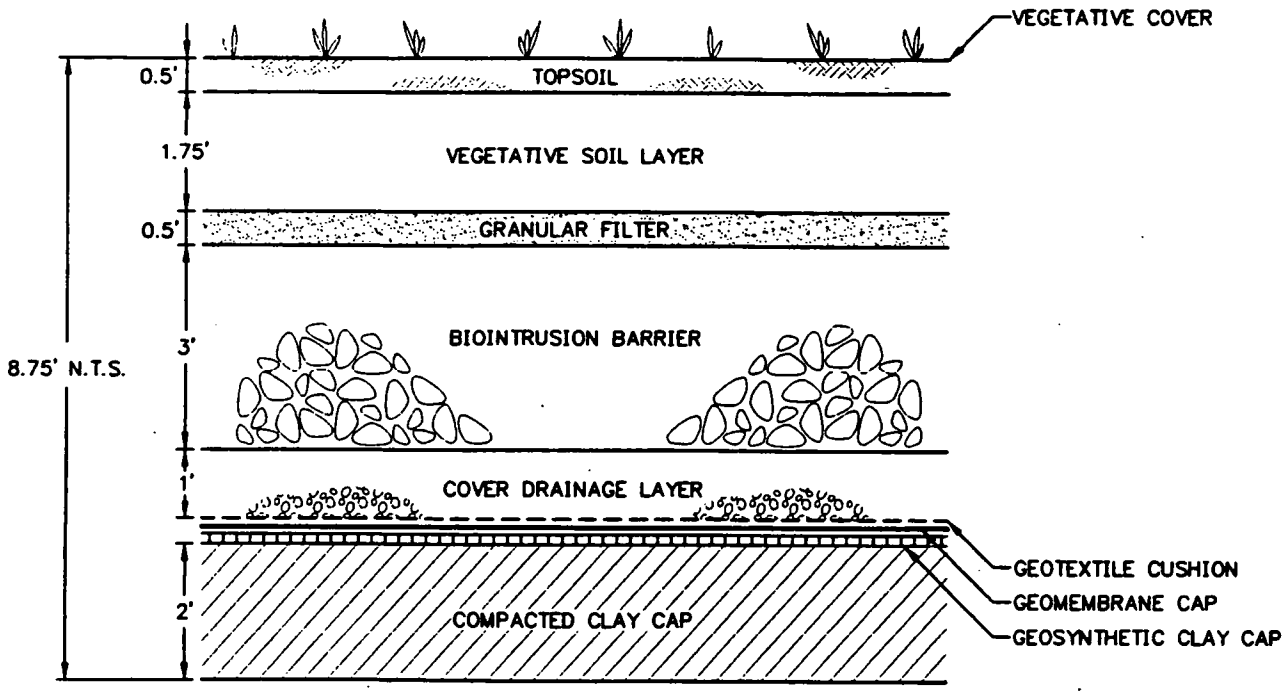

FIGURE 3: FINAL COVER SYSTEM

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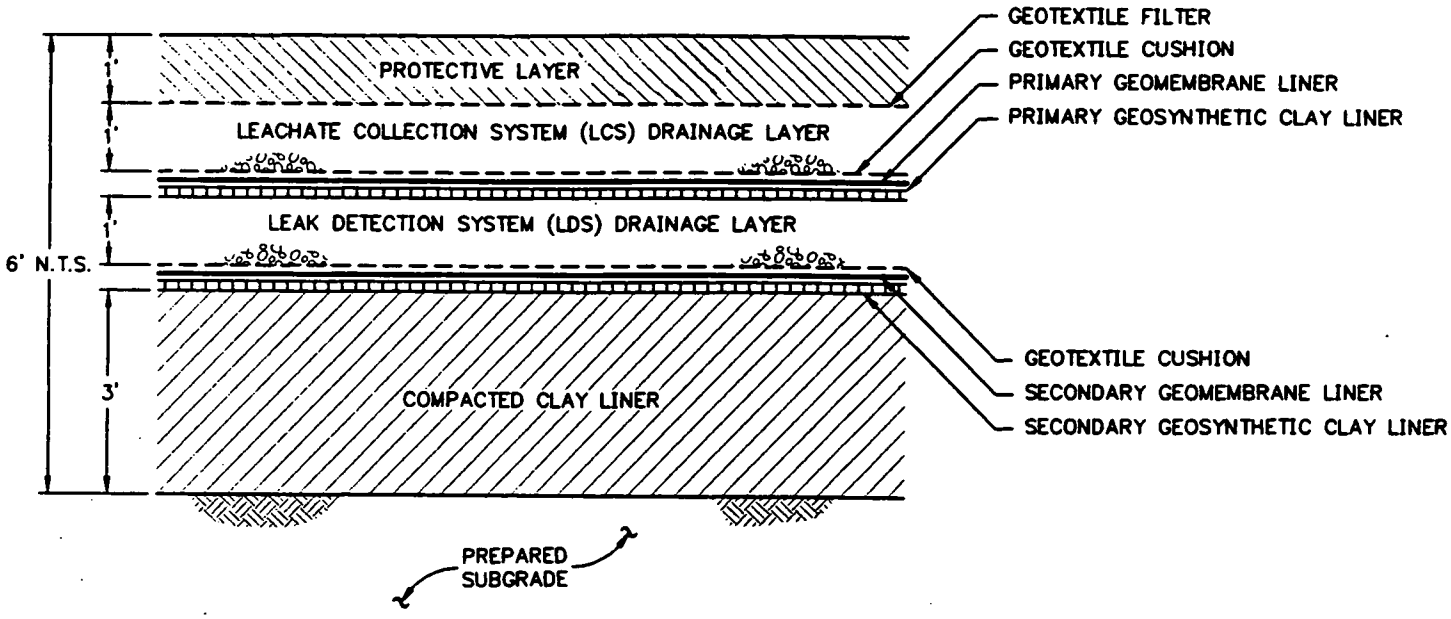

FIGURE 4: LINER SYSTEM

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STEP 4: CALCULATE THE VOLUME OF ENDS BASED ON FIGURE 5, 6, & 7. THE ENDS COMBINED TOGETHER CREATE A VOLUME SIMILAR TO A PYRAMID. THE PYRAMID IS DIVIDED INTO 4 PARTS (20:1, 10:1, 6:1 SLOPES, AND THE LINER). FOR PURPOSES OF CALCULATING THE GROSS VOLUME OF THE ENDS.

- $$\forall_1 = \frac{1}{3}\left(H_3 - \frac{H_2+H_4}{2}\right)\left(W_3+W_4\right)^2 \checkmark$$

- $$\forall_2 = \frac{1}{3}\left(\frac{H_2+H_4}{2} - \frac{H_1+H_5}{2}\right)\left(\left(W_3+W_4\right)^2 + \left(W_2+W_3+W_4+W_5\right)^2 + \sqrt{\left(W_3+W_4\right)^2\left(W_2+W_3+W_4+W_5\right)^2}\right) \checkmark$$

- $$\forall_3 = \frac{1}{3}\left(\frac{H_1+H_5}{2}\right)\left(\left(W_2+W_3+W_4+W_5\right)^2 + \overbrace{\left(W_1+W_2+W_3+W_4+W_5+W_6\right)}^{=W_{11}}{}^2 + \sqrt{\left(W_2+W_3+W_4+W_5\right)^2 + \underbrace{\left(W_1+W_2+W_3+W_4+W_5+W_6\right)}_{=W_{11}}{}^2}\right) \checkmark$$

- $$\forall_4 = \frac{1}{3}\left(H_6\right)\left(\left(W_8\right)^2 + \left(W_{10}\right)^2 + \sqrt{\left(W_8^2\right)\left(W_{10}^2\right)}\right) \checkmark$$

- $$\forall_{ENDS} = \forall_1 + \forall_2 + \forall_3 + \forall_4 \quad \text{(GROSS VOLUME)} \checkmark$$

Written by: RATM Date: 95/10/12 (YY MM DD) Reviewed by: DRW Date: 95/10/16 (YY MM DD)

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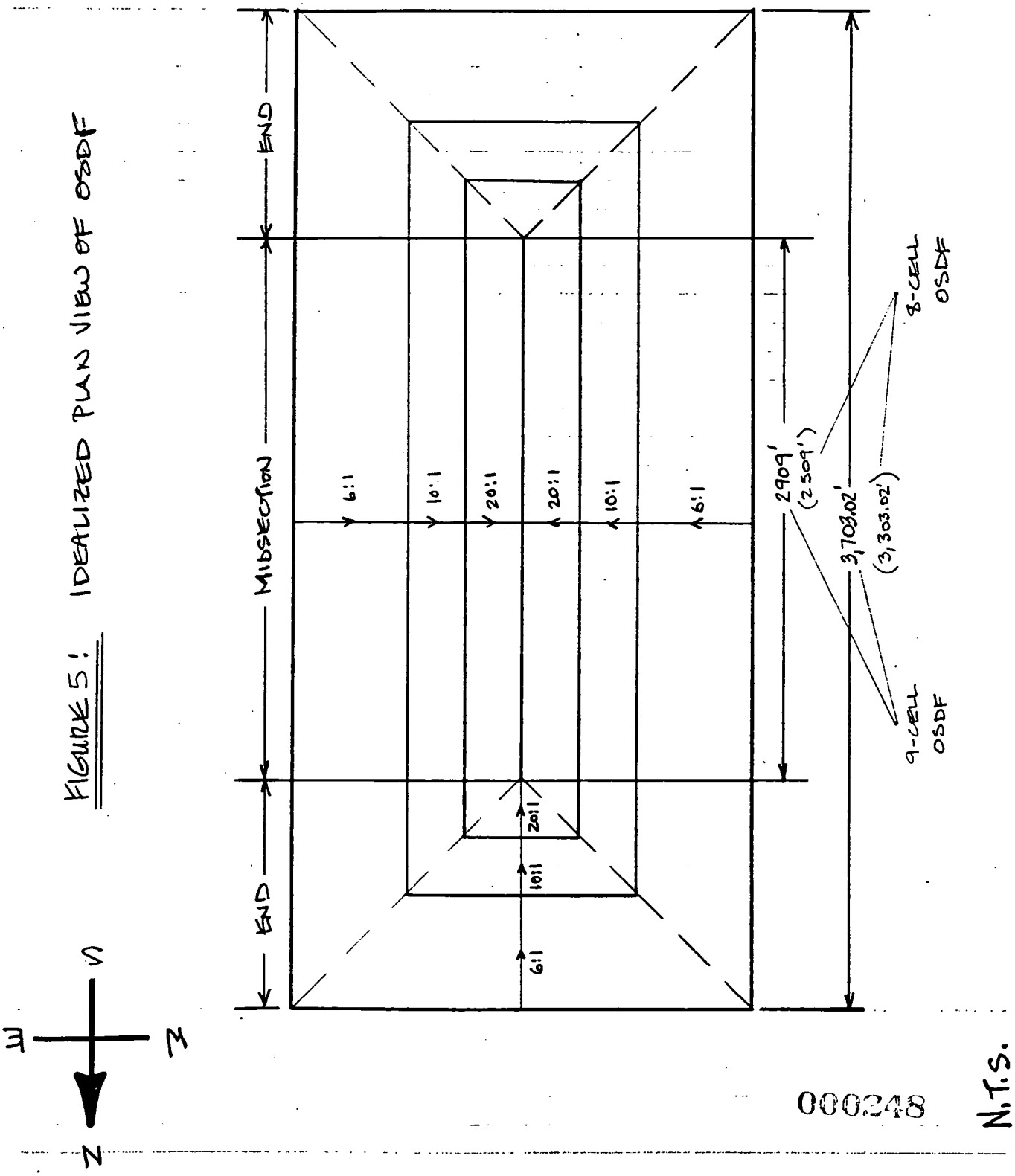
FIGURE 5: IDEALIZED PLAN VIEW OF OSDF



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Written by: RAM Date: 95/10/12 (YY MM DD) Reviewed by: DGN Date: 95/10/16 (YY MM DD)

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE3900 Task No.: 11.1

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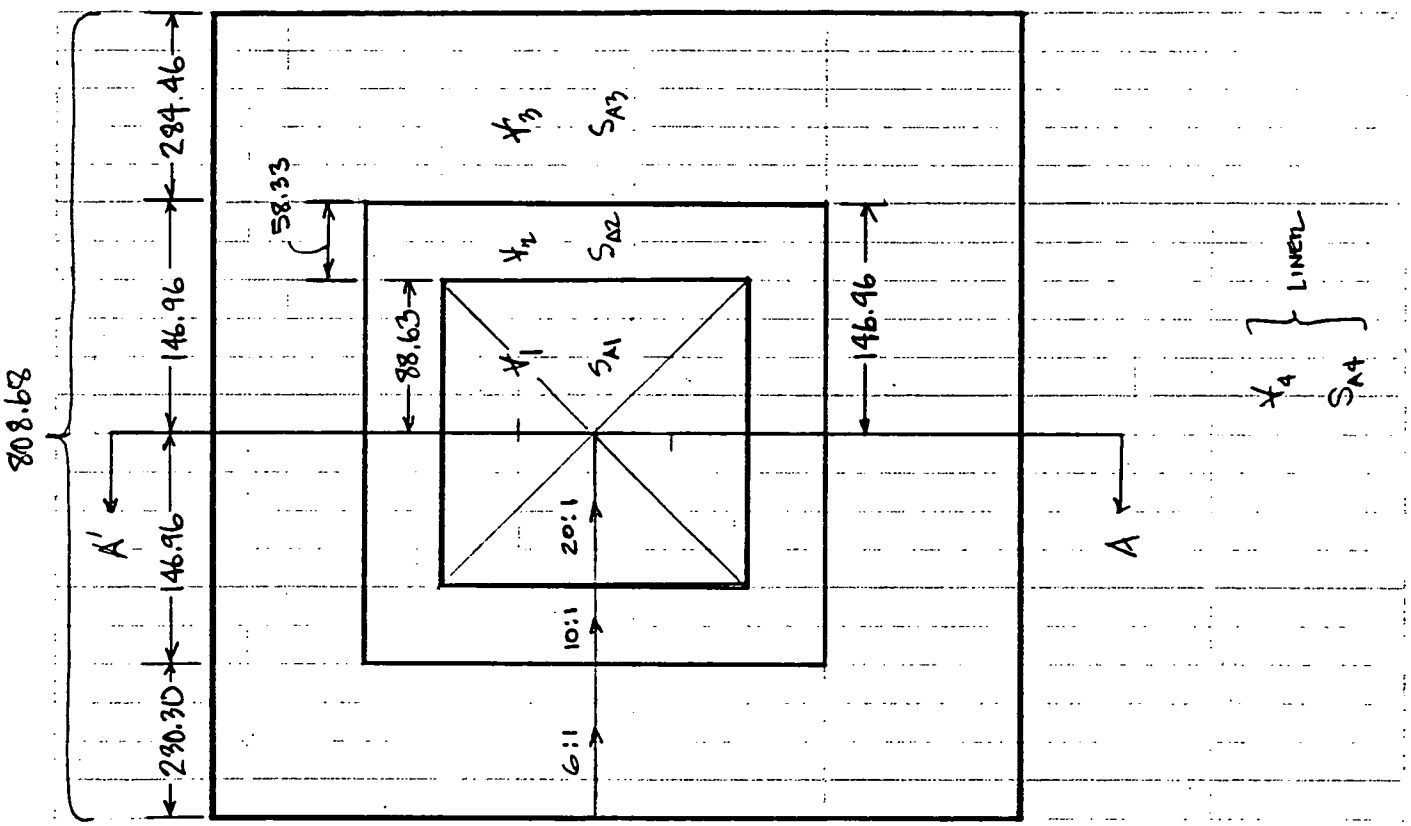

* FOR TRUNCATED PYRAMID:

$$V = \frac{d}{3}\left(A_1 + A_2 + \sqrt{A_1 A_2}\right)$$

REFERENCE:

O'ROURKE, C.E., GENERAL ENGINEERING HANDBOOK, McGRAW-HILL, NY, 1940, p28 (section 1)

FIGURE 6

N.T.S.

Written by: RAFA Date: 95/10/12 (YY MM DD) Reviewed by: DBW Date: 95/10/16 (YY MM DD)

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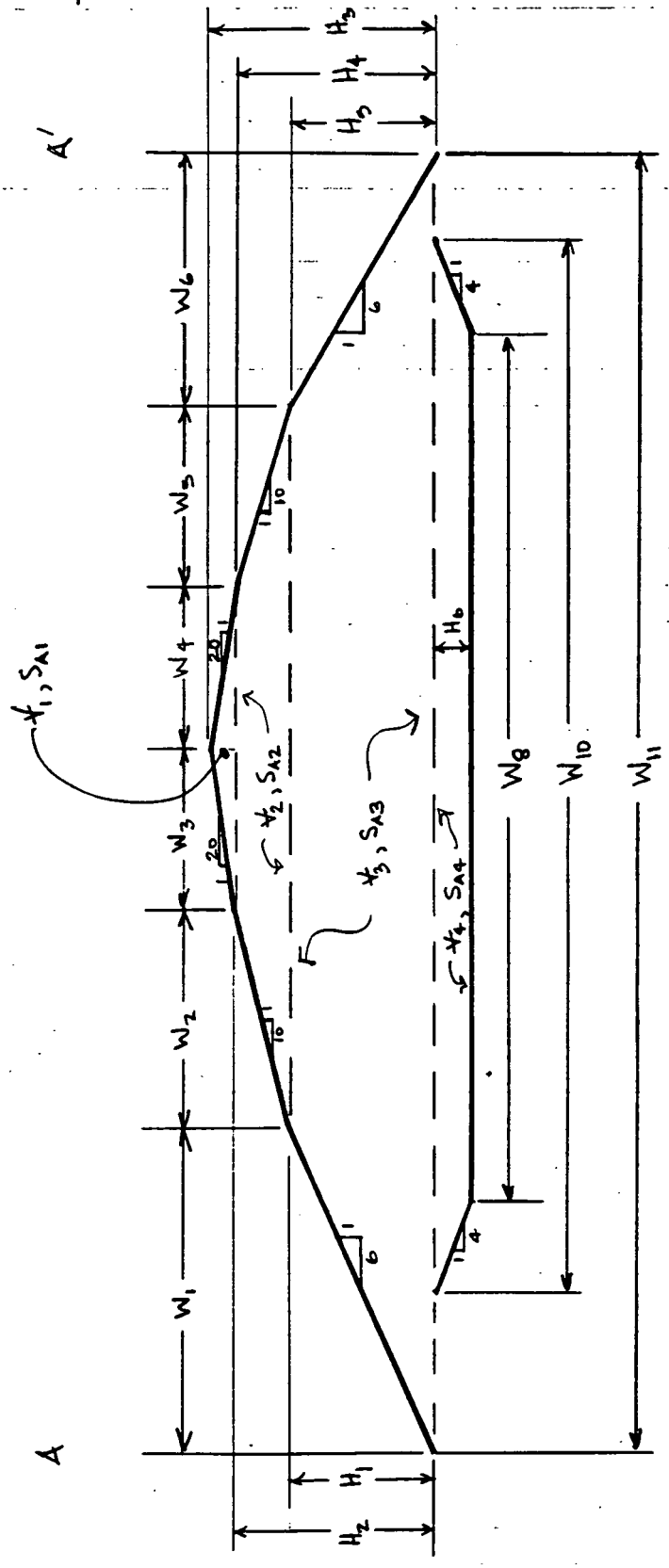

FIGURE 7: IDEALIZED CROSS-SECTION A-A' (FIGURE 6)

Written by: RAM Date: 95/10/12 (YY/MM/DD) Reviewed by: DBW Date: 95/10/16 (YY/MM/DD)

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STEP 5: IN ORDER TO DETERMINE THE VOLUME OF THE COVER AND LINER SYSTEM AT THE ENDS, IT IS NECESSARY TO CALCULATE THE SURFACE AREA OF THE ENDS.

- $S_{A1} = 2\left(\frac{1}{2}\left(2(W_3)\right)(L_3)\right) + 2\left(\frac{1}{2}\left(2(W_4)\right)(L_4)\right)$ ✓

- $S_{A2} = 4\left(\frac{L_2+L_5}{2}\right)\left(\frac{(W_3+W_4)+(W_2+W_3+W_4+W_5)}{2}\right)$ ✓

- $S_{A3} = 2\left(\frac{W_{11}+(W_2+W_3+W_4+W_5)}{2}\right)(L_1) + 2\left(\frac{W_{11}+(W_2+W_3+W_4+W_5)}{2}\right)(L_6)$ ✓

- $S_{A4} = W_8^2 + 4(L_7)\left(\frac{W_8+W_{10}}{2}\right)$ ✓

- V_c (COVER) $= 8.75'\left(S_{A1}+S_{A2}+S_{A3}\right)$ ✓

- V_L (LINER) $= 5.0'\left(S_{A4}\right)$ ✓

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STEP 6: CALCULATE THE NET VOLUME OF THE ENDS.

- NET VOLUME (ENDS) = GROSS VOLUME − (VOL COVER + VOL LINER) ✓

STEP 7: CALCULATE VOLUME OF INTERCELL BERMS (SEE FIGURE 8)

- $A_1 = \frac{1}{2}(b_1)(h_1)$ ✓
- $A_2 = (h_1)(b_2)$ ✓
- $A_3 = (b_3)\left(\frac{h_2 + h_3}{2}\right)$ ✓
- $A_4 = (b_4)(h_4)$ ✓
- $A_5 = \frac{1}{2}(b_5)(h_4)$ ✓

- AVG LENGTH OF INTERCELL BERMS $= \frac{W_8 + W_{10}}{2} = L_{AVG}$ (FIGURE 2) ✓

- TOTAL VOLUME OF INTERCELL BERMS (V_{IB})

THERE ARE 8 INTERCELL BERMS FOR 9-CELL OSDF

$$V_{IB} = \underset{(or\ 7)}{8}(A_1 + A_2 + A_3 + A_4 + A_5)(L_{AVG}) \checkmark$$

THERE ARE 7 INTERCELL BERMS FOR 8-CELL OSDF ✓

STEP 8: CALCULATE NET VOLUME (TOTAL)

- NET VOLUME = NET VOLUME (ENDS) + (A_N)(LENGTH OF MIDSECTION) − V_{IB} ✓

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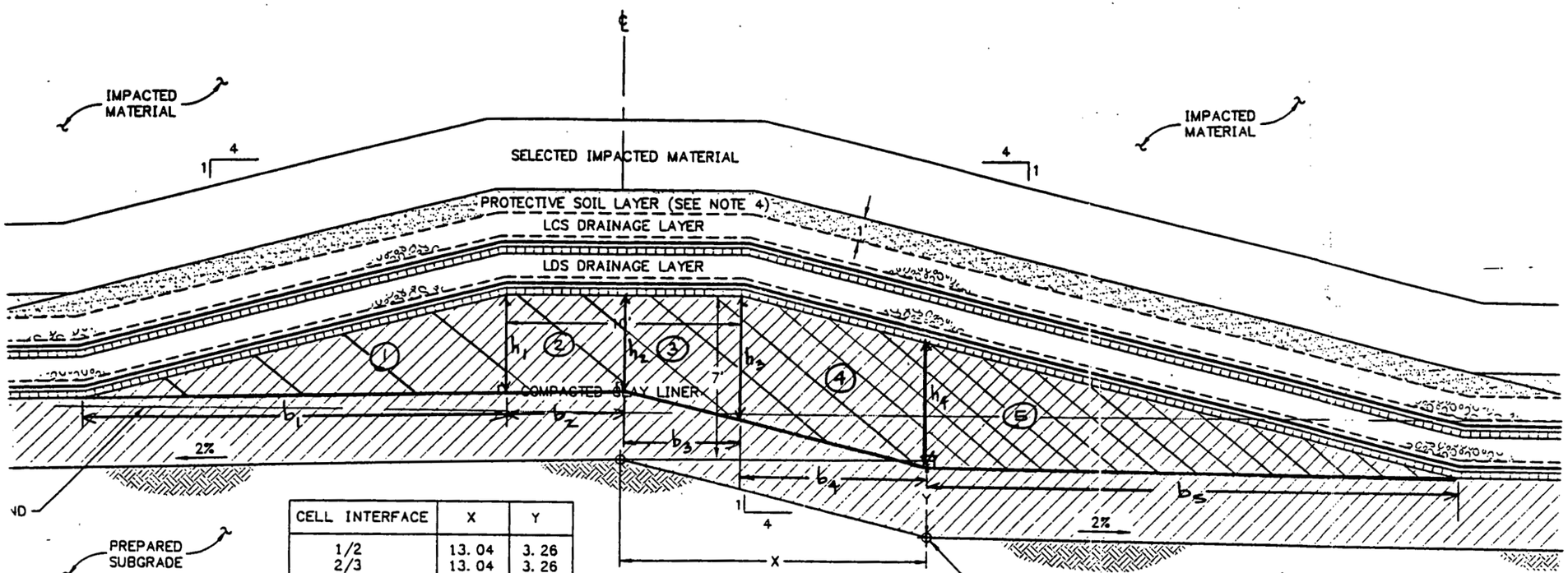

CELL INTERFACE	X	Y
1/2	13.04	3.26
2/3	13.04	3.26
3/4	13.04	3.26
4/5	13.04	3.26
5/6	13.04	3.26
6/7	8.69	2.17
7/8	8.69	2.17
8/9	8.69	2.17

DET-NO DETAIL

SHT-NO LINER SYSTEM AT INTERCELL BERM

~~SCALE 1" = 1'~~ NTS

XREF: F95XA025

FIGURE 8

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Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE3900 Task No.: 11.1

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OSDF CAPACITY

VERIFICATION

DATA VERIFICATION PACKAGE

Written by: RAM Date: 95 / 10 / 12 (YY MM DD) Reviewed by: DBW Date: 95 / 10 / 16 (YY MM DD)

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE 3900 Task No.: 11.1

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DIMENSIONS:

- DIMENSIONS OF AVERAGE E-W CROSS-SECTION (AUTOCAD®) ARE SHOWN IN FIGURE 1.

- N-S DIMENSIONS OF 9-CELL OSDF (9th CELL IS CONTINGENCY CELL):

  TOTAL LENGTH = 3,703.02 ft

  LENGTH OF MIDSECTION = 2,909 ft

- N-S DIMENSIONS OF 8-CELL OSDF (NO CONTINGENCY CELL):

  TOTAL LENGTH = 3,303.02 ft

  LENGTH OF MIDSECTION = 2,509 ft

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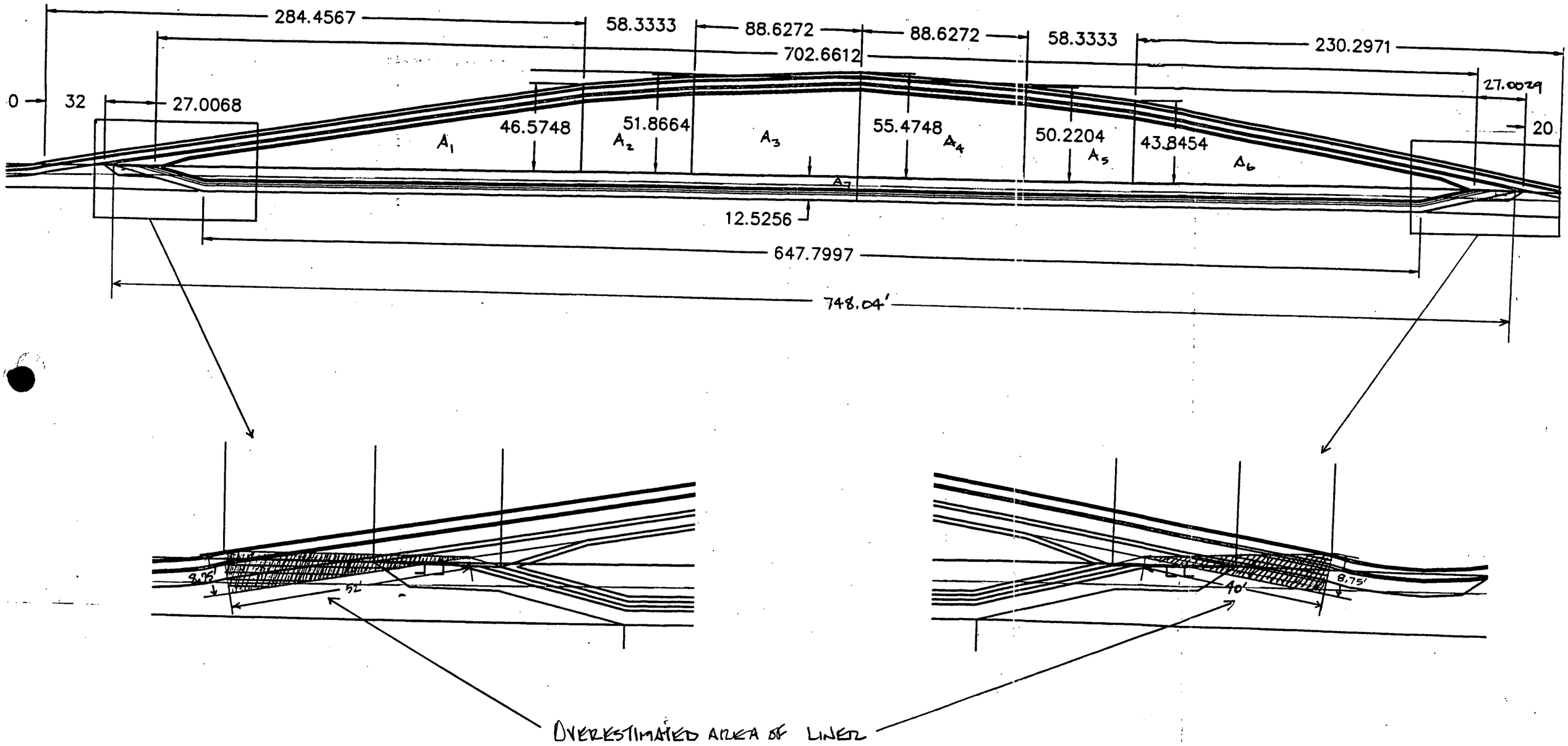


FIGURE 1:

Written by: RAM Date: 95/10/12 (YY MM DD) Reviewed by: BL Date: 95/10/16 (YY MM DD)

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE 3900 Task No.: 11.1

OSDF CAPACITY VERIFICATION CALCULATIONS

Written by: RAM Date: 95/10/12 (YY/MM/DD) Reviewed by: BL Date: 95/10/16 (YY/MM/DD)

Client: Fernco Project: FERNALD OSDF Project/Proposal No.: GE 3900 Task No.: 11.1

CALCULATE VARIOUS DIMENSIONS SHOWN IN FIGURE 1:

- $L_1 = \sqrt{H_1^2 + W_1^2} = \sqrt{(46.57')^2 + (284.46')^2} = 288.25$ ft ✓
- $L_2 = \sqrt{(H_2 - H_1)^2 + W_2^2} = \sqrt{(51.87' - 46.57')^2 + (58.33')^2} = 58.57$ ft ✓
- $L_3 = \sqrt{(H_3 - H_2)^2 + W_3^2} = \sqrt{(55.47' - 51.87')^2 + (88.63')^2} = 88.70$ ft ✓
- $L_4 = \sqrt{(H_3 - H_4)^2 + W_4^2} = \sqrt{(55.47' - 50.22')^2 + (88.63')^2} = 88.79$ ft ✓
- $L_5 = \sqrt{(H_4 - H_5)^2 + W_5^2} = \sqrt{(50.22' - 43.85')^2 + (58.33')^2} = 58.68$ ft ✓
- $L_6 = \sqrt{H_5^2 + W_6^2} = \sqrt{(43.85')^2 + (230.30')^2} = 234.44$ ft ✓
- $L_7 = L_9 = \sqrt{H_6^2 + W_7^2} = \sqrt{(12.53')^2 + (50.12')^2} = 51.66$ ft ✓
- $L_8 = W_8 = 647.80'$

CALCULATE AREA OF E-W CROSS-SECTION

- $A_1 = \frac{1}{2}(W_1)(H_1) = \frac{1}{2}(284.46')(46.57') = 6{,}623.65$ ft^2 ✓
- $A_2 = \left(\frac{H_1 + H_2}{2}\right)(W_2) = \left(\frac{46.57' + 51.87'}{2}\right)(58.33') = 2{,}871.00$ ft^2 ✓
- $A_3 = \left(\frac{H_2 + H_3}{2}\right)(W_3) = \left(\frac{51.87' + 55.47'}{2}\right)(88.63') = 4{,}756.77$ ft^2 ✓

Written by: RAM Date: 95/10/12 (YY MM DD) Reviewed by: BL Date: 95/10/16 (YY MM DD)

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE 3900 Task No.: 11.1

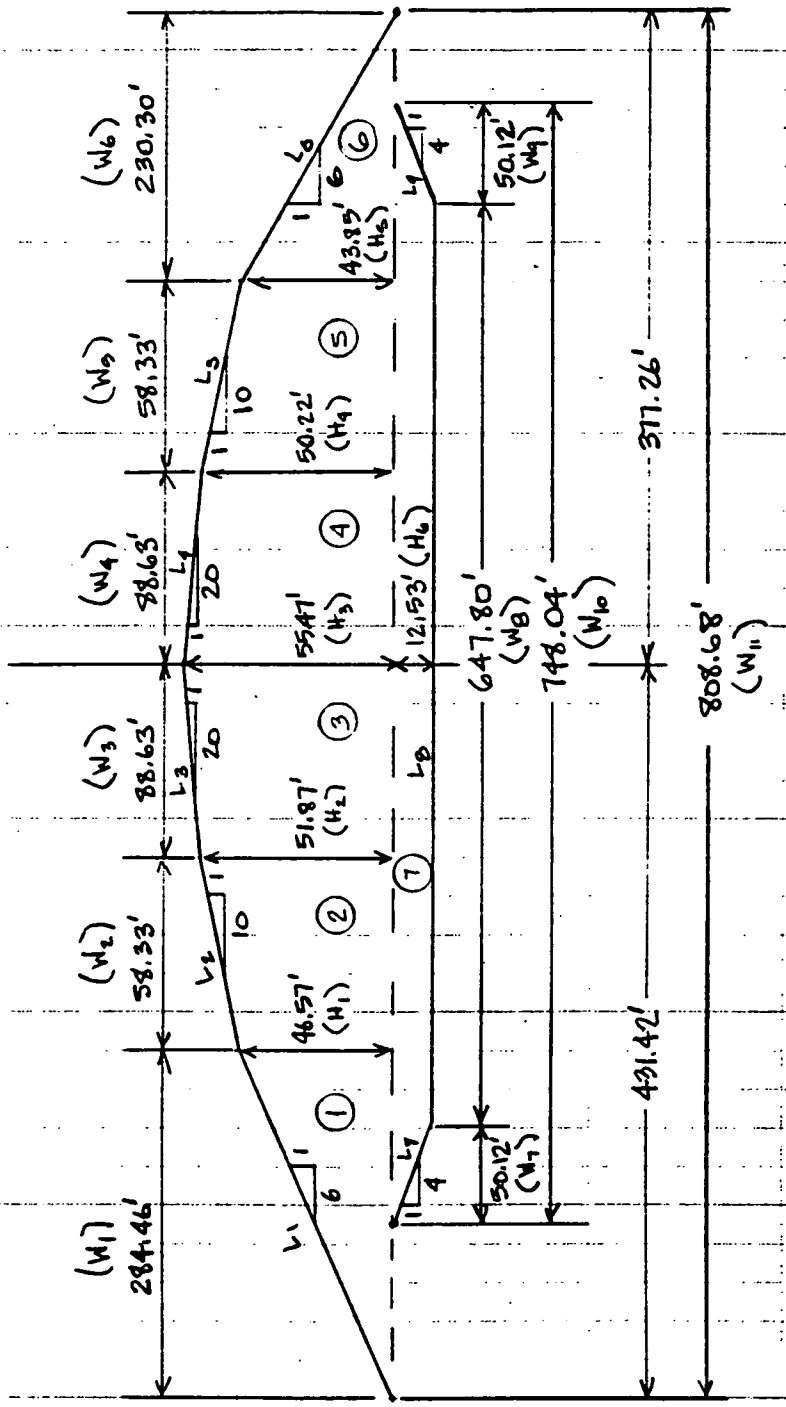


FIGURE : E-W CROSS-SECTION

NTS

Written by: RAM Date: 95/10/12 Reviewed by: B.L Date: 95/10/16

Client: FERMCO Project: FERNALD DSDF Project/Proposal No.: GE3900 Task No.: 11.1

- $A_4 = \left(\frac{H_3+H_4}{2}\right)(W_4) = \left(\frac{55.47'+50.22'}{2}\right)(88.63') = 4{,}683.65\ ft^2$ ✓

- $A_5 = \left(\frac{H_4+H_5}{2}\right)(W_5) = \left(\frac{50.22'+43.85'}{2}\right)(58.33') = 2{,}743.55\ ft^2$ ✓

- $A_6 = \frac{1}{2}(H_5)(W_6) = \frac{1}{2}(43.85')(230.30') = 5{,}049.33\ ft^2$ ✓

- $A_7 = (W_8)(H_6) + 2\left[\frac{1}{2}(H_6)(W_7)\right]$

  $= (647.80')(12.53') + 2\left[\frac{1}{2}(12.53')(50.12')\right] = 8{,}744.94\ ft^2$ ✓

- $A_G = A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7$

$A_G = 35{,}472.89\ ft^2$ ✓

CALCULATE CROSS-SECTIONAL AREA OF COVER & LINER

- $A_C = 8.75'(L_1 + L_2 + L_3 + L_4 + L_5 + L_6)$

  $= 8.75'(288.25' + 58.57' + 88.70' + 88.79' + 58.68' + 234.44')$

$A_C = 7{,}152.51\ ft^2$ ✓

- $A_L = 5.0'(L_7 + L_8 + L_9) = 5.0'(51.66' + 647.80' + 51.66')$

$A_L = 3{,}755.60\ ft^2$ ✓

- $A_O = 402.5\ ft^2$ (AREA OF OVER ESTIMATION, SEE CALCULATION PROCEDURES PACKAGE.)

Written by: RAM Date: 95/10/12 (YY/MM/DD) Reviewed by: B.L Date: 95/10/16 (YY/MM/DD)

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE3900 Task No.: 11.1

CALCULATE NET AREA:

- $A_N = A_G - (A_C + A_L - A_D) = 35{,}472.89\ ft^2 - (7{,}152.51\ ft^2 + 3{,}755.60\ ft^2 - 402.5\ ft^2)$

$$A_N = 24{,}967.28\ ft^2 \checkmark$$

CALCULATE VOLUME OF ENDS:

- $$V_1 = \frac{1}{3}\left(H_3 - \frac{H_2 + H_4}{2}\right)(W_3 + W_4)^2$$

$$= \frac{1}{3}\left(55.47' - \frac{51.87' + 50.22'}{2}\right)(88.63' + 88.63')^2$$

$$V_1 = 46{,}346.13\ ft^3\ (1{,}716.52\ cyd) \checkmark$$

- $$V_2 = \frac{1}{3}\left(\frac{H_2 + H_4}{2} - \frac{H_1 + H_5}{2}\right)\left((W_3 + W_4)^2 + (W_2 + W_3 + W_4 + W_5)^2 + \sqrt{(W_3 + W_4)^2 (W_2 + W_3 + W_4 + W_5)^2}\right)$$

$$= \frac{1}{3}\left(\frac{51.87' + 50.22'}{2} - \frac{46.57' + 43.85'}{2}\right)\left((2 \cdot 88.63')^2 + (2 \cdot 88.63' + 2 \cdot 58.33')^2 + \sqrt{(2 \cdot 88.63')^2 (2 \cdot 88.63' + 2 \cdot 58.33')^2}\right)$$

$$V_2 = 330{,}475.60\ ft^3\ (12{,}239.84\ cyd) \checkmark$$

Written by: RAM Date: 95/10/12 (YY/MM/DD) Reviewed by: B.L Date: 95/10/16 (YY/MM/DD)

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE 3900 Task No.: 11.1

- $$\forall_3 = \frac{1}{3}\left(\frac{H_1+H_5}{2}\right)\left((W_2+W_3+W_4+W_5)^2+(W_{11})^2+\sqrt{(W_2+W_3+W_4+W_5)^2(W_{11})^2}\right)$$

$$= \frac{1}{3}\left(\frac{46.97'+43.85'}{2}\right)\left((2\cdot 58.33'+2\cdot 88.63')^2+(808.68')^2 + \sqrt{(2\cdot 58.33'+2\cdot 88.63')^2(808.68)^2}\right)$$

$$\forall_3 = 14{,}739{,}055.78\ ft^3\ (545{,}890.95\ cyd)$$ ✓

- $$\forall_4 = \frac{1}{3}(H_6)\left(W_8^2+W_{10}^2+\sqrt{(W_8^2)(W_{10}^2)}\right)$$

$$= \frac{1}{3}(12.53')\left((647.80')^2+(748.04')^2+\sqrt{((647.80')^2(748.04')^2)}\right)$$

$$\forall_4 = 6{,}113{,}758.70\ ft^3\ (226{,}435.51\ cyd)$$ ✓

- $$\forall_{ENDS} = \forall_1+\forall_2+\forall_3+\forall_4 \quad \text{(GROSS VOLUME)}$$

$$= 46{,}346.13\ ft^3 + 330{,}475.60\ ft^3 + 14{,}739{,}055.78\ ft^3 + 6{,}113{,}758.70\ ft^3$$

$$\underline{\underline{\forall_{ENDS} = 21{,}229{,}636.21\ ft^3\ (786{,}282.82\ cyd)}}$$ ✓

Written by: RAM Date: 95/10/12 (YY MM DD) Reviewed by: BL Date: 95/10/16 (YY MM DD)

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE3900 Task No.: 11.1

CALCULATE SURFACE AREA OF ENDS

- $S_{A1} = 2\left(\frac{1}{2}\left(2(W_3)\right)(L_3)\right) + 2\left(\frac{1}{2}\left(2(W_4)\right)(L_4)\right)$

$= \left(2(88.63')(88.70')\right) + \left(2(88.63')(88.79')\right)$

$S_{A1} = 31{,}461.88\ ft^2$ ✓

- $S_{A2} = 4\left(\frac{L_2+L_5}{2}\right)\left(\frac{(W_3+W_4)+(W_2+W_3+W_4+W_5)}{2}\right)$

$= 4\left(\frac{58.68'+58.57'}{2}\right)\left(\frac{(2\cdot 88.63')+(2\cdot 88.63'+2\cdot 58.33')}{2}\right)$

$S_{A2} = 55{,}245.86\ ft^2$ ✓

- $S_{A3} = 2\left(\frac{W_{11}+(W_2+W_3+W_4+W_5)}{2}\right)(L_1)$

$+ 2\left(\frac{W_{11}+(W_2+W_3+W_4+W_5)}{2}\right)(L_6)$

$= 2\left(\frac{808.68'+(2\cdot 88.63'+2\cdot 58.33')}{2}\right)(288.25')$

$+ 2\left(\frac{808.68'+(2\cdot 88.63'+2\cdot 58.33')}{2}\right)(234.44')$

$S_{A3} = 576{,}317.99\ ft^2$ ✓

Written by: RAM Date: 99/10/12 (YY MM DD) Reviewed by: R.L Date: 95/10/16 (YY MM DD)

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE 3900 Task No.: 11.1

- $S_{A4} = W_8^2 + 4(L_7)\left(\frac{W_4 + W_{10}}{2}\right)$

$= (647.80')^2 + 4(51.66')\left(\frac{647.8' + 748.04'}{2}\right)$ ✓

$S_{A4} = 563{,}863.03\ ft^2$ ✓

CALCULATE VOLUME OF COVER & LINER FOR ENDS

- $\forall_c = 8.75'(S_{A1} + S_{A2} + S_{A3})$

$= 8.75'(31{,}461.88\ ft^2 + 55{,}245.86\ ft^2 + 576{,}317.99\ ft^2)$

$\forall_c = 5{,}801{,}475.14\ ft^3\ (214{,}869.45\ cyd)$

- $\forall_L = 5.0'(S_{A4})$

$= 5.0'(563{,}863.03\ ft^2)$

$\forall_L = 2{,}819{,}315.14\ ft^3\ (104{,}419.08\ cyd)$ ✓

CALCULATE NET VOLUME OF ENDS

- $\forall_{ENDS}(NET) = \forall_{ENDS}(GROSS) - (\forall_c + \forall_L)$

$= 786{,}282.82\ cyd - (214{,}869.45\ cyd + 104{,}419.08\ cyd)$

$\forall_{ENDS}(NET) = 466{,}994.29\ cyd$ ✓

Written by: RAM Date: 95/10/13 Reviewed by: 13.L Date: 95/10/16

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE3900 Task No.: 11.1

CALCULATE VOLUME OF INTERCELL BERMS

- $A_1 = \frac{1}{2}(b_1)(h_1) = \frac{1}{2}(18')(4.1') = 36.9\ ft^2$ ✓
- $A_2 = (h_1)(b_2) = (4.1')(5.2') = 21.32\ ft^2$ ✓
- $A_3 = (b_3)\left(\frac{h_2+h_3}{2}\right) = (4.8')\left(\frac{4.1'+5.3'}{2}\right) = 22.56\ ft^2$ ✓
- $A_4 = (b_4)(h_4) = (8.1')(5.3') = 42.93\ ft^2$ ✓
- $A_5 = \frac{1}{2}(b_5)(h_4) = \frac{1}{2}(23')(5.3') = 60.95\ ft^2$ ✓

$A_T = A_1 + A_2 + A_3 + A_4 + A_5 = 184.66\ ft^2$ ✓

- $L_{AVG} = \frac{W_8 + W_{10}}{2} = \frac{647.80' + 748.04'}{2} = 697.92'$ ✓

\# of intercell berms 9-CELL OSDF

- $V_{IB-9} = 8(A_T)(L_{AVG}) = 8(184.66\ ft^2)(697.92')$

$V_{IB-9} = 1{,}031{,}023.26\ ft^3\ (38{,}186.05\ cyd)$ ✓

8-CELL OSDF

$V_{IB-8} = 7(A_T)(L_{AVG}) = 7(184.66\ ft^2)(697.92')$

$V_{IB-8} = 902{,}145.35\ ft^3\ (33{,}412.79\ cyd)$ ✓

Written by: RAM Date: 95/10/13 Reviewed by: BL Date: 95/10/16

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE3900 Task No.: 11.1

CALCULATE NET VOLUME (TOTAL) (9-CELL OSDF)

- $\forall_N(\text{TOTAL}) = \forall_{\text{ENDS}}(\text{NET}) + (A_N)(\text{LENGTH OF MIDSECTION}) - \forall_{IB-9}$

$= 466{,}994.29\ \text{cyd} + (24{,}967.28\ \text{ft}^2)(2909\ \text{ft})(1\ \text{yd}^3/27\ \text{ft}^3) - 38{,}186.05\ \text{cyd}$

$\forall_N(\text{TOTAL}) = 3{,}118{,}801.48\ \text{cyd}$ ✓

CALCULATE NET VOLUME (TOTAL) (8-CELL OSDF)

- $\forall_N(\text{TOTAL}) = \forall_{\text{ENDS}}(\text{NET}) + A_N(\text{LENGTH OF MIDSECTION}) - \forall_{IB-8}$

$= 466{,}994.29\ \text{cyd} + (24{,}967.28\ \text{ft}^2)(2509\ \text{ft})\left(\frac{1\ \text{yd}^3}{27\ \text{ft}^3}\right) - 33{,}412.79\ \text{cyd}$

$\forall_N(\text{TOTAL}) = 2{,}753{,}689.11\ \text{cyd}$ ✓

Written by: RAM Date: 95/10/13 (YY MM DD) Reviewed by: B.L Date: 95/10/16 (YY MM DD)

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE3900 Task No.: 11.1

OSDF CAPACITY VERIFICATION

(AUTOCAD® PROCEDURES AND QUANTITIES)

INTRODUCTION:

THE PURPOSE OF THIS SECTION IS TO PRESENT AN OVERVIEW OF THE AUTOCAD® PROCEDURES USED TO CALCULATE THE OSDF CAPACITY AND TO PRESENT THE CAPACITY QUANTITIES CALCULATED USING AUTOCAD®.

METHOD OF ANALYSIS:

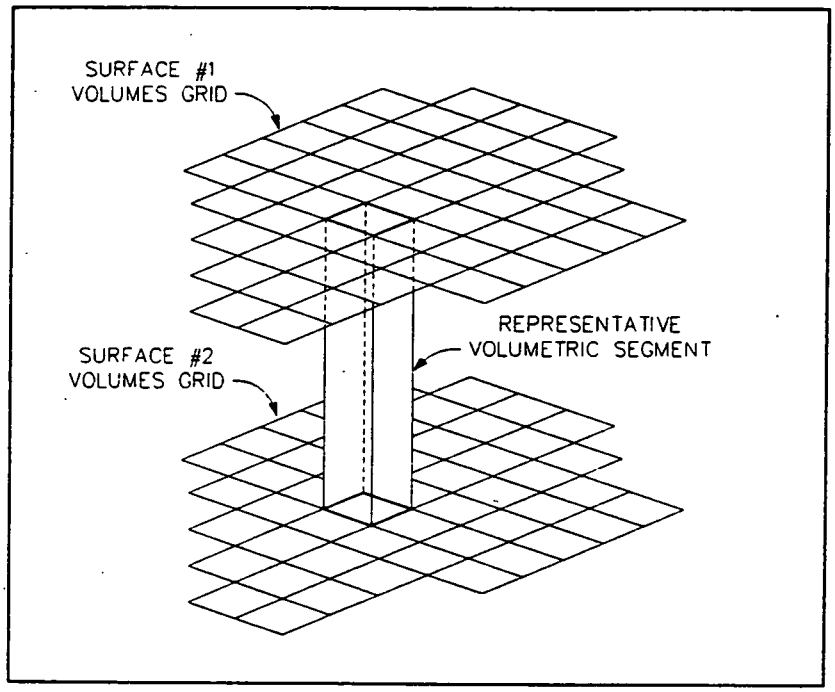
USING THE EARTHWORKS VOLUME CALCULATION PACKAGE DEVELOPED BY SOFTDESK FOR AUTOCAD® [SOFTDESK, 1994], THE USER CHOOSES TWO SURFACES BETWEEN WHICH AUTOCAD® CALCULATES THE VOLUME. AUTOCAD® GENERATES A TIN (TRIANGULAR IRREGULAR NETWORK) SURFACE FOR EACH OF THE SURFACES CHOSEN BY THE USER. THE TOP OF THE LEACHATE COLLECTION SYSTEM (LCS) PLAN AND THE TOP OF THE CONTOURING LAYER WERE THE TWO SURFACES CHOSEN IN ORDER TO DETERMINE THE OSDF CAPACITY USING THE GRID METHOD. THE GRID METHOD INTERPOLATES VOLUMES USING GRIDS (CHOSEN TO BE 10' x 10' GRIDS) OVERLAID ON THE

(CONTINUED)

Written by: RAM Date: 95/10/13 (YY MM DD) Reviewed by: B.L Date: 95/10/16 (YY MM DD)

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE3900 Task No.: 11.1

THE TWO TIN SURFACES. THE VOLUMES ARE CALCULATED USING THE PRISMOIDAL VOLUME OF ALL GRIDS AND SUMMARIZING. THE FOLLOWING ILLUSTRATION IS A REPRESENTATION OF THE GRID METHOD.



Calculating Volumes Using Grid Based Earthworks Method

REFERENCE:

SOFTDESK, INC., SOFTDESK® CIVIL/SURVEY: EARTHWORKS REFERENCE MANUAL, HENNIKER, NH, NOVEMBER 1994.

Written by: RAM Date: 95/10/13 Reviewed by: B.L Date: 95/10/16

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE 3900 Task No.: 11.1

- 9-CELL OSDF:

OSDF CAPACITY – CALCULATED USING AUTOCAD®

- SEE P. 15 AND 16 :

$\forall_{NET}$(AUTOCAD® USER #1) = 3,278,426.60 cyd

$\forall_{NET}$(AUTOCAD® USER #2) = 3,272,361.87 cyd

$\forall_{NET}$ (AVG) = 3,275,394.24 cyd ✓

COMPARISON: AUTOCAD® CAPACITY vs. HAND-CALC. CAPACITY

$\forall_{NET}$(AUTOCAD®) = 3,275,394.24 cyd ✓

$\forall_{NET}$ (HAND) = 3,118,801.48 cyd ✓

$$\% \text{ DIFFERENCE} = \frac{\forall_{NET}(\text{AUTOCAD®}) - \forall_{NET}(\text{HAND})}{\forall_{NET}(\text{AUTOCAD®})} * (100)$$

$$= \frac{3{,}275{,}394.24 \text{ cyd} - 3{,}118{,}801.48 \text{ cyd}}{3{,}275{,}394.24 \text{ cyd}} * (100)$$

% DIFFERENCE = 4.80% ✓

Written by: RAM Date: 95 / 10 / 16 (YY MM DD) Reviewed by: B.L. Date: 95 / 10 / 16 (YY MM DD)

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE3900 Task No.: 11.1

- 8-CELL OSDF:

OSDF CAPACITY - CALCULATED USING AUTOCAD®.

- SEE P.15 AND 16:

V_{NET} (AUTOCAD® USER #1) = 2,900,618.05 cyd ✓

V_{NET} (AUTOCAD® USER #2) = 2,895,452.11 cyd ✓

V_{NET} (AVG) = 2,898,035.08 cyd ✓

COMPARISON: AUTOCAD® CAPACITY vs. HAND-CALC. CAPACITY

V_{NET}(AUTOCAD®) = 2,898,035.08 cyd ✓

V_{NET}(HAND) = 2,753,689.11 cyd ✓

$$\% \text{ DIFFERENCE} = \frac{V_{NET}(\text{AUTOCAD®}) - V_{NET}(\text{HAND})}{V_{NET}(\text{AUTOCAD®})}(100)$$

$$= \frac{(2{,}898{,}035.08 \text{ cyd} - 2{,}753{,}689.11 \text{ cyd})}{2{,}898{,}035.08 \text{ cyd}}(100)$$

% DIFFERENCE = 4.98 % ✓

B2 — 95/10/16

RAM 95/10/13

FERMCO FERNALD OSDF GE3900 11.1

Subsite Volume Table: Unadjusted

Stratum	Surf1	Surf2	Cut yards	Fill yards	Net yards
Subsite: S1					
cover	lcs	cov-8	0.00	312498.91	312498.91 (F)
Subsite: S2					
cover	lcs	cov-8	0.00	382964.23	382964.23 (F)
Subsite: S3					
cover	lcs	cov-8	0.00	380800.21	380800.21 (F)
Subsite: S4					
cover	lcs	cov-8	0.00	380378.59	380378.59 (F)
Subsite: S5					
cover	lcs	cov-8	0.00	380758.11	380758.11 (F)
Subsite: S6					
cover	lcs	cov-8	0.00	381458.23	381458.23 (F)
Subsite: S7					
cover	lcs	cov-8	0.00	377893.28	377893.28 (F)
Subsite: S8					
cover	lcs	cov-8	0.00	377808.55	377808.55 (F)
Subsite: S9					
cover	lcs	cov-8	0.00	303866.49	303866.49 (F)

3,278,426.60 cyd
(9-CELL OSDF)

- 400' LENGTH OF MIDSECTION
- V (8-CELL OSDF) = 3,278,426.60 − 377,808.55
  = 2,900,618.05 cyd
  (8-CELL OSDF)

RAM 95/10/13

FERMCO FERNALD OSDF GE3900 11.1

Subsite Volume Table: Unadjusted

Stratum	Surf1	Surf2	Cut yards	Fill yards	Net yards
Subsite: J1					
vol-1	johna	cov-8	0.00	311268.05	311268.05 (F)
Subsite: J2					
vol-1	johna	cov-8	0.00	381997.36	381997.36 (F)
Subsite: J3					
vol-1	johna	cov-8	0.00	380830.08	380830.08 (F)
Subsite: J4					
vol-1	johna	cov-8	0.00	380876.36	380876.36 (F)
Subsite: J5					
vol-1	johna	cov-8	0.00	380411.40	380411.40 (F)
Subsite: J6					
vol-1	johna	cov-8	0.00	380050.57	380050.57 (F)
Subsite: J7					
vol-1	johna	cov-8	0.00	377301.16	377301.16 (F)
Subsite: J8					
vol-1	johna	cov-8	0.00	376909.76	376909.76 (F)
Subsite: J9					
vol-1	johna	cov-8	0.00	302717.13	302717.13 (F)

3,272,361.87 cyd
(9-CELL OSDF)

- 400' LENGTH OF MIDSECTION
- ∀ (8-CELL OSDF) = 3,272,361.87 − 376,909.76
  = 2,895,452.11 cyd
  (8-CELL OSDF)

APPENDIX A

COMPUTER SOFTWARE USED TO PREPARE CALCULATIONS PACKAGE

1. Autodesk®, Inc., AutoCAD® Release 13 User's Guide, September 1994.

2. SOFTDESK®, Inc., SOFTDESK® Civil/Survey: Earthworks Reference Manual, Henner, NH, November 1994.

See Section 1.2 of the Design Parameter Summary.

2.3 Earthwork Required Volume

COMPUTATION COVER SHEET

SUBJECT OF CALCULATION: EARTHWORK REQUIRED VOLUME

Computations By: (Cognizant Engineer)
Signature: Paul J. Sabatini — Date: 20 Feb 1996
Printed Name and Title: PAUL J. SABATINI, SENIOR STAFF ENGINEER

Assumptions and Procedures Checked by: (Checker)
Signature: B B Mazanti — Date: 22 Feb 96
Printed Name and Title: B. B. MAZANTI, Consultant

Computations Checked by:
Signature: B B Mazanti — Date: 22 Feb 96
Printed Name and Title: B. B. MAZANTI, Consultant

Computations Backchecked by: (Cognizant Engineer)
Signature: Paul J. Sabatini — Date: 22 Feb 1996
Printed Name and Title: PAUL J. SABATINI, SENIOR STAFF ENGINEER

Approved by: (PDP)
Signature: Kara L Olen — Date: 22 Feb 96
Printed Name and Title: Kara L. Olen, Asst Proj Engr

Approved by: (DTL and TETL)
Signature: [illegible] — Date: 23 Feb 96
Printed Name and Title: Kenneth W Cargill, Associate

Record of Revision (Number and initial all revisions)

Rev. No.	Reason	Date	By	Checked	Approval
C	Intermediate Design				
D	Addition of Contouring layer and road Aggregate quantities	5 APRIL 96	DCP	K. Olen	[illegible] 5 Apr 96

Written by: Paul J. Sabatini Date: 20 Feb 1996 Reviewed by: [illegible] Date: 2/2

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE-3900 Task No.: 8.11

OSDF EARTHWORK REQUIREMENTS
EXECUTIVE SUMMARY

Earthwork quantities for the OSDF are calculated in this section. All quantities are presented as compacted volumes. The earthwork quantities were calculated for the following components of the OSDF:

- compacted clay liner;
- leachate detection system (LDS) drainage layer;
- leachate collection system (LCS) drainage layer;
- protective layer;
- compacted clay cap;
- cover drainage layer;
- biointrusion barrier;
- choke layer;
- granular filter;
- vegetative soil layer;
- topsoil;
- seasonal cover;
- riprap; and
- compacted fill.
- CONTOURING LAYER
- AGGREGATE BASE
- AGGREGATE SUBBASE

AD, DGP 2 APRIL 96

(KW)

Written by: Paul J. Sabatini Date: 20 Feb 1996 Reviewed by: [illegible] Date: [illegible]

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE-3900 Task No.: 8.11

The required quantities (in cubic yards) are summarized below.

	8 Cells	9 Cells
• compacted clay liner	297,231	334,097
• leachate detection system (LDS) drainage layer	85,589	96,286
• leachate collection system (LCS) drainage layer	106,302	119,608
• protective layer	64,892(1)	72,982(1)
• compacted clay cap	194,582	218,286
• cover drainage layer	124,070	138,441
• biointrusion barrier	293,896	329,585
• choke layer	23,784	26,691
• granular filter	57,428	64,177
• vegetative soil layer	232,166	258,741
• topsoil	57,428	64,177
• seasonal cover	25,151	28,744
• riprap(2)	26,574	26,574
• compacted fill	124,437	137,071 Δ P, DGP
• CONTOURING LAYER	87,658	98,532 2 APRIL 96
• AGGREGATE BASE	30,578	30,578
• AGGREGATE SUBBASE	41,306	41,306

(1) Quantities for protective soil layer reflect both impacted and non-impacted material.

(2) Riprap quantities, as calculated herein, are for the entire OSDF and are not calculated on a per cell basis.

EARTHWORK REQUIRED VOLUME

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2.	Collection and Verification of Data	1/1
3.	Calculation Results	1/32
	a. Summary of Required Earthwork Quantities	20/32
	b. Summary of Required Road Aggregate Quantities	20a/32

Written by: Paul J. Sabatini Date: 96 / 2 / 20 (YY MM DD) Reviewed by: BAM Date: 96 / 3 / 2 (YY MM DD)

Client: Fernco Project: Fernald Project/Proposal No.: GE3900 Task No.: 3.11

OSDF Earthwork Requirements

Calculation Procedures

The purpose of the calculations presented in this package is to estimate earthwork quantities for the OSDF. These calculations were performed for individual components or portions of the OSDF. The earthwork quantities were calculated for each of the following portions of the OSDF:

- intercell berm;
- inner cell (i.e., Cells 2-8) liner system;
- end cell (i.e., Cells 1 and 9) liner system;
- inner cell (i.e., Cells 2-8) cover system;
- end cell (i.e., Cells 1 and 9) cover system.

In addition, earthwork quantities associated with the following were also calculated:

- seasonal cover for each cell;
- riprap requirements for the OSDF drainage channels; and
- compacted fill requirements for each cell. AD, DGP, 2 APRIL 96
- ROAD AGGREGATE FOR EACH OF THE 3 OSDF CONSTRUCTION STAGES (i.e., early, middle and final stages)

Written by: Paul J. Sabatini Date: 96/2/20 Reviewed by: [illegible] Date: 96/2/2[illegible]

Client: FEMPCO Project: Fernald Project/Proposal No.: GE3900 Task No.: 8.11

The earthwork components of the OSDF include:

- compacted clay liner (CCL);
- leachate detection system (LDS) drainage layer;
- leachate collection system (LCS) drainage layer;
- protective layer (PL);
- compacted clay cap (CCC);
- cover drainage layer (CDL);
- biointrusion barrier (BB);
- choke layer (CL)
- granular filter (GF)
- vegetative soil layer (VSL);
- topsoil (TS);
- seasonal cover (SC)
- riprap (RR); and
- compacted fill (FILL).
- CONTOURING LAYER (CL)
- AGGREGATE BASE (AB)
- AGGREGATE SUBBASE (AS)

DO, DGP 2APR96

The organization of the calculations performed herein is summarized in Table 1. Each portion of the OSDF corresponds to a calculation, as indicated in the table. For each of the ~~eight~~ NINE calculations performed, methods, assumptions, and schematic sketches and figures are presented.

Written by: Paul J. Sabatini Date: 96/2/20 (YY/MM/DD) Reviewed by: [illegible] Date: 96/2/21 (YY/MM/DD)

Client: FERMCO Project: Fernald Project/Proposal No.: GE3900 Task No.: 5.11

For each of the ~~eight~~ NINE calculations, the appropriate drawings from the design drawings (USDOE, FEMP, OSDF, "Intermediate Design Package) were used. Component areas and volumes were calculated by hand using information from the drawings and the methods described below: ΔD, DGP, 2 APRIL 96

- required dimensions were scaled directly off the design drawings and volumes were calculated;
- cross-sectional areas or plan areas were evaluated using a digital planimeter and volumes were calculated accordingly; and
- required volumes were computer generated using specific design drawings.

Written by: DGP Date: 96/4/2 (YY MM DD) Reviewed by: Date: / / (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 8.2

ΔD, DGP 2 APRIL 96 (KW)

TABLE 1. SUMMARY OF OSDF EARTHWORK CALCULATIONS

CALCULATION NO.	PORTION OF OSDF	EARTHWORK MATERIALS FOR PORTION OF OSDF																
		CCL	LDS	LCS	PL	CCC	CDL	BB	CL	GF	VSL	TS	SC	RR	FILL	CL	AB	AS
1	interceil berm	✓	✓	✓	✓(1)													
2	inner cell liner system	✓	✓	✓	✓													
3	end cell liner system	✓	✓	✓	✓													
4	inner cell cover system					✓	✓	✓	✓	✓	✓	✓				✓		
5	end cell cover sys. (cal 1 and 9)					✓	✓	✓	✓	✓	✓	✓				✓		
6	seasonal cover												✓					
7	riprap													✓				
8	general fill														✓			
9	ROAD AGGREGATE																✓	✓

Notes: (1) Protective soil layer for intercell berm includes both impacted and non-impacted material

Written by: Paul J. Sabatini Date: 96 / 2 / 20 (YY MM DD) Reviewed by: BDM Date: 96 / 2 / 2. (YY MM DD)

Client: FERMCO Project: Fernald Project/Proposal No.: GE3900 Task No.: 8.11

OSDF Earthwork Requirements

Collection and Verification of Data

The data used to estimate the earthwork quantities for the OSDF were obtained directly from the design drawings (USDOE, FEMP, OSDF, "Intermediate Design Package"). Specific drawings used are presented in the calculation results package.

Written by: Paul J. Sabatini Date: 96 / 2 / 20 (YY MM DD) Reviewed by: [illegible] Date: 96 / 2 / [illegible] (YY MM DD)

Client: FERMCO Project: Fernald Project/Proposal No.: GE3900 Task No.: 8.11

OSDF Earthwork Requirements

Calculation Results

Calculation No. 1 : Intercell Berm

- Summary of dimensions to be used in calculations

Width of intercell berm (Figure 1)	59 ft	✓
Length of intercell berm (Figure 2)	705 ft	✓
Length of intercell berm along impacted runoff catchment area (Figure 3)	285 ft	✓
Length of intercell berm outside impacted runoff catchment area (Figure 3)	420 ft	✓
Approximate length along top of intercell berm (toe-to-toe length) (Figure 1)	61 ft	✓
Cross-sectional area of compacted clay liner at intercell berm (Figure 1)	281 ft^2	✓
Additional compacted clay liner area (Figure 4)	98 ft^2	✓
Cross-sectional area of protective layer (non-impacted material) (Figure 1)	46 ft^2	✓
Cross-sectional area of additional LCS material on intercell berm (North side) along impacted runoff catchment area (Figure 1)	15 ft^2	✓
* Cross-sectional area of protective layer (impacted material) on intercell berm (North side) outside impacted runoff catchment area (Figure 1)	15 ft^2	✓

* This material "replaces LCS material which discontinues at termination of impacted runoff catchment area.

Written by: Paul J. Sabatini Date: 96 / 2 / 20 (YY MM DD) Reviewed by: [illegible] Date: 96 / 2 / 21 (YY MM DD)

Client: FERMCO Project: Fernald Project/Proposal No.: GE3900 Task No.: 8.11

- Earthwork quantities per intercell berm

Compacted Clay Liner

$$\frac{(281\,ft^2)(705\,ft) + (98\,ft^2)(59\,ft)(2\,sides)}{27\,ft^3/yd^3} = 7{,}765\,yd^3$$

LDS Drainage Layer

$$\frac{(61\,ft)(705\,ft)(1\,ft)}{27\,ft^3/yd^3} = 1{,}593\,yd^3$$

LCS Drainage Layer

.. along runoff catchment area

$$\frac{(61\,ft)(285\,ft)(1\,ft) + (15\,ft^2)(285\,ft)}{27\,ft^3/yd^3} = 803\,yd^3$$

.. outside runoff catchment area

$$\frac{(61\,ft)(420\,ft)(1\,ft)}{27\,ft^3/yd^3} = 949\,yd^3$$

$1{,}752\,yd^3$

Protective Layer

.. non-impacted material

$$\frac{(46\,ft^2)(705\,ft)}{27\,ft^3/yd} = 1{,}201\,yd^3$$

.. select impacted material

$$\frac{(15\,ft^2)(420\,ft)}{27\,ft^3/yd^3} = 233\,yd^3$$

$1{,}434\,yd^3$

Written by: Paul J. Sabatini Date: 96 / 12 / 20 (YY MM DD) Reviewed by: [illegible] Date: 96 / 12 / 21 (YY MM DD)

Client: FERMCO Project: Fernald Project/Proposal No.: GE3900 Task No.: E.11

Calculation No. 2: Inner Cell Liner System

- Summary of dimensions to be used in calculations

Liner system component thicknesses	Figure 5
Length of inner cell (Figure 2); length is measured along top of compacted clay liner for calculation of compacted clay liner volume	705 ft
Length of inner cell (Figure 2); length is measured from crest of liner system sideslope to crest of liner system sideslope for calculation of other liner system components	723 ft
Cell width (Figure 6); width is measured from toe of intercell berm to toe of intercell berm at the top of the compacted clay liner	340 ft
Additional compacted clay liner area (Figure 4)	98 ft^2
Length (East-West) of impacted runoff catchment area (Figure 3)	285 ft
Length (North-South) of impacted runoff catchment area (Figure 3) measured from toe of intercell berm	232 ft

Written by: Paul J. Sabatini Date: 96 / 2 / 20 (YY MM DD) Reviewed by: BMM Date: 96 / 2 / 23 (YY MM DD)

Client: FERMCO Project: Fernald Project/Proposal No.: GE3900 Task No.: 8.11

- Earthwork quantities per inner cell liner system

Compacted Clay Liner

$$\frac{(705\,ft)(340)(3\,ft) + (98\,ft^2)(340\,ft)(2\,sides)}{27\,ft^3/yd^3} = 29{,}101\,yd^3 \checkmark$$

LDS Drainage Layer

$$\frac{(723\,ft)(340\,ft)(1\,ft)}{27\,ft^3/yd^3} = 9{,}104\,yd^3 \checkmark$$

LCS Drainage Layer

.. in impacted runoff catchment area

$$\frac{(285\,ft)(232\,ft)(2\,ft)}{27\,ft^3/yd^3} = 4{,}898\,yd^3 \checkmark$$

.. outside impacted runoff catchment area

$$\frac{[(723\,ft)(340\,ft) - (285\,ft)(232\,ft)](1\,ft)}{27\,ft^3/yd^3} = \underline{6{,}656\,yd^3} \checkmark$$

$11{,}554\,yd^3$ ✓

Protective Layer (select, impacted material)

$$\frac{[(723\,ft)(340\,ft) - (285\,ft)(232\,ft)](1\,ft)}{27\,ft^3/yd^3} = 6{,}656\,yd^3 \checkmark$$

Written by: Paul J. Sabatini Date: 96 / 2 / 20 (YY MM DD) Reviewed by: HBM Date: 96 / 2 / 21 (YY MM DD)

Client: FERMCO Project: Fernald Project/Proposal No.: GE3406 Task No.: E.11

Calculation No. 3: End Cell Liner System

The calculation of earthwork quantities for the end cells (i.e., Cell 1 and Cell 9) vary from that of the inner cells due to the additional materials for the north side perimeter berm (Cell 1) and the south side perimeter berm (Cell 9). The differences between the end cell liner system calculation as compared to the inner cell liner system calculation is illustrated schematically using the sketch on the next page (Sketch 1).

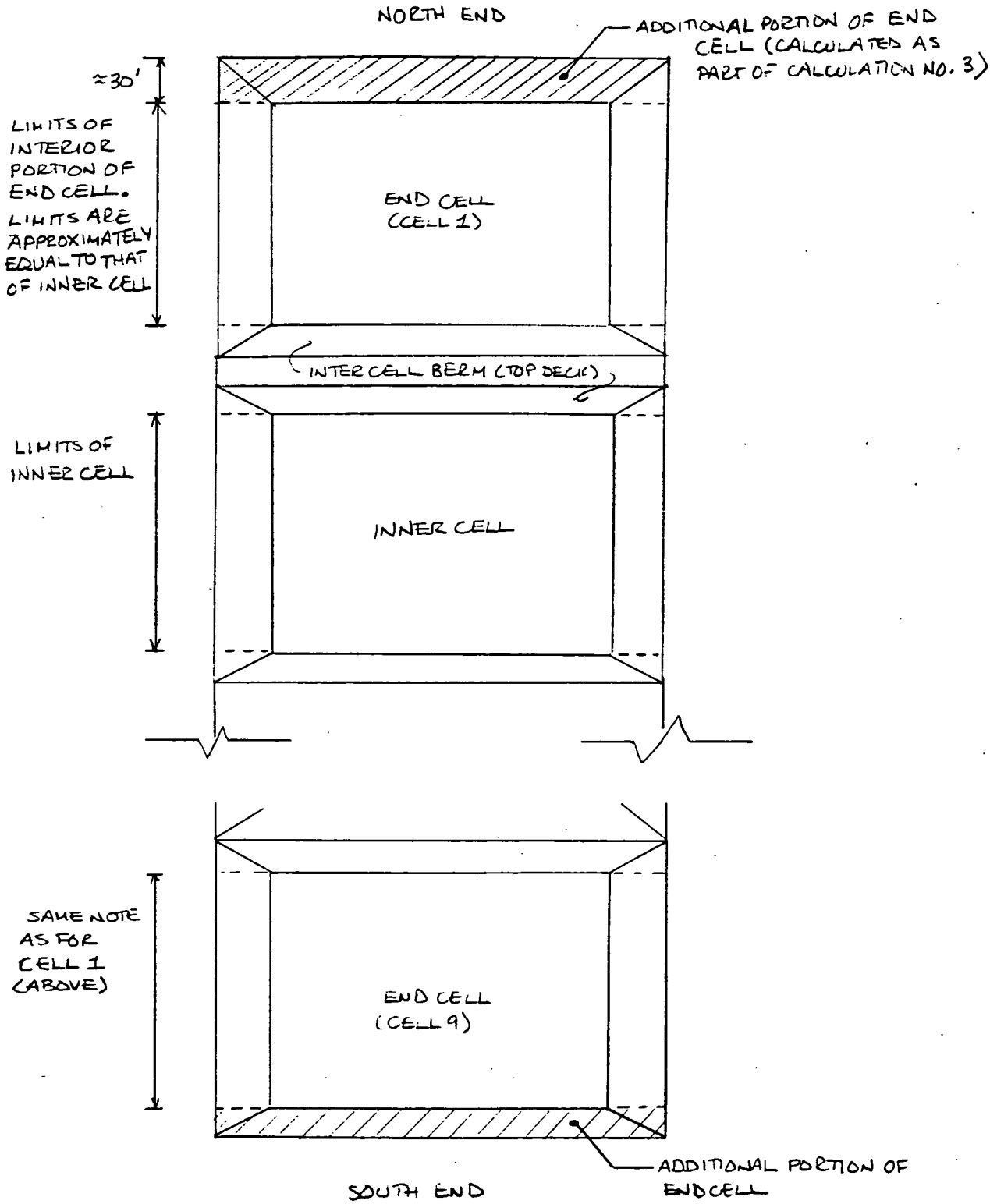
- Summary of dimensions to be used in calculations

  Width of end cell perimeter berm (Figure 3) 30 ft ✓

Note: dimensions used for Calculation No. 2 are also used for this calculation.

Written by: Paul J. Sabatini Date: 96 / 2 / 20 (YY MM DD) Reviewed by: [illegible] Date: 96 / 2 / 21 (YY MM DD)

Client: FEMPC Project: Fernald Project/Proposal No.: GE3400 Task No.: 3.11



SKETCH 1 - PLAN OF OSDF BASE LINER SYSTEM (NOT TO SCALE)

Written by: Paul J. Sabatini Date: 96 / 2 / 20 (YY MM DD) Reviewed by: [illegible] Date: 96 / 2 / 21 (YY MM DD)

Client: FERUCO Project: Fernald Project/Proposal No.: GE3900 Task No.: 5.11

- Earthwork quantities per end cell (cell 1 and cell 9) perimeter berm

Compacted Clay Liner

$$\frac{(723\,ft)(30\,ft)(3\,ft) + (98\,ft^2)(723\,ft)}{27\,ft^3/yd^3} = 5{,}034\,yd^3 \checkmark$$

LDS Drainage Layer

$$\frac{(723\,ft)(30\,ft)(1\,ft)}{27\,ft^3/yd^3} = 803\,yd^3 \checkmark$$

LCS Drainage Layer

$$\frac{(723\,ft)(30\,ft)(1\,ft)}{27\,ft^3/yd^3} = 803\,yd^3 \checkmark$$

Protective Layer (select, impacted material)

$$\frac{(723\,ft)(30\,ft)(1\,ft)}{27\,ft^3/yd^3} = 803\,yd^3 \checkmark$$

- Earthwork quantities per end cell (add quantities from above and those from Calculation No. 2)

Compacted Clay Liner	$29{,}101\,yd^3 + 5{,}034\,yd^3 =$	$34{,}135\,yd^3$ ✓
LDS Drainage Layer	$9{,}104\,yd^3 + 803\,yd^3 =$	$9{,}907\,yd^3$ ✓
LCS Drainage Layer	$11{,}554\,yd^3 + 803\,yd^3 =$	$12{,}357\,yd^3$ ✓
Protective Layer select, impacted material	$6{,}656\,yd^3 + 803\,yd^3 =$	$7{,}459\,yd^3$ ✓

Written by: Paul J. Sabatini Date: 96 / 2 / 20 (YY MM DD) Reviewed by: [illegible] Date: 96 / 2 / 21 (YY MM DD)

Client: FERMCO Project: Fernald Project/Proposal No.: GE3900 Task No.: 8.11

Calculation No. 4 : Inner Cell Cover System

- Summary of dimensions to be used in calculations

Final cover system component thicknesses	Figure 7
Length of final cover system (for calculation of compacted clay cap volume (Figure 2))	673 ft ✓
Length of final cover system (for calculation of other cover system components (Figure 2))	785 ft ✓
Additional compacted clay area for final cover system (Figure 4)	127 ft² ✓
Width of final cover system (from ℄ of intercell berm to ℄ of intercell berm) (Figure 6)	400± ft ✓
Additional component areas beyond point X on Figure 4 (*)	
.. topsoil	31.5 ft² ✓
.. vegetative soil layer	210 ft² ✓
.. granular filter	31.5 ft² ✓
.. biointrusion barrier	27 ft² ✓
.. cover drainage layer	92.5 ft² ✓
LENGTH OF FINAL COVER SYSTEM (FOR CALCULATION OF CONTOURING LAYER VOLUME (FIGURE 2))	734 ft ✓ (VO)

AD, DGP 2 APRIL 96

* For the OSDF, the distance from point (X) to the cover drainage layer tie-in varies from approximately 80 to 110 ft. For each cell, a distance of 100 ft was assumed. Therefore, the additional cover component areas calculated using Figure 4 (and as reported above), are considered to be representative for the OSDF. ✓

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Written by: Paul J. Sabatini Date: 96 / 2 / 20 (YY MM DD) Reviewed by: [illegible] Date: 96 / 2 / 21 (YY MM DD)

Client: FERMCO Project: Fernald Project/Proposal No.: GE3900 Task No.: 5.11

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CONTOURING LAYER $\frac{(734\ ft)(400\ ft)(1\ ft)}{27\ ft^3/yd^3}$ = 10,874 yd^3

Earthwork quantities per inner cell cover system

Compacted Clay Cap

$\frac{(673\ ft)(400\ ft)(2\ ft) + (127\ ft^2)(400\ ft)\ 2\ sides}{27\ ft^3/yd^3}$ = 23,704 yd^3 ✓

Cover Drainage Layer

$\frac{(785\ ft)(400\ ft)(1\ ft) + (92.5\ ft^2)(400\ ft)\ 2\ sides}{27\ ft^3/yd}$ = 14,371 yd^3 ✓

Biointrusion Barrier

$\frac{(785\ ft)(400\ ft)(3\ ft) + (27\ ft^2)(400\ ft)\ 2\ sides}{27\ ft^3/yd^3}$ = 35,689 yd^3 ✓

Choke Layer (*)

$\frac{(785\ ft)(400\ ft)(0.25\ ft)}{27\ ft^3/yd^3}$ = 2,907 yd^3 ✓

Granular Filter

$\frac{(785\ ft)(400\ ft)(0.5\ ft) + (31.5\ ft^2)(400\ ft)\ 2\ sides}{27\ ft^3/yd^3}$ = 6,749 yd^3 ✓

Vegetative Soil Layer

$\frac{(785\ ft)(400\ ft)(1.75\ ft) + (210\ ft^2)(400\ ft)\ 2\ sides}{27\ ft^3/yd^3}$ = 26,575 yd^3 ✓

Topsoil Layer

$\frac{(785\ ft)(400\ ft)(0.5\ ft) + (31.5\ ft^2)(400\ ft)\ 2\ sides}{27\ ft^3/yd^3}$ = 6,749 yd^3 ✓

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(*) The choke stone layer shall be graded into the top 6" of the biointrusion barrier. For the choke stone layer quantity estimate, it is assumed that a quantity equivalent to a 3"-thick layer is necessary to [illegible]

Written by: Paul J. Sabatini Date: 96 / 2 / 20 (YY MM DD) Reviewed by: [illegible] Date: 96 / 2 / 21 (YY MM DD)

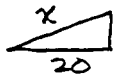
Client: FERMCO Project: Fernald Project/Proposal No.: GE 5900 Task No.: 8.11

Calculation No. 5 : End Cell Cover System

Based on the design drawings for the OSDF, it is reasonable to assume that the earthwork quantities for the cover system components of each end cell (i.e., Cell 1 and Cell 9) are approximately equal. For this calculation, quantities for the Cell 1 cover system are calculated. These quantities are also reported in Table 2 for Cell 9.

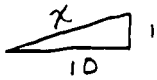
- Calculate surface area of Cell 1 final cover system to use in quantity calculations

  a) determine multiplier to convert plan areas to surface areas *

  - for 20:1 slope 

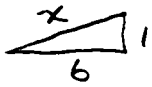
    $x = 20.025$

    $\therefore$ multiplier $= 20.025/20 = 1.0012$

  - for 10:1 slope 

    $x = 10.0499$

    $\therefore$ multiplier $= 10.0499/10 = 1.0050$

  - for 6:1 slope 

    $x = 6.0828$

    $\therefore$ multiplier $= 6.0828/6 = 1.0138$

* This method is reasonable if plan lengths shown in Sketch 2 are true. For the purposes of this calculation, it is assumed that the OSDF sits on a flat surface so that only cover slope lengths need to be corrected.

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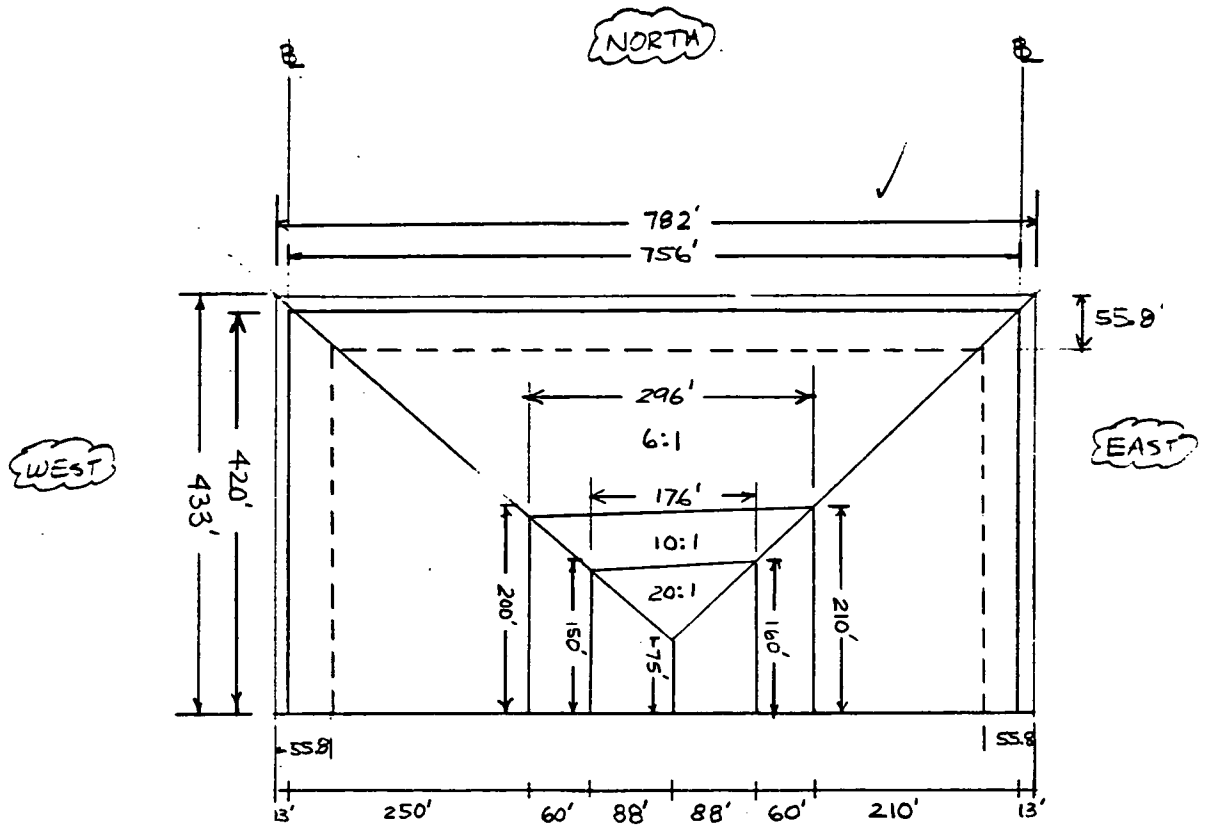
Written by: Paul J. Sabatini Date: 96 / 12 / 20 (YY MM DD) Reviewed by: [illegible] Date: 96 / 12 / 2 (YY MM DD)

Client: FERMCO Project: Fernald Project/Proposal No.: GE3900 Task No.: 8.11



— — — — EXTENT OF CONSTANT THICKNESS COMPACTED CLAY AND OF CONSTANT SLOPE FOR CONTOURING LAYER.

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Sketch 2 - FINAL COVER SYSTEM (NORTH END CELL)

Written by: Paul J. Sabatini Date: 96 / 10 / 20 (YY MM DD) Reviewed by: [illegible] Date: 96 / 2 / 2 / 1 (YY MM DD)

Client: FERMCO Project: Fernald Project/Proposal No.: GE3900 Task No.: 8.11

b) Calculate North side area

$$\text{Area} = \frac{1}{2}\left[\frac{233+223}{2}\left[782+296\right]\right] * 1.0138 + \quad \{6:1\}$$

$$\frac{1}{2}\left[50(296+176)\right] * 1.005 + \quad \{10:1\}$$

$$\frac{1}{2}\left[\frac{75+85}{2}(176)\right] * 1.0012 \quad \{20:1\}$$

Area = 143,496 ft² ✓

c) Calculate West side area

$$\text{Area} = \frac{1}{2}\left[(250+13)\left[433+200\right]\right] * 1.0138 + \quad \{6:1\}$$

$$\frac{1}{2}\left[60(200+150)\right] * 1.005 + \quad \{10:1\}$$

$$\frac{1}{2}\left[88(75+150)\right] * 1.0012 \quad \{20:1\}$$

Area = 104,853 ft² ✓

d) Calculate East side area

$$\text{Area} = \frac{1}{2}\left[(210+13)\left[433+210\right]\right] * 1.0138 + \quad \{6:1\}$$

$$\frac{1}{2}\left[60(210+160)\right] * 1.005 + \quad \{10:1\}$$

$$\frac{1}{2}\left[88(75+160)\right] * 1.0012$$

Area = 94,192 ft² ✓

e) Total area = 143,496 ft² + 104,853 ft² + 94,192 ft²

= 342,541 ft² ✓

Written by: Paul J. Sabatini Date: 96 / 2 / 20 (YY MM DD) Reviewed by: [illegible] Date: 96 / 2 / 21 (YY MM DD)

Client: FERMCO Project: Fernald Project/Proposal No.: GE3900 Task No.: 8.11

f) To compute the volume of the end cell cover components, the following adjustments need to be made:

- the compacted clay "area" needs to be reduced by 55.8' (see Sketch 2) and the additional compacted clay area (127 ft²; see Figure 4) needs to be added

.. area to reduce by

$$\text{Area} = 2 \times \frac{1}{2}(55.8')\left[433+(433-55.8)\right] * 1.0138 + \frac{1}{2}(55.8')\left[782+(782-55.8-55.8)\right] * 1.0138$$

$$= 86{,}915 \text{ ft}^2 \text{ (to be subtracted)}$$

.. area to increase by

multiply area of additional clay (127 ft²) by the perimeter of the end cell; use average perimeter measured $\frac{1}{2}(55.8') = 28$ ft in from point (X) (Figure 4); perimeter along that line is 1540 ft (Figure 8).

$$\text{Area} = 127 \text{ ft}^2 (1540) = 195{,}580 \text{ ft}^3$$

- SEE PAGE 13a AD, DOP 2 APRIL 96
- for other cover components, multiply additional areas (see Calculation No. 4) by the perimeter of the end cell; use perimeter measured approximately 50 ft from the perimeter berm baseline (Figure 4); perimeter along that line is 1820 ft (Figure 8).

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Written by: DGP Date: 96 / 4 / 2 (YY MM DD) Reviewed by: Date: 96 / / (YY MM DD)

Client: FERMCO Project: Fernald Project/Proposal No.: GE 3900 Task No.: 8.11

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- the CONTOURING LAYER "AREA" needs to be reduced by 55.8' (see Sketch 2) and the additional CONTOURING LAYER AREA (30.5 ft²; see Figure 4) needs to be added

∴ area to reduce by

$$A_{Ma} = 2 \times \frac{1}{2}(55.8')\left[433+(433-55.8)\right] * 1.0138 + \frac{1}{2}(55.8')\left[782+(782-55.8-55.8)\right] * 1.0138$$

$$= 86{,}915 \text{ ft}^2 \text{ (to be subtracted)}$$

∴ area to increase by

multiply area of additional clay (30.5 ft²) by the perimeter of the end cell; use average perimeter measured $\frac{1}{2}(55.8') = 28$ ft in from point (X) (Figure 4); perimeter along that line is 1540 ft (Figure 8).

$A_{Ma} = 30.5 \text{ ft}^2 (1540) = 46{,}970 \text{ ft}^3$

Written by: Paul J. Sabatini Date: 96 / 2 / 20 (YY MM DD) Reviewed by: MJM Date: 96 / 2 / 2 (YY MM DD)

Client: FERMCO Project: Fernald Project/Proposal No.: GE3900 Task No.: 8.11

- Earthwork quantities for end cell cover system

Compacted Clay Cap

$$\frac{(342{,}541\,ft^2)(2\,ft) - (86{,}915\,ft^2)(2\,ft) + 195{,}580\,ft^3}{27\,ft^3/yd^3} = 26{,}179\,yd^3 \checkmark$$

Cover Drainage Layer

$$\frac{(342{,}541\,ft^2)(1\,ft) + (1820\,ft)(92.5\,ft^2)}{27\,ft^3/yd^3} = 18{,}922\,yd^3 \checkmark$$

Biointrusion Barrier

$$\frac{(342{,}541)(3.0\,ft) + (1820\,ft)(27\,ft^2)}{27\,ft^3/yd^3} = 39{,}881\,yd^3 \checkmark$$

Choke Layer (*)

$$\frac{(342{,}541)(0.25\,ft)}{27\,ft^3/yd^3} = 3{,}171\,yd^3 \checkmark$$

Granular Filter

$$\frac{(342{,}541\,ft^2)(0.5\,ft) + (1820\,ft)(31.5\,ft^2)}{27\,ft^3/yd^3} = 8{,}467\,yd^3 \checkmark$$

Vegetative Soil Layer

$$\frac{(342{,}541\,ft^2)(1.75\,ft) + (1820\,ft)(210\,ft^2)}{27\,ft^3/yd^3} = 36{,}358\,yd^2 \checkmark$$

Topsoil

$$\frac{(342{,}541\,ft^2)(0.5\,ft) + (1820\,ft)(31.5\,ft^2)}{27\,ft^3/yd^3} = 8{,}467\,yd^3 \checkmark$$

(*) See note on bottom of page 9.

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CONTOURING LAYER

$$\frac{(342{,}541\,ft^2)(1\,ft) - (86{,}915\,ft^2)(1\,ft) + 46{,}970\,ft^3}{27\,ft^3/yd^3} = 11{,}207\,yd^3$$

ΔD DGP 2 APRIL 96

Written by: Paul J. Sabatini Date: 96 / 12 / 20 (YY MM DD) Reviewed by: [illegible] Date: 96 / 02 / 2[illegible] (YY MM DD)

Client: FERMCO Project: Fernald Project/Proposal No.: GE3900 Task No.: 5.11

Calculation No. 6. Seasonal Cover for Each Cell

The thickness of seasonal cover for the OSDF cells is 1 ft. For the purposes of this quantity estimate, it is assumed that the plan area of the seasonal cover shown in Figure 9 is representative of that for each cell of the OSDF. Seasonal cover is not placed on the final cell.

Seasonal Cover (all cells except last cell)

$$\frac{(97{,}000\,ft^2)(1\,ft)}{27\,ft^3/yd^3} = 3{,}593\,yd^3$$

Written by: Paul J. Sabatini Date: 96 / 2 / 20 (YY MM DD) Reviewed by: [illegible] Date: 96 / 2 / 2[illegible] (YY MM DD)

Client: FERUCO Project: Fernald Project/Proposal No.: GE 3900 Task No.: E.11

Calculation No. 7: Riprap Requirements for the OSDF Drainage Channels

The volume of riprap required for the OSDF drainage channels was calculated by multiplying the cross-sectional area of the riprap channels (Figure 10) by an approximate running length of the channels (Figure 11).

East Drainage Channel: $\frac{(3{,}660\ ft)(80\ ft)^2}{27\ ft^3/yd} = 10{,}845\ yd^3$

North Drainage Channel: $\frac{(890\ ft)(112\ ft^2)}{27\ ft^3/yd^3} = 3{,}692\ yd^3$

West Drainage Channel and Access Corridor: $\frac{(720\ ft)(59\ ft^2)}{27\ ft^3/yd^3} + \frac{(3660\ ft)(58\ ft^2)}{27\ ft^3/yd^3} = 9{,}436\ yd^3$

South Drainage Channel: $\frac{(390\ ft)(46\ ft^2)}{27\ ft^3/yd^3} = 1{,}517\ yd^3$

North Drainage Channel and Diversion Berm: $\frac{(380\ ft)(77\ ft^2)}{27\ ft^3/yd^3} = 1{,}084\ yd^3$

TOTAL: $26{,}574\ yd^3$

Written by: Paul J. Sabatini Date: 96 / 2 / 20 (YY / MM / DD) Reviewed by: [illegible] Date: 96 / 2 / 21 (YY / MM / DD)

Client: FEMPCO Project: Fernald Project/Proposal No.: GE3900 Task No.: 8.11

Calculation No. 8: Compacted Fill Requirements for Each Cell

Compacted fill requirements were calculated by comparing the existing grades of the OSDF to the subgrade grading plan for each cell. The results are summarized below for each cell.

Cell 1	16,246 yd^3
Cell 2	6,254 yd^3
Cell 3	14,755 yd^3
Cell 4	16,847 yd^3
Cell 5	23,882 yd^3
Cell 6	15,244 yd^3
Cell 7	11,264 yd^3
Cell 8	12,637 yd^3
Cell 9	19,945 yd^3

These volumes were computed by CADD using Sheet G-3, "Subgrade Grading Plan". Actual results of this computation are given in Table 1.

Written by: DSP Date: 96/4/1 (YY MM DD) Reviewed by: KCOlen Date: 96/4/1 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3700 Task No.: 9.11

CALCULATION No. 9: ROAD AGGREGATE FOR EACH STAGE OF OSDF CONSTRUCTION. THE LAYOUTS OF ROADS AND THE ADMINISTRATION AREA FOR WHICH ROAD AGGREGATE IS REQUIRED ARE SHOWN IN FIGURES 12, 13 AND 14 FOR THE EARLY, MIDDLE AND FINAL STAGES OF OSDF CONSTRUCTION. QUANTITIES FOR BASE AND SUBBASE COMPONENTS OF ROAD AGGREGATE ARE CALCULATED SEPARATELY FOR EACH STAGE.

- SUMMARY OF DIMENSIONS TO BE USED FOR EACH STAGE OF OSDF CONSTRUCTION.

AGGREGATE LAYER THICKNESS AND ROAD WIDTHS:

	BASE[2] AGGREGATE	SUBBASE[2] AGGREGATE	ROAD[3] WIDTH
CONSTRUCTION HAUL ROAD	0.75 ft	1.17 ft	38 ft
IMPACTED MATERIAL HAUL ROAD	0.75 ft	1.33 ft	38 ft
ACCESS CORRIDOR	0.5 ft	0.5 ft	15 ft
CONSTRUCTION ADMINISTRATION AREA	0.67 ft	N.A.[1]	N.A.[1]

1 N.A. = NOT APPLICABLE
2 AGGREGATE LAYER THICKNESSES WERE OBTAINED FROM DESIGN DRAWINGS OR DESIGN CALCULATIONS
2 ROAD WIDTHS WERE MEASURED FROM DESIGN DRAWINGS

Written by: DGP Date: 96/4/1 (YY MM DD) Reviewed by: K. Olen Date: 96/4/1 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 5.11

- SUMMARY OF DIMENSIONS TO BE USED IN CALCULATIONS FOR THE EARLY STAGE OF OSDF CONSTRUCTION. THE EARLY STAGE CORRESPONDS TO THE CONSTRUCTION OF OSDF CELLS 1, 2 AND 3. THE ACCESS CORRIDOR WILL BE CONSTRUCTED FOR CELLS 1 AND 2.

CENTERLINE LENGTHS AND PLAN AREAS FOR ROADS AND THE ADMINISTRATION AREA CONSTRUCTED FOR THE EARLY STAGE. (FIGURES 12 AND 15)

	CENTER LINE LENGTH	PLAN AREA
CONSTRUCTION HAUL ROAD	5350 ft ✓	7,500 SF ✓
IMPACTED MATERIAL ACCESS Rd.	1,490 ft ✓	22,300 SF ✓
ACCESS CORRIDOR	230 ft ✓	21,100 SF ✓
CONSTRUCTION ADMINISTRATION AREA	———	98,000 SF ✓
IMPACTED MATERIAL ACCESS RAMP	———	27,800 SF ✓

- ROAD AGGREGATE QUANTITIES FOR THE EARLY STAGE OF OSDF CONSTRUCTION.

BASE AGGREGATE FOR THE CONSTRUCTION HAUL ROAD

$$\frac{[(5{,}350\,ft)(38\,ft) + 7{,}500\,ft^2)](0.75\,ft)}{27\,ft^3/yd^3} \qquad 5{,}856\ yd^3 \checkmark$$

BASE AGGREGATE FOR THE IMPACTED MATERIAL ACCESS Rd

$$\frac{[(1{,}490\,ft)(38\,ft) + 22{,}300\,SF](0.75\,ft)}{27\,ft^3/yd^3} \qquad 2{,}192\ yd^3 \checkmark$$

BASE AGGREGATE FOR THE ACCESS CORRIDOR

$$\frac{[(230\,ft)(15\,ft) + 21{,}100\,SF](0.5\,ft)}{27\,ft^3/yd^3} \qquad 455\ yd^3 \checkmark$$

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Written by: DCP Date: 96 / 4 / 1 Reviewed by: KOlen Date: 96 / 4 / [illegible]

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: [illegible]

BASE AGGREGATE FOR THE CONSTRUCTION ADMINISTRATION AREA

$$\frac{(98{,}000\ sf)(0.67\ ft)}{27\ ft^3/yd^3} \qquad 2{,}432\ yd^3 \checkmark$$

BASE AGGREGATE FOR THE IMPACTED MATERIAL ACCESS RAMP

$$\frac{(27{,}800\ sf)(0.75\ ft)}{27\ ft^3/yd^3} \times 3\ CELLS \qquad 2{,}317\ yd^3 \checkmark$$

SUBBASE AGGREGATE FOR THE CONSTRUCTION MATERIAL HAUL ROAD

$$\frac{[(5{,}350\ ft)(38\ ft) + 7{,}500\ ft^2](1.17\ ft)}{27\ ft^3/yd^3} \qquad 9{,}135\ yd^3 \checkmark$$

SUBBASE AGGREGATE FOR THE ACCESS CORRIDOR

$$\frac{[(230\ ft)(15\ ft) + 21{,}100\ ft^2](0.5\ ft)}{27\ ft^3/yd^3} \qquad 455\ yd^3 \checkmark$$

SUBBASE AGGREGATE FOR THE IMPACTED MATERIAL ACCESS RAMP

$$\frac{(27{,}800\ sf)(1.33\ ft)}{27\ ft^3/yd^3} \times 3\ CELLS \qquad 4{,}108\ yd^3 \checkmark$$

SUBBASE AGGREGATE FOR THE IMPACTED MATERIAL ACCESS Rd

$$\frac{[(1{,}490\ ft)(38\ ft) + 22{,}300\ ft^2](1.33\ ft)}{27\ ft^3/yd^3} \qquad 3{,}888\ yd^3 \checkmark$$

TOTAL BASE AGGREGATE FOR THE EARLY STAGE

$$5{,}856\ yd^3 + 2{,}192\ yd^3 + 455\ yd^3 + 2{,}432\ yd^3 + 2{,}317\ yd^3 = \underline{\underline{13{,}252\ yd^3}} \checkmark$$

TOTAL SUBBASE AGGREGATE FOR THE EARLY STAGE

$$9{,}135\ yd^3 + 455\ yd^3 + 4{,}108\ yd^3 + 3{,}888\ yd^3 = \underline{\underline{17{,}586\ yd^3}} \checkmark$$

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Written by: DGP Date: 96 / 4 / 1 Reviewed by: C. Ow Date: 96 / 4 / 1
YY MM DD YY MM DD

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3956 Task No.: 3.1

- SUMMARY OF DIMENSIONS TO BE USED IN CALCULATIONS FOR THE MIDDLE STAGE OF OSDF CONSTRUCTION. THE MIDDLE STAGE CORRESPONDS TO CELLS 4, 5 AND 6. (FIGURE 13) THE ACCESS CORRIDOR ROAD WILL BE CONSTRUCTED ALONG CELLS 3, 4 AND 5.

  THE FOLLOWING LENGTHS AND AREAS ARE FOR ADDITIONAL ROAD LENGTHS CONSTRUCTED FOR THE MIDDLE STAGE AND THE RELOCATED ADMINISTRATION AREA

	LENGTH OF ROAD	PLAN AREA
CONSTRUCTION HAUL ROAD	2,340 ft ✓	———
IMPACTED MATERIAL ACCESS Rd	1,520 ft ✓	21,100 ft² ✓
ACCESS CORRIDOR	1,200 ft ✓	———
CONSTRUCTION ADMINISTRATION A.	———	118,400 ft² ✓
IMPACTED MATERIAL ACCESS RAMP	———	27,800 ft² ✓

- ROAD AGGREGATE QUANTITIES FOR THE MIDDLE STAGE OF OSDF CONSTRUCTION

  BASE AGGREGATE FOR THE CONSTRUCTION HAUL Rd

$$\frac{(2,340\,ft)(38\,ft)(0.75\,ft)}{27\,ft^3/yd^3} \qquad 2,470\,yd^3 \checkmark$$

  BASE AGGREGATE FOR THE IMPACTED MATERIAL ACCESS Rd

$$\frac{[(1,520\,ft)(38\,ft) + 21,100\,ft^2](0.75\,ft)}{27\,ft^3/yd^3} \qquad 2,191\,yd^3 \checkmark$$

  BASE AGGREGATE FOR THE ACCESS CORRIDOR

$$\frac{(1,200\,ft)(15\,ft)(0.5\,ft)}{27\,ft^3/yd^3} \qquad 333\,yd^3 \checkmark$$

  BASE AGGREGATE FOR THE CONSTRUCTION ADMINISTRATION AREA

$$\frac{(118,400\,ft^2)(0.67\,ft)}{27\,ft^3/yd^3} \qquad 2,938\,yd^3 \checkmark$$

Written by: DEP Date: 96/4/1 (YY MM DD) Reviewed by: K Olin Date: 96/4/1 (YY MM DD)

Client: FERMCO Project: GSDF Project/Proposal No.: GE3900 Task No.: 5.11

BASE AGGREGATE FOR THE IMPACTED MATERIAL ACCESS RAMP

SAME AS FOR EARLY STAGE 2,317 yd³

SUBBASE AGGREGATE FOR THE CONSTRUCTION HAUL Rd

$$\frac{(2{,}340\ ft)(38\ ft)(1.17\ ft)}{27\ ft^3/yd^3} \quad 3{,}853\ yd^3$$

SUBBASE AGGREGATE FOR THE IMPACTED MATERIAL ACCESS Rd

$$\frac{[(1{,}520\ ft)(38\ ft) + 21{,}100\ ft^2]\ 1.33\ ft}{27\ ft^3/yd^3} \quad 3{,}885\ yd^3$$

SUBBASE AGGREGATE FOR THE ACCESS CORRIDOR

$$\frac{(1{,}200\ ft)(15\ ft)(0.5)}{27\ ft^3/yd^3} \quad 333\ yd^3$$

SUBBASE AGGREGATE FOR THE IMPACTED MATERIAL ACCESS RAMP

SAME AS FOR EARLY STAGE 4,108 yd³

TOTAL BASE AGGREGATE FOR THE MIDDLE STAGE

2,470 yd³ + 2,191 yd³ + 333 yd³ + 2938 yd³ + 2,317 yd³ = 10,249 yd³

TOTAL SUBBASE AGGREGATE FOR THE MIDDLE STAGE

3,853 yd³ + 3,885 yd³ + 333 yd³ + 4,108 yd³ = 12,179 yd³

Written by: [illegible] Date: 96/4/1 (YY MM DD) Reviewed by: [illegible] Date: 96/4/[illegible] (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3960 Task No.: [illegible]

- SUMMARY OF DIMENSIONS TO BE USED IN CALCULATIONS FOR THE FINAL STAGE OF OSDF CONSTRUCTION. THE FINAL STAGE CORRESPONDS TO CELLS 7, 8 AND 9 (FIGURE 14). THE ACCESS CORRIDOR ROAD WILL BE CONSTRUCTED ALONG CELLS 6, 7, 8 AND 9 AND FROM CELL 9 TO ITS INTERSECTION WITH THE NORTH ENTRANCE RD. (FIGURE 16)

THE FOLLOWING LENGTHS AND AREAS ARE FOR ADDITIONAL ROAD LENGTHS CONSTRUCTED FOR THE FINAL STAGE.

	LENGTH OF ROAD	PLAN AREA
CONSTRUCTION HAUL RD	1,880 ft ✓	
IMPACTED MATERIAL ACCESS RD	1,520 ft ✓	14,900 ft² ✓
ACCESS CORRIDOR	1,600 + 1130 ft (Fig. 14) (Fig. 16)	
IMPACTED MATERIAL ACCESS RAMP		27,800 ft² ✓

- ROAD AGGREGATE QUANTITIES FOR THE FINAL STAGE OF OSDF CONSTRUCTION

BASE AGGREGATE

CONSTRUCTION HAUL RD

$$\frac{[(1{,}880\ ft)(38\ ft)]\ 0.75}{27\ ft^3/yd^3} \qquad 1{,}984\ yd^3 \checkmark$$

IMPACTED MATERIAL ACCESS RD

$$\frac{[(1{,}520\ ft)(38\ ft) + 14{,}900\ ft^2](0.75\ ft)}{27\ ft^3/yd^3} \qquad 2{,}018\ yd^3 \checkmark$$

ACCESS CORRIDOR

$$\frac{(1{,}600\ ft + 1130\ ft)(0.5\ ft)(15\ ft)}{27\ ft^3/yd^3} \qquad 758\ yd^3 \checkmark$$

IMPACTED MATERIAL ACCESS RAMP

SAME AS FOR EARY STAGE 2,317 yd³ ✓

Written by: DGP Date: 96/4/1 Reviewed by: C. Olin Date: 96/4/5

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 8.1

SUBBASE AGGREGATE

CONSTRUCTION HAUL RD

$$\frac{[(1{,}880\,ft)(38\,ft)] * 1.17\,ft}{27\,ft^3/yd^3} \qquad 3{,}096\,yd^3$$

IMPACTED MATERIAL ACCESS RD

$$\frac{[(1{,}520\,ft)(38\,ft) + 141{,}900\,ft^2](1.33\,ft)}{27\,ft^3/yd^3} \qquad 3{,}579\,yd^3$$

ACCESS CORRIDOR

$$\frac{(1{,}600\,ft + 1130\,ft)(0.5\,ft)(15\,ft)}{27\,ft^3/yd^3} \qquad 758\,yd^3$$

IMPACTED MATERIAL ACCESS RAMP

SAME AS FOR EARLY STAGE $4{,}108\,yd^3$

TOTAL BASE AGGREGATE FOR THE FINAL STAGE

$1{,}984\,yd^3 + 2{,}018\,yd^3 + 758\,yd^3 + 2{,}317\,yd^3 = 7{,}077\,yd^3$

TOTAL SUBBASE AGGREGATE FOR THE FINAL STAGE

$3096\,yd^3 + 3579\,yd^3 + 758\,yd^3 + 4{,}108\,yd^3 = 11{,}541\,yd^3$

Written by: Paul J. Sabatini Date: 96/2/20 (YY/MM/DD) Reviewed by: [illegible] Date: 96/2/21 (YY/MM/DD)

Client: FERMCO Project: Fernald Project/Proposal No.: GE3900 Task No.: 8.11

Summary of Earthwork Requirements

Quantities of each earthwork component are summarized on Table 2. A summary of OSDF earthwork components that each cell is comprised of is shown below.

Cell 1: intercell berm
end cell liner system
end cell cover system
seasonal cover
compacted fill

Cells 2-8: intercell berm
inner cell liner system
inner cell cover system
seasonal cover
compacted fill

Cell 9: end cell liner system
end cell cover system
compacted fill

Note: The quantity of riprap is associated with the OSDF drainage channels and not with individual cells.

SUMMARY OF ROAD AGGREGATE REQUIREMENTS

AD, DGD
2 APRIL 96

QUANTITIES OF EACH ROAD AGGREGATE COMPONENT ARE SUMMARIZED IN TABLE 3.

Paul J. Sabatini
96 2-20
GE3900
Task 8.11

TABLE 1.

OSDF Cut and General Fill Volume Calculations

Subsite Volume Table: Unadjusted

	Stratum	Surf1	Surf2	Cut yards	Fill yards	Net yards	
Cell 1	Subsite: 10 eg-bs	rdog	bsgrd	90442.58	16245.92	74196.66	(C)
Cell 2	Subsite: 11 eg-bs	rdog	bsgrd	68363.85	6253.86	62109.99	(C)
Cell 3	Subsite: 12 eg-bs	rdog	bsgrd	61457.78	14754.29	46703.49	(C)
Cell 4	Subsite: 13 eg-bs	rdog	bsgrd	39177.44	16846.93	22330.51	(C)
Cell 5	Subsite: 14 eg-bs	rdog	bsgrd	12909.28	23881.41	10972.13	(F)
Cell 6	Subsite: 15 eg-bs	rdog	bsgrd	30656.57	15243.96	15412.61	(C)
Cell 7	Subsite: 16 eg-bs	rdog	bsgrd	44792.03	11263.63	33528.40	(C)
Cell 8	Subsite: 17 eg-bs	rdog	bsgrd	49676.19	12633.13	37043.05	(C)
Cell 9	Subsite: 18 eg-bs	rdog	bsgrd	211525.74	19944.89	191580.85	(C)
			TOTALS	559,325	124,435	456,835	(for 8 cells)*
				609,001	137,068	493,878	(for 9 cells)

- General Fill consists of the compacted borrow material volume required to bring the OSDF subgrade to grade.

* Volume for 8 cells was obtained by subtracting volume for Cell 9 from total volume for 9 cells.

Paul J. Sabatini

TABLE 2. SUMMARY OF REQUIRED EARTHWORK QUANTITIES

Cell No.	Compacted Clay Liner (cy)	LDS Drainage Layer (cy)	LCS Drainage Layer (cy)	Protective Soil Layer (impacted) (cy)	Protective Soil Layer (non-Impacted) (cy)	Compacted Clay Cap (cy)	Cover Drainage Layer (cy)	Biointrusion Barrier (cy)	Choke Layer (cy)	Granular Filter (cy)	Vegetative Soil Layer (cy)	Topsoil (cy)	Seasonal Cover (cy)	Compacted Fill (cy)	(ontouring) LAYER (cy)
1	41,900	11,500	14,109	7,692	1,201	26,179	18,922	39,881	3,171	8,467	36,358	8,467	3,593	16,246	11,207
2	36,866	10,697	13,306	6,889	1,201	23,704	14,371	35,689	2,907	6,749	26,575	6,749	3,593	6,254	10,874
3	36,866	10,697	13,306	6,889	1,201	23,704	14,371	35,689	2,907	6,749	26,575	6,749	3,593	14,755	10,874
4	36,866	10,697	13,306	6,889	1,201	23,704	14,371	35,689	2,907	6,749	26,575	6,749	3,593	16,847	10,874
5	36,866	10,697	13,306	6,889	1,201	23,704	14,371	35,689	2,907	6,749	26,575	6,749	3,593	23,882	10,874
6	36,866	10,697	13,306	6,889	1,201	23,704	14,371	35,689	2,907	6,749	26,575	6,749	3,593	15,244	10,874
7	36,866	10,697	13,306	6,889	1,201	23,704	14,371	35,689	2,907	6,749	26,575	6,749	3,593	11,264	10,874
8	34,135	9,907	12,357	7,459	-	26,179	18,922	39,881	3,171	8,467	36,358	8,467	-	19,945	11,207
TOTAL	297,231	85,589	106,302	56,485	8,407	194,582	124,070	293,896	23,784	57,428	232,166	57,428	25,151	124,437	87,658
TOTAL (9 cells)	334,097	96,286	119,608	63,374	9,608	218,286	138,441	329,585	26,691	64,177	258,741	64,177	28,744	137,071	98,532

Total riprap = 26,574 cy

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2-1-1/96

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000211

Written by: DGP Date: 96 / 4 / 2 (YY MM DD) Reviewed by: K. Oller Date: [illegible] (YY MM DD)

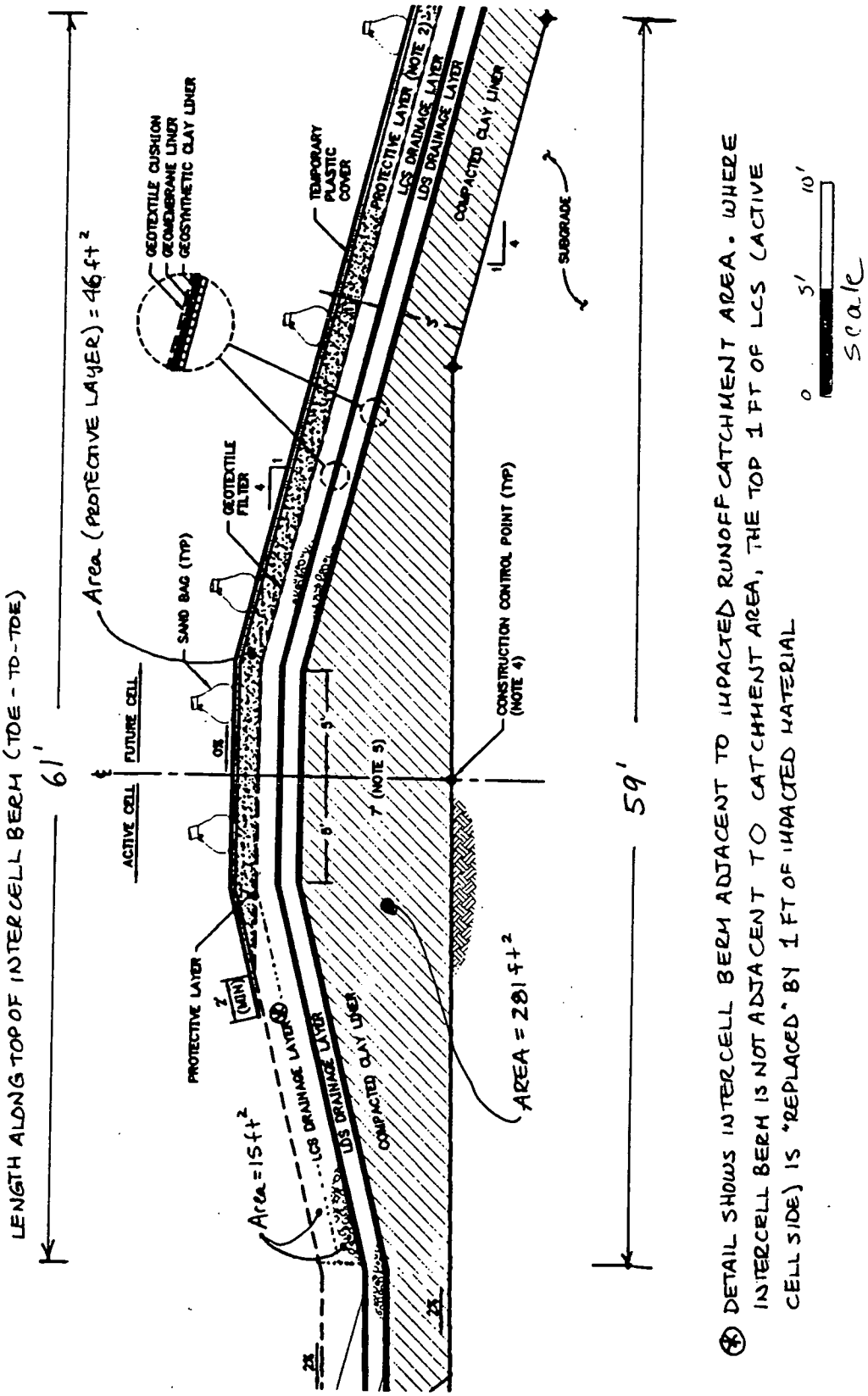
Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 3.11

Table 3. Summary of required road aggregate quantities.

OSDF Construction Stage	Base Aggregate (cy)	Subbase Aggregate (cy)
Early	13,252	17,586
Middle	10,249	12,179
Final	7,077	11,541
Total	30,578	41,306

Written By: Paul J. Sabatini Date: 96-2-20 Reviewed by: [illegible] Date: 96-2-2[illegible]

Client: FERMCO Project: Fernald Project/Proposal No.: GE3900 Task No.: 8.11



⊛ DETAIL SHOWS INTERCELL BERM ADJACENT TO IMPACTED RUNOFF CATCHMENT AREA. WHERE INTERCELL BERM IS NOT ADJACENT TO CATCHMENT AREA, THE TOP 1 FT OF LCS (ACTIVE CELL SIDE) IS "REPLACED" BY 1 FT OF IMPACTED MATERIAL

FIGURE 1. INTERCELL BERM
(FIGURE TAKEN FROM DESIGN DRAWINGS, DETAIL - LINER SYSTEM TERMINATION AT INTERCELL BERM AND IMPACTED RUNOFF CATCHMENT AREA)

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Written By: Paul J. Sabatini Date: 96 2-20 Reviewed by: [illegible] Date: 96-2-21

Client: FERMCO Project: Fernald Project/Proposal No.: GE3900 Task No.: 8.11

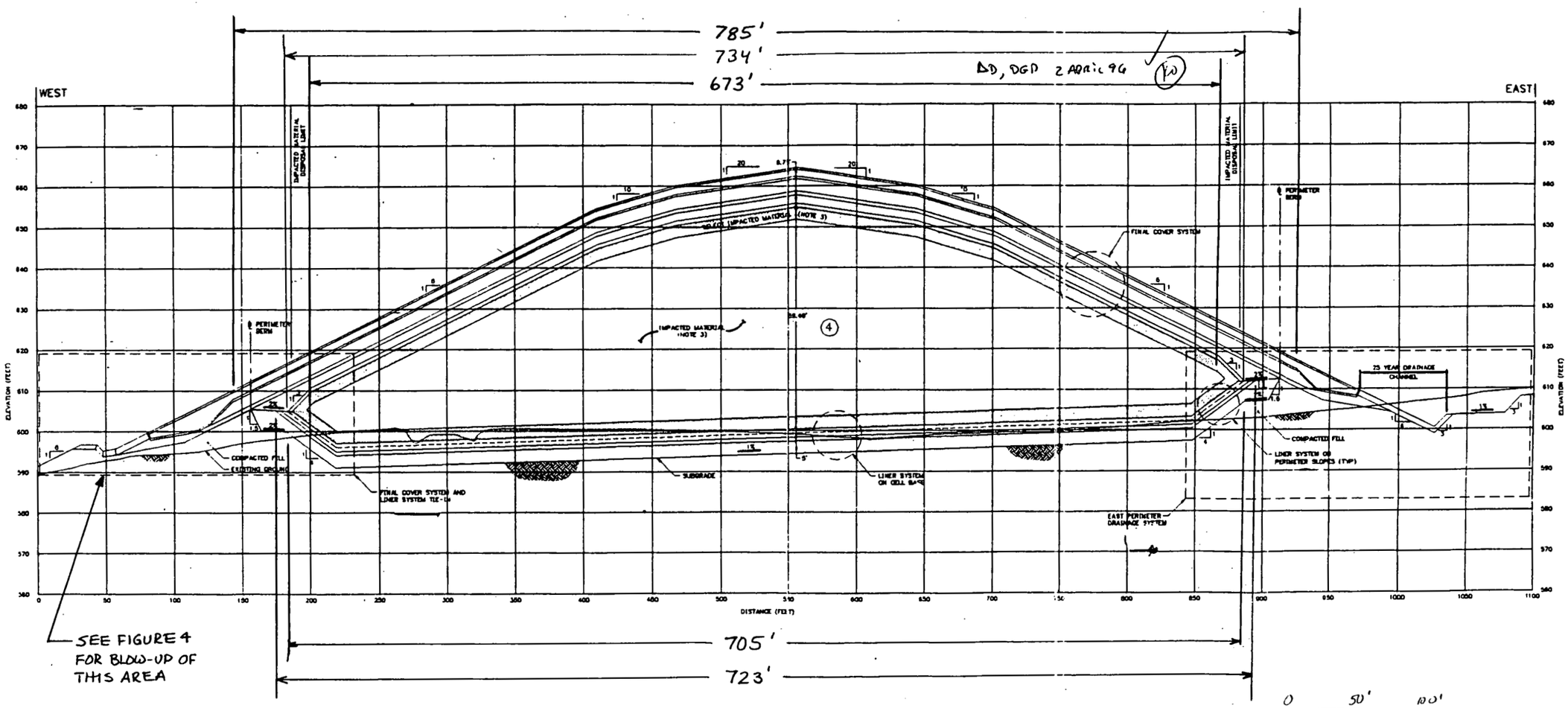


FIGURE 2. EAST-WEST SECTION AT CELL BASE 4
(FIGURE TAKEN FROM DESIGN DRAWINGS)

Written By: Paul J. Sabatini Date: 96 2-20 Reviewed by: [illegible] Date: 96-2-21

Client: FERMCO Project: Fernald Project/Proposal No.: GE3900 Task No.: 8.11

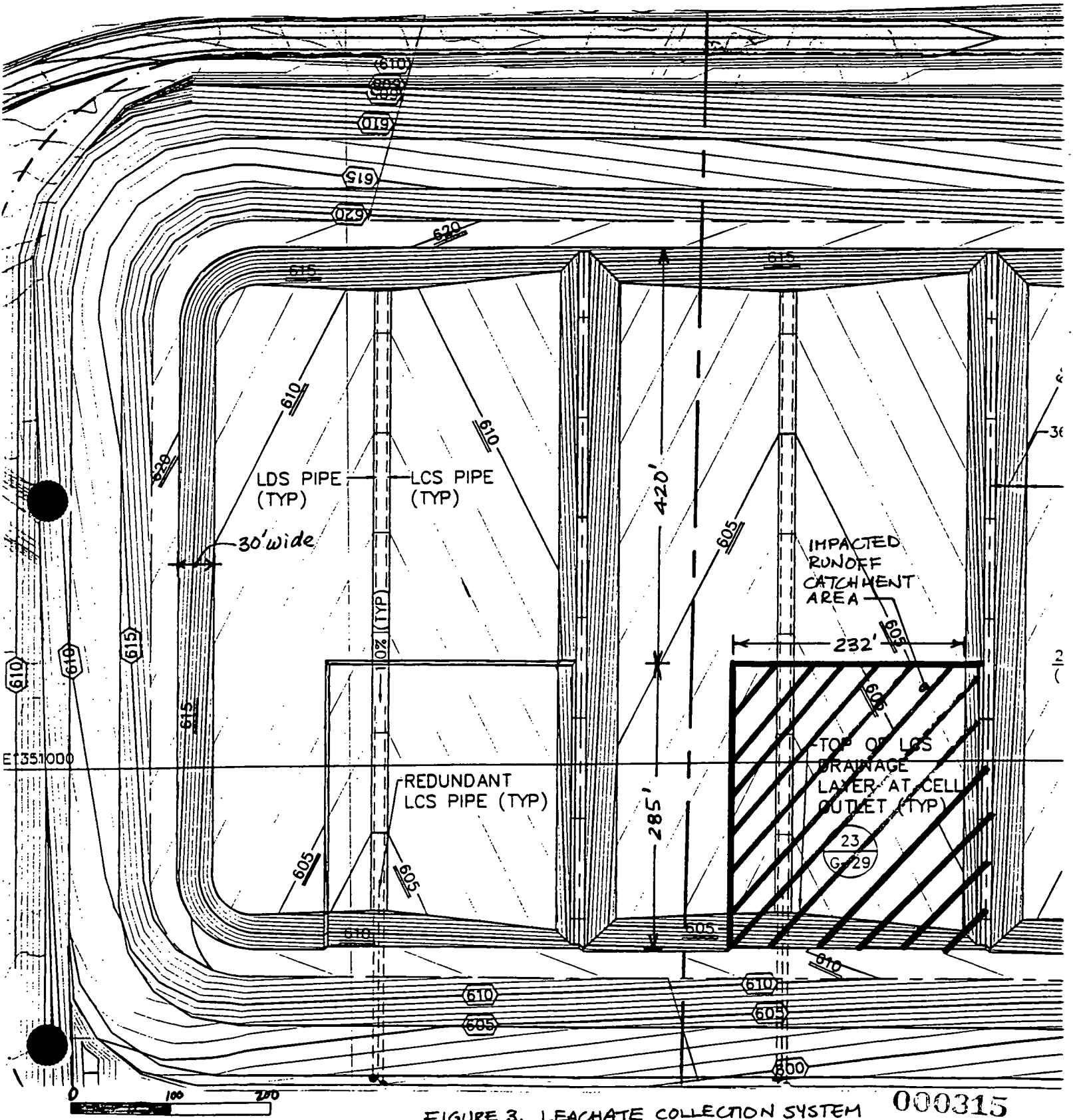


FIGURE 3. LEACHATE COLLECTION SYSTEM GRADING PLAN (FIGURE TAKEN FROM DESIGN DRAWINGS)

Written By: Paul J. Sabatini Date: 96-2-20 Reviewed by: BBM Date: 96-2-21

Client: FERMCO Project: Fernald Project/Proposal No.: GE3900 Task No.: 8.11

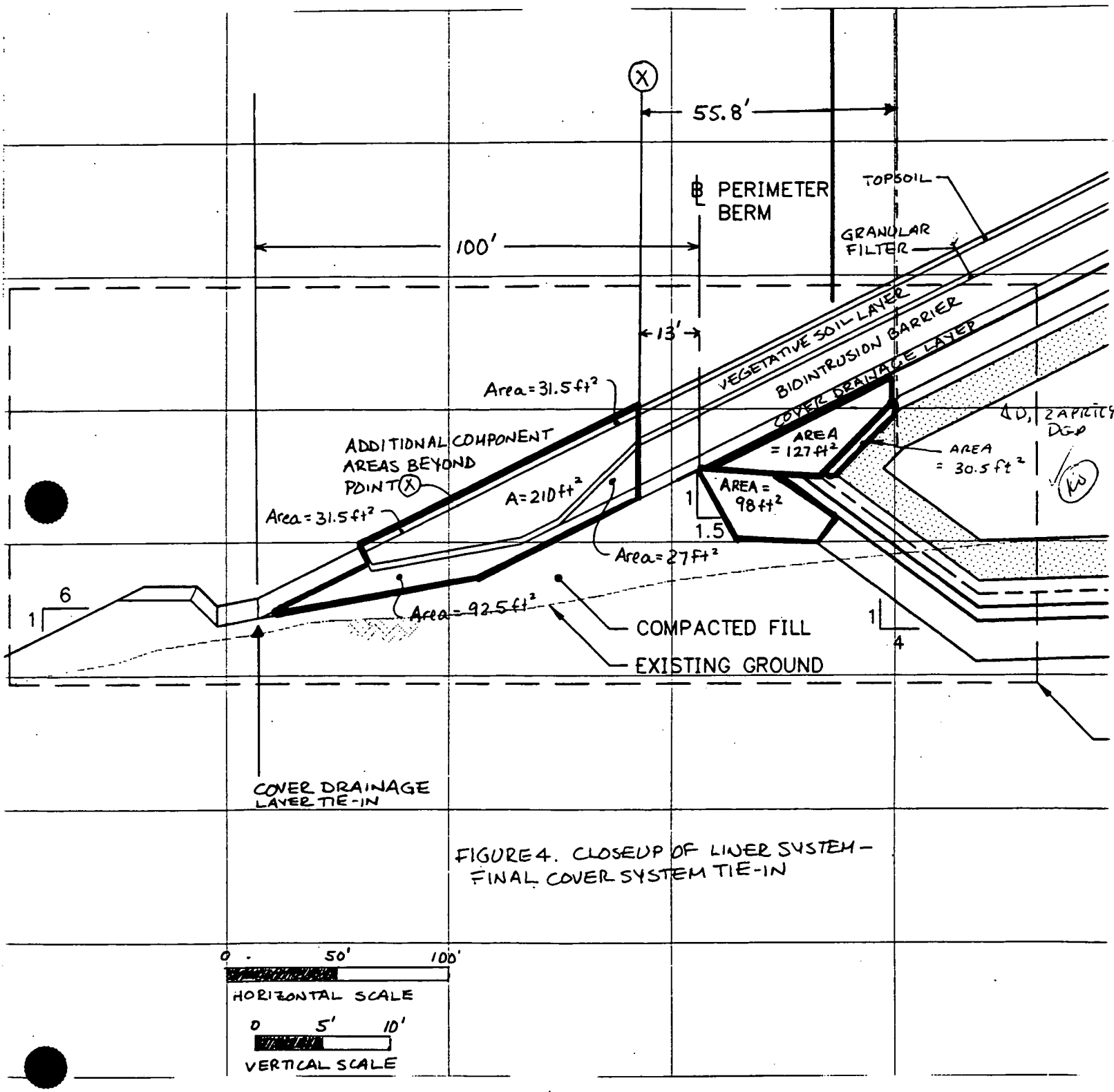
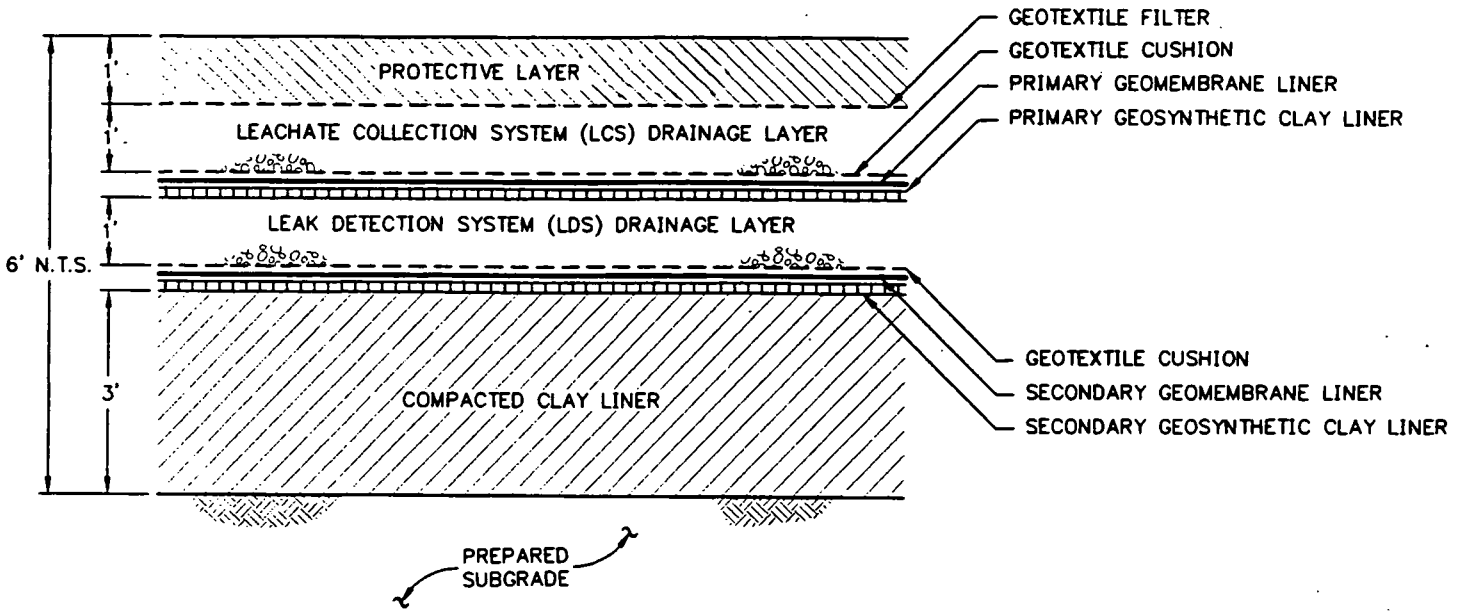


FIGURE 4. CLOSEUP OF LINER SYSTEM – FINAL COVER SYSTEM TIE-IN

Written By: Paul J. Sabatini Date: 96-2-20 Reviewed by: [illegible] Date: 96-2-21

Client: FERMCO Project: Fernald Project/Proposal No.: GE3900 Task No.: 8.11



LINER SYSTEM

FIGURE 5. LINER SYSTEM
(FIGURE TAKEN FROM DESIGN DRAWINGS)

GEOSYNTEC CONSULTANTS Page 26 of 32

Written By: Paul J. Sabatini Date: 96 2-20 Reviewed by: [illegible] Date: 96-2-21

Client: ~~Fernald~~ FERCO Project: Fernald Project/Proposal No.: GE3900 Task No.: 8.11

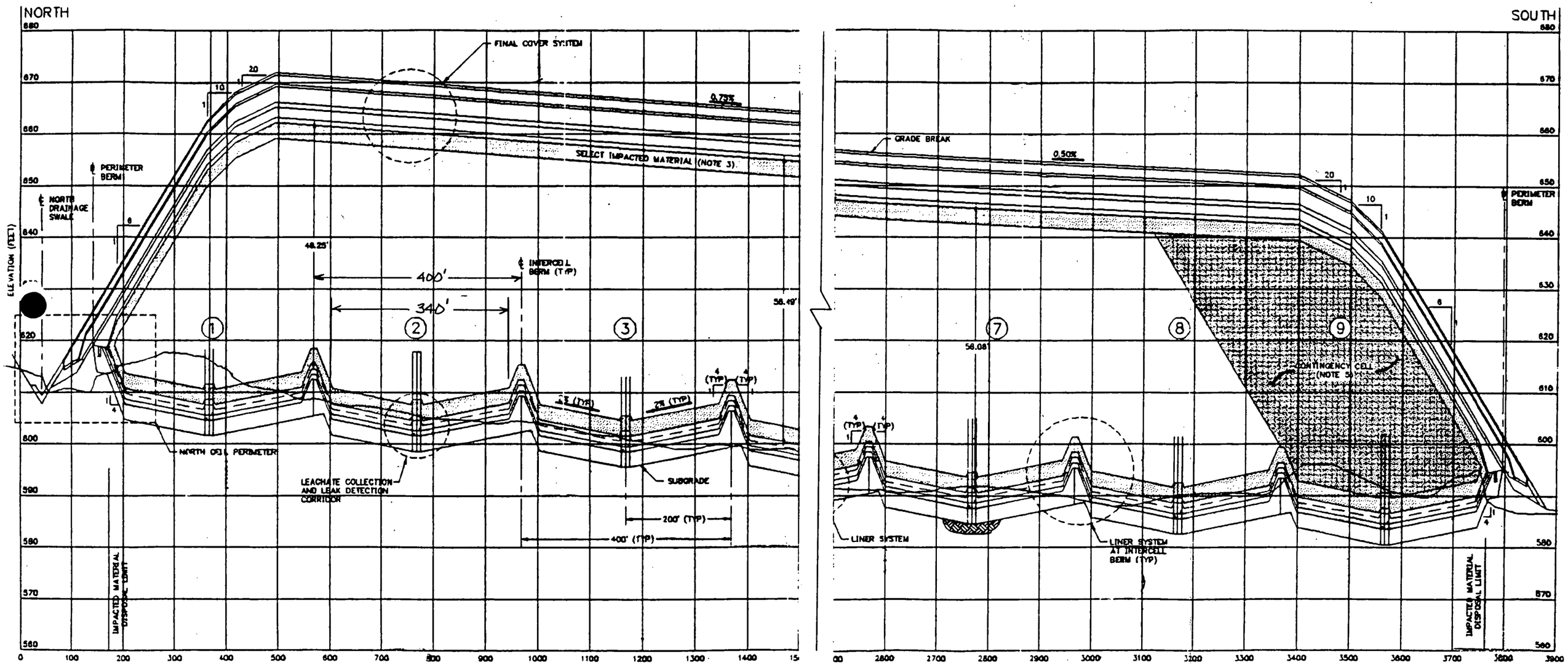
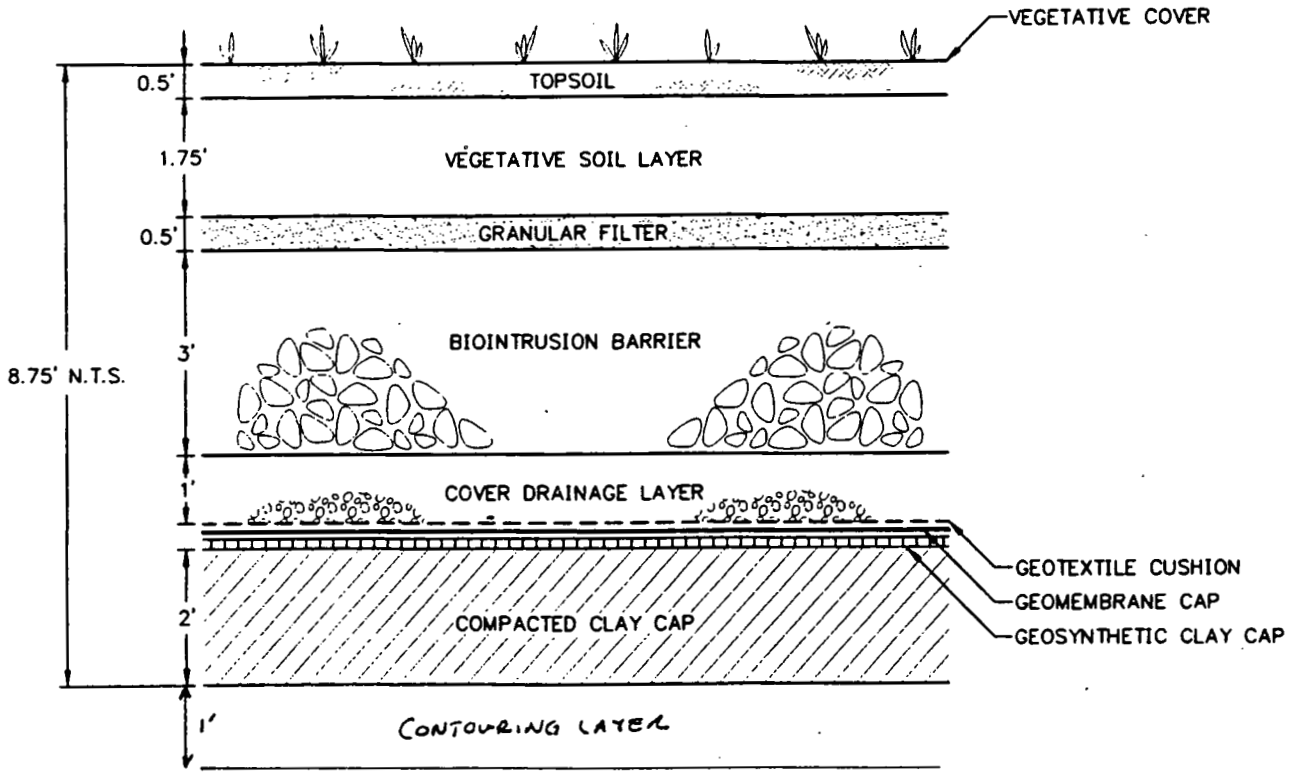


FIGURE 6. NORTH-SOUTH CROSS SECTION
(FIGURE TAKEN FROM DESIGN DRAWINGS)

Written By: Paul J. Sabatini Date: 96 2-20 Reviewed by: [illegible] Date: 96-3-21

Client: FERMCO Project: Fernald Project/Proposal No.: GE3966 Task No.: 8.11



AD, DGP 2 APRIL 96

FINAL COVER SYSTEM

FIGURE 7. FINAL COVER SYSTEM
(FIGURE ~~TAKEN~~ MODIFIED FROM DESIGN DRAWINGS)

Written By: Paul J. Sabatini Date: 96 2-20 Reviewed by: MJM Date: 96-2-2

Client: FERMCO Project: Fernald Project/Proposal No.: GE3900 Task No.: 8.11

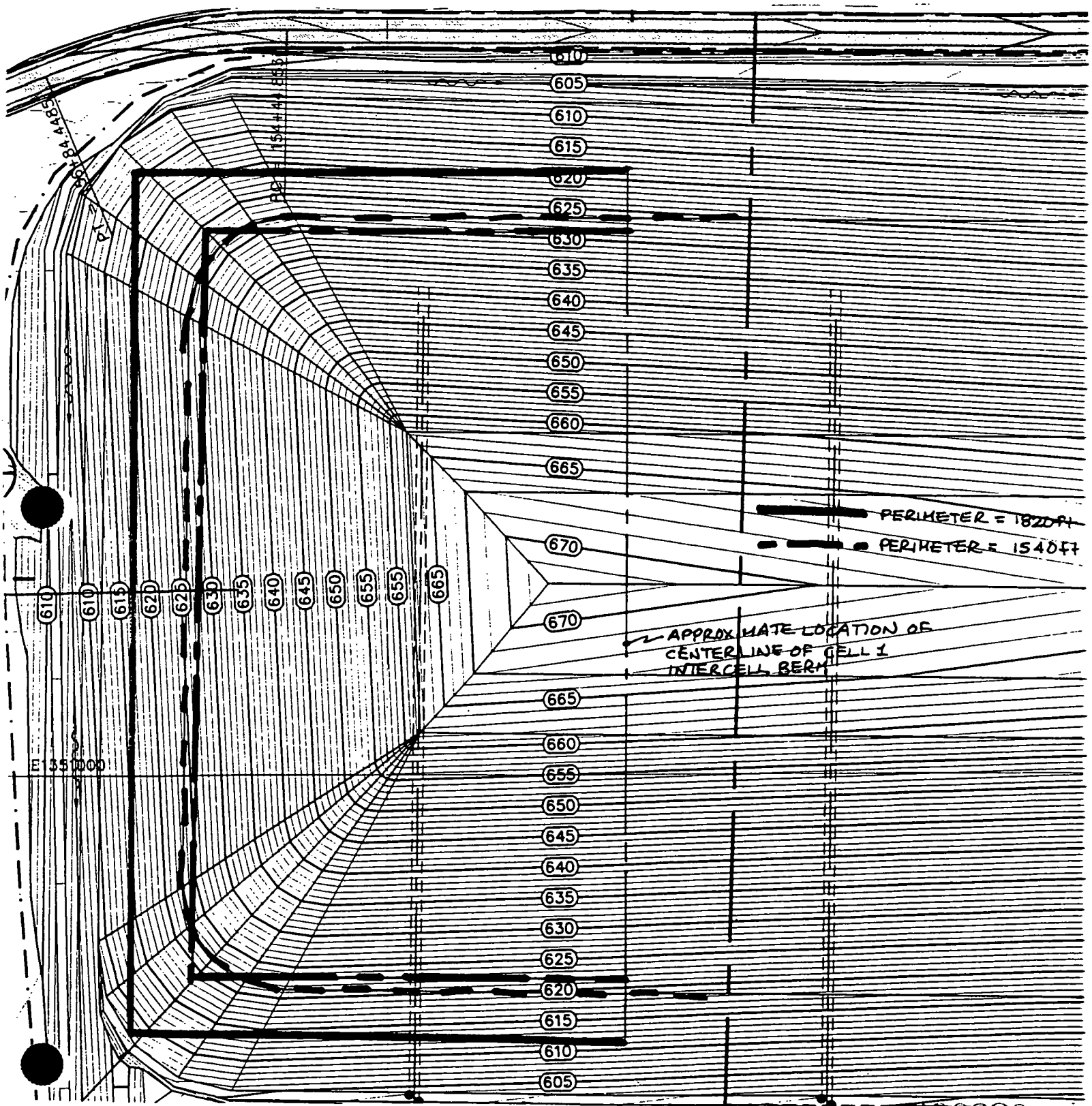
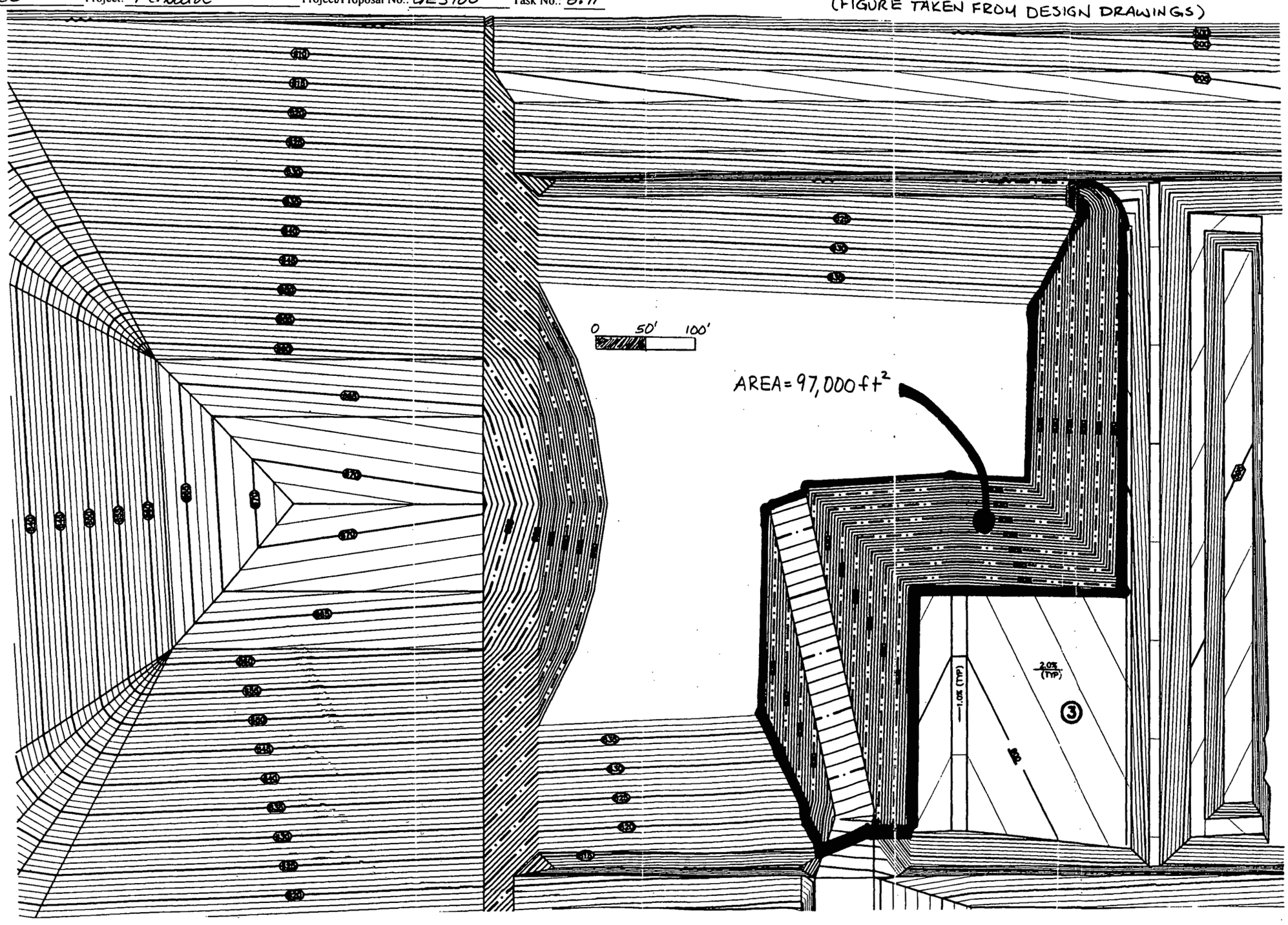


FIGURE 8. FINAL COVER SYSTEM GRADING PLAN
(FIGURE TAKEN FROM DESIGN DRAWINGS)

Written By: Paul J. Sabatini Date: 96-2-20 Reviewed by: [illegible] Date: 2/21/96

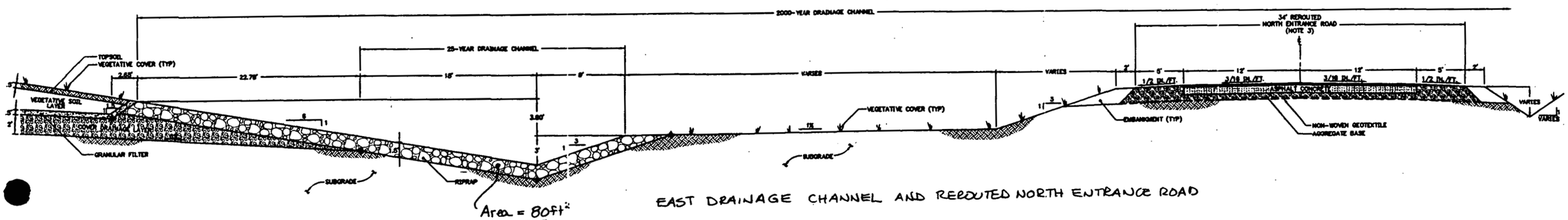
Client: FERMCO Project: Fernald Project/Proposal No.: GE3900 Task No.: 8.11

FIGURE 9. SITE DEVELOPMENT PLAN EARLY STAGE
PHASE 3 CELLS 3,2,1
(FIGURE TAKEN FROM DESIGN DRAWINGS)

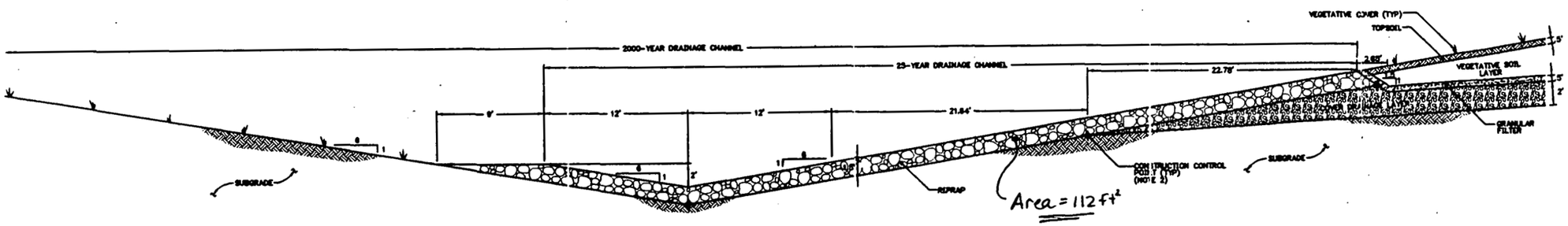


Written By: Paul J. Sabatini Date: 96 2-20 Reviewed by: [illegible] Date: 96-2-21

Client: FEMPO Project: Fernald Project/Proposal No.: GE3906 Task No.: 8.11



EAST DRAINAGE CHANNEL AND REROUTED NORTH ENTRANCE ROAD



NORTH DRAINAGE CHANNEL

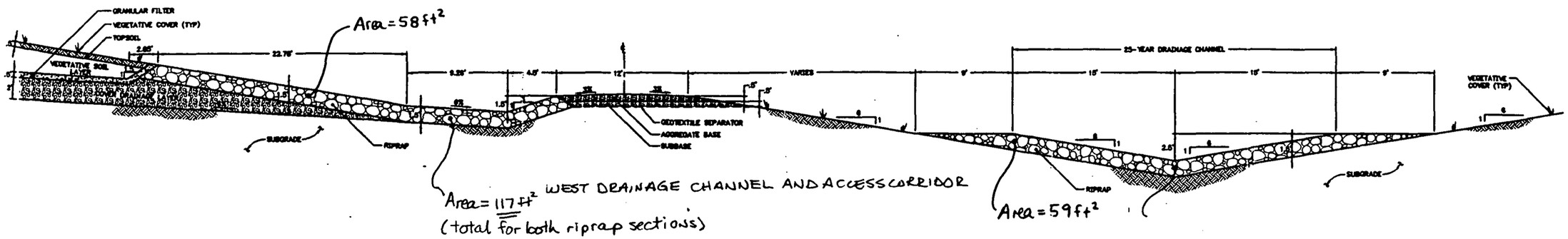
0 10' 20'

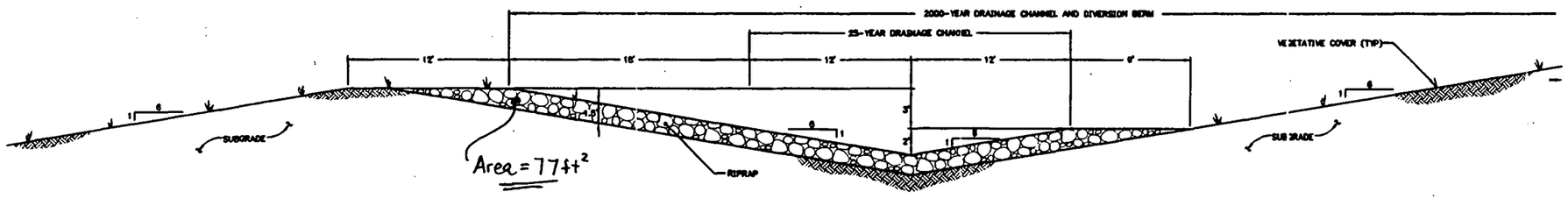
FIGURE 10. RIPRAP REQUIREMENT CALCULATIONS

(FIGURE TAKEN FROM DESIGN DRAWINGS - STORMWATER MANAGEMENT DETAILS)

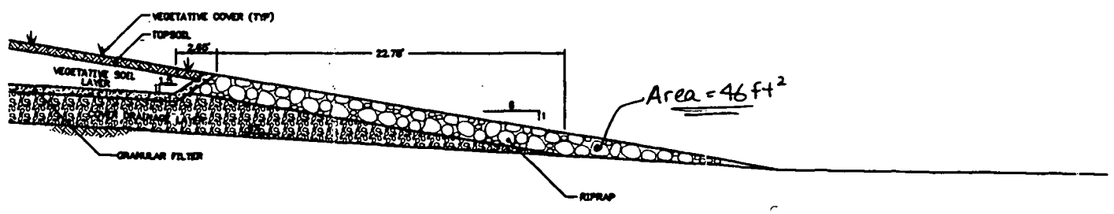
Written By: Paul J. Sabatini Date: 96-2-20 Reviewed by: [illegible] Date: 96-2-21

Client: FEMCO Project: Fernald Project/Proposal No.: GE3900 Task No.: 8.11





NORTH DRAINAGE CHANNEL AND DIVERSION BERM



SOUTH DRAINAGE CHANNEL

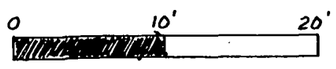


FIGURE 10 (CONT.). RIPRAP REQUIREMENT CALCULATIONS

(FIGURE TAKEN FROM DESIGN DRAWINGS - STORMWATER MANAGEMENT DETAILS)

Written By: Paul J. Sabatini Date: 96 2-20 Reviewed by: MBM Date: 96-2-21

Client: FERMCO Project: Fernald Project/Proposal No.: GE3900 Task No.: 8.11

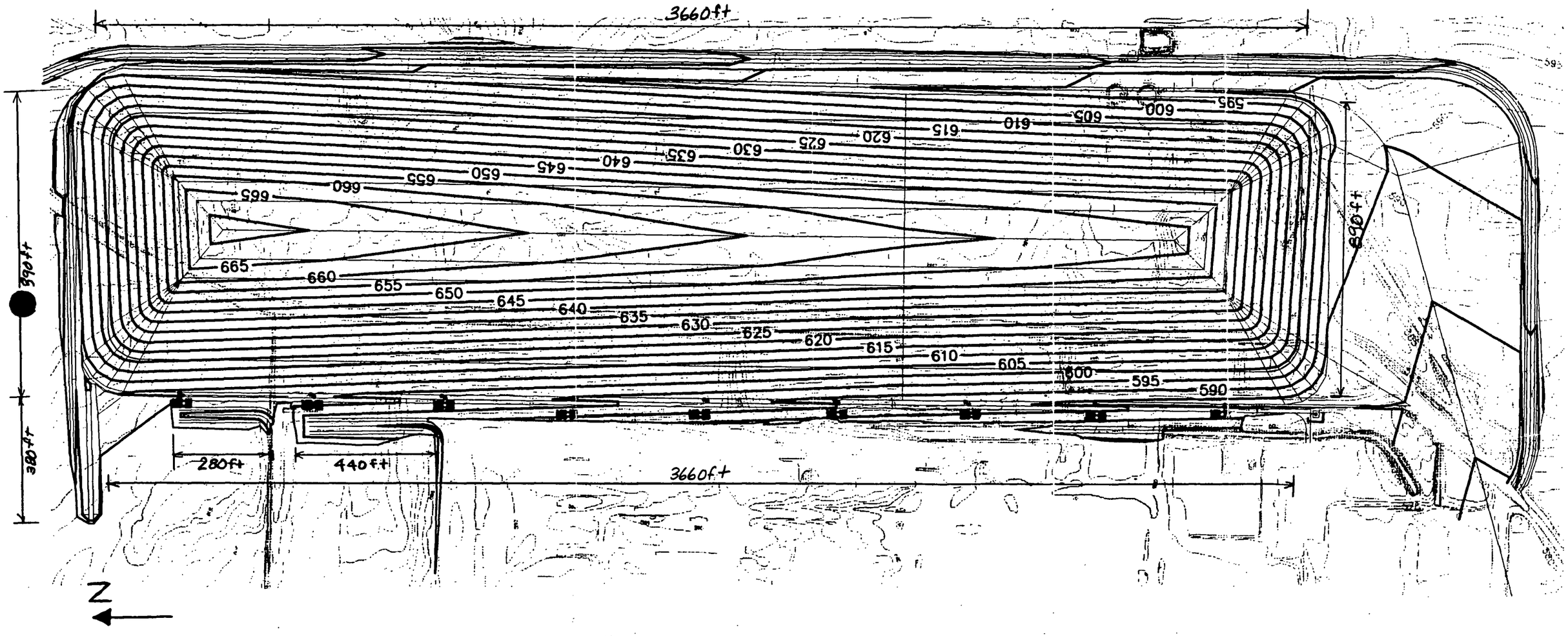
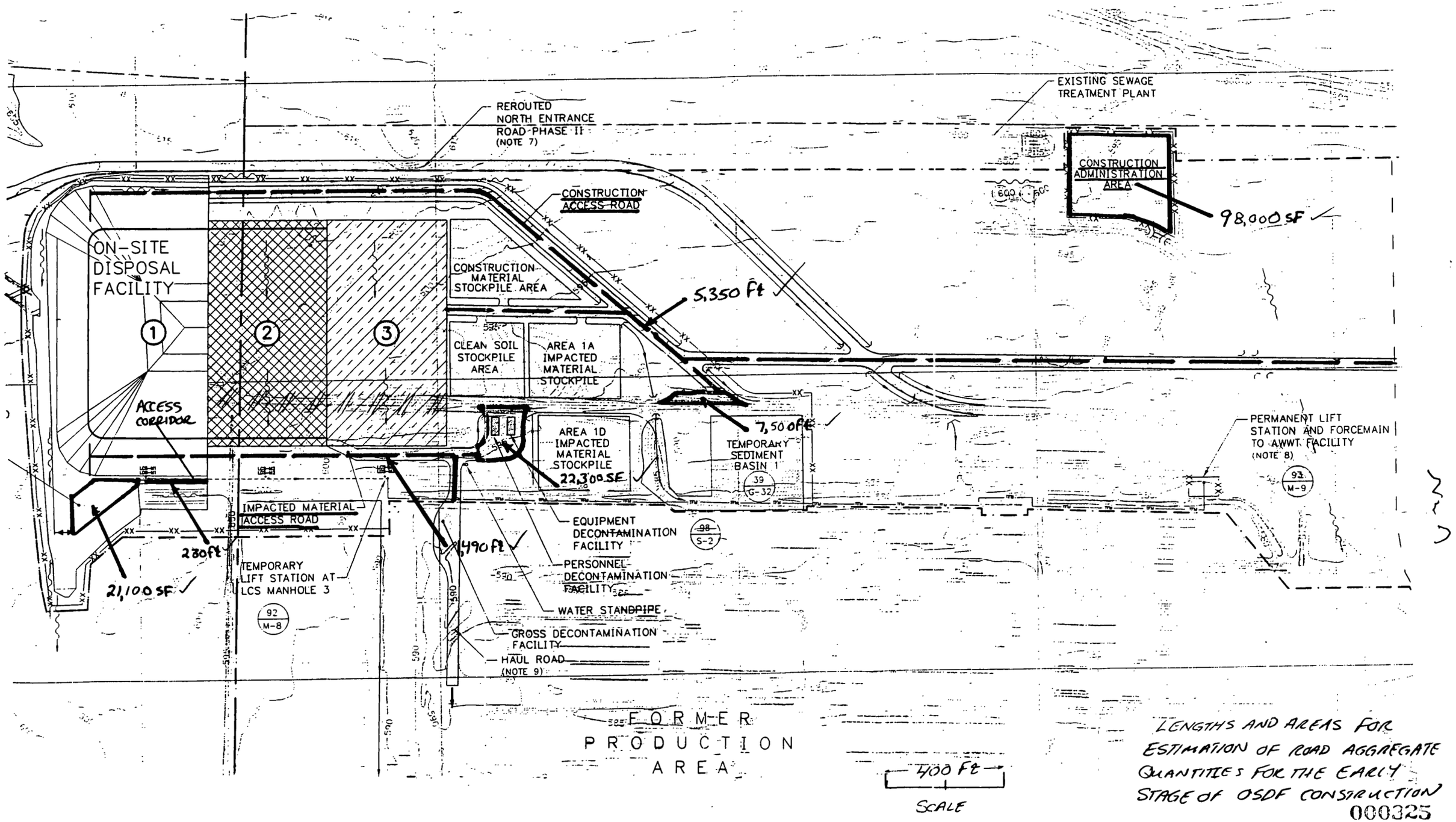


FIGURE 11. APPROXIMATE RUNNING LENGTHS OF DRAINAGE CHANNELS
(FIGURE TAKEN FROM DESIGN DRAWINGS - FINAL COVER SYSTEM GRADING PLAN)

Written By: DGP Date: 2 APRIL 96 Reviewed by: K. Olen Date: 4/6/96

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 8.2



LENGTHS AND AREAS FOR ESTIMATION OF ROAD AGGREGATE QUANTITIES FOR THE EARLY STAGE OF OSDF CONSTRUCTION

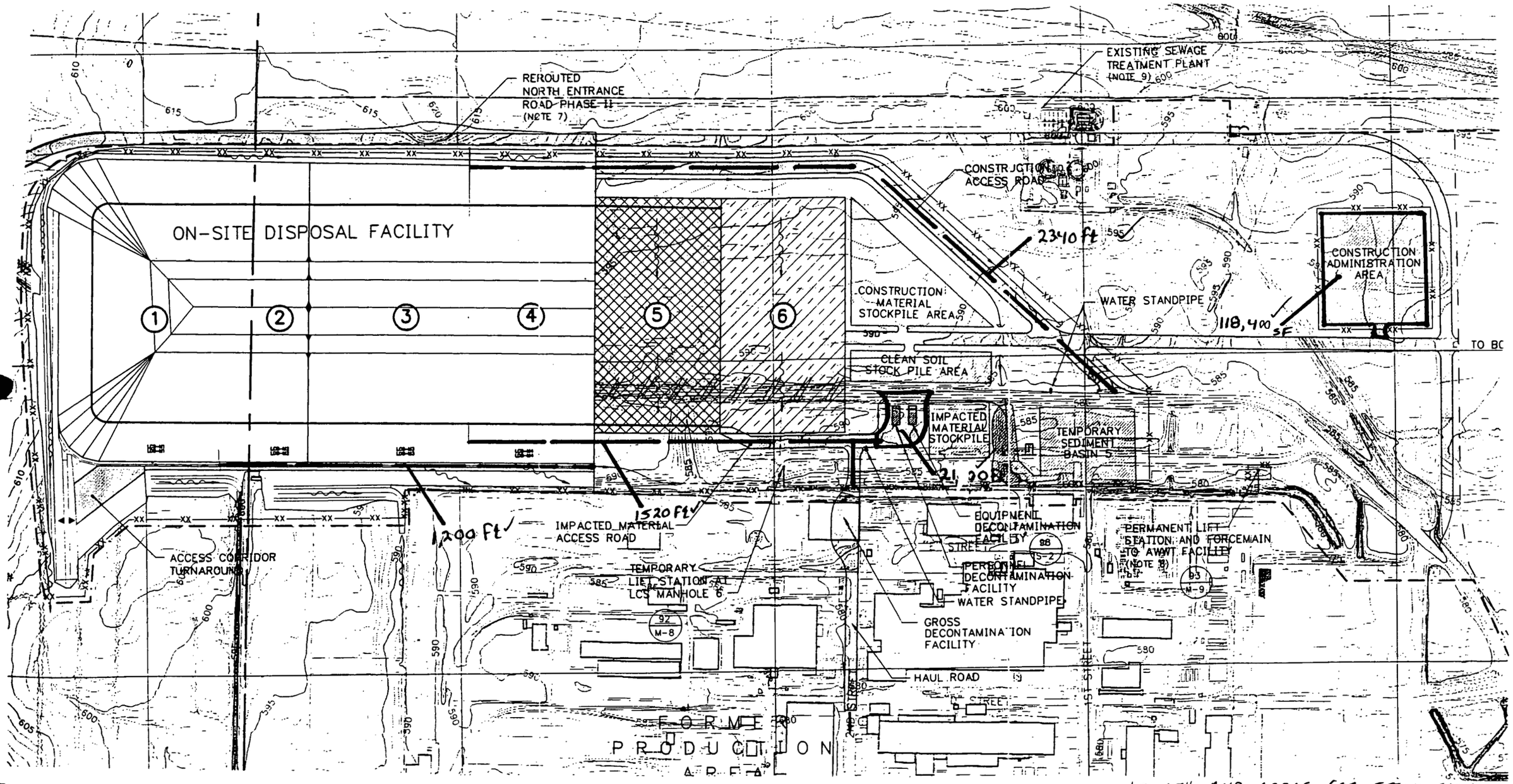
FIGURE 12

FROM THE DESIGN DRAWING "SITE DEVELOPMENT PLAN EARLY STAGE"

GEOSYNTEC CONSULTANTS Page ____ of ____

Written By: DGP Date: 2 APRIL 96 Reviewed by: K. Olen Date: 4/4/96

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 8.2



FROM DESIGN DRAWING "SITE DEVELOPMENT PLAN MIDDLE STAGE"

LENGTH AND AREAS FOR ESTIMATION OF ROAD AGGREGATE QUANTITIES FOR THE MIDDLE STAGE OF OSDF CONSTRUCTION

FIGURE 13

GEOSYNTEC CONSULTANTS Page ____ of ____

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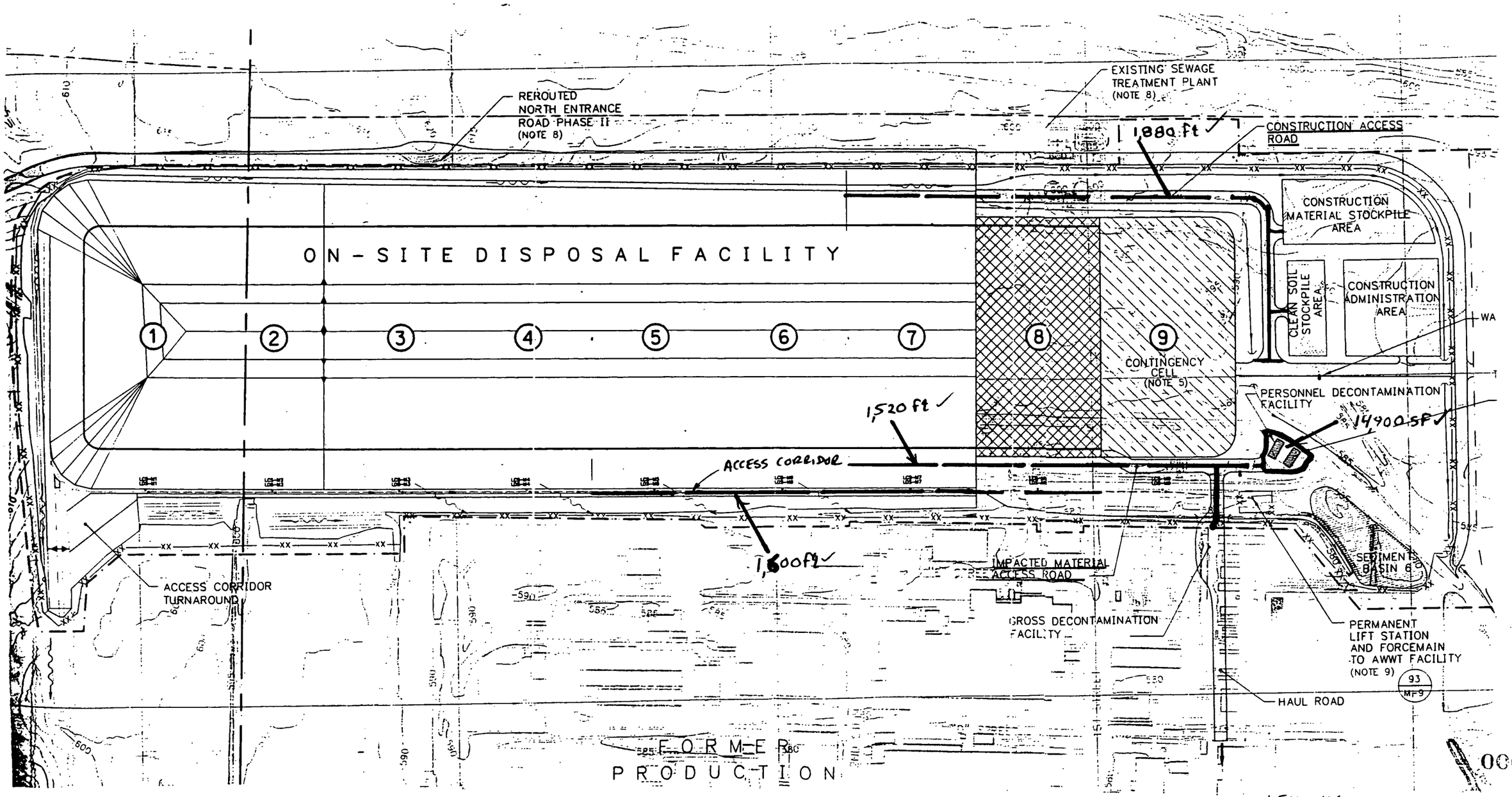
Written By: DGP Date: 2 APR 1996 Reviewed by: K. Oler Date: 4/6/96

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 8.2



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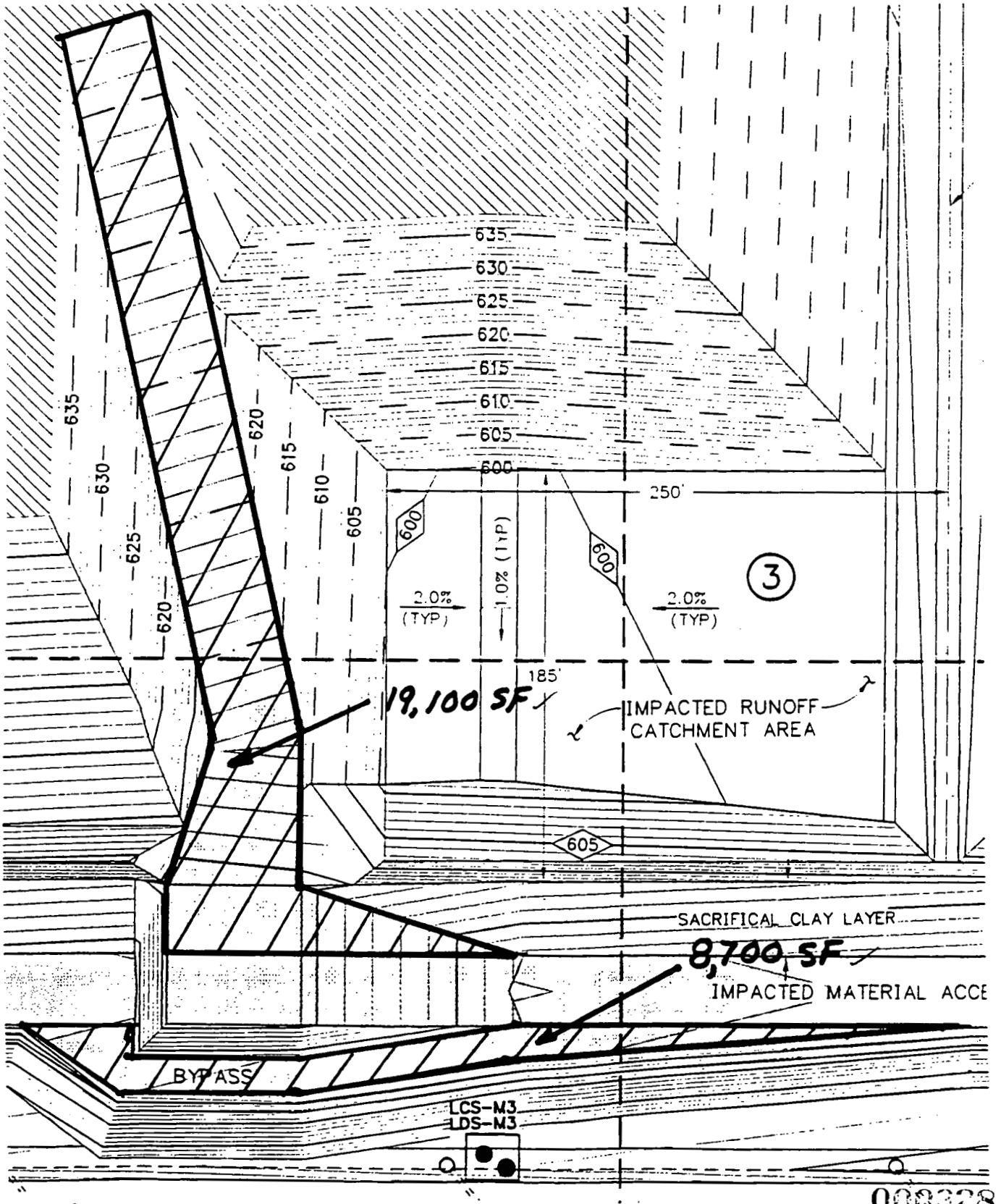
FROM DESIGN DRAWING "SITE DEVELOPMENT PLAN FINAL STAGE"

LENGTHS AND AREAS FOR ESTIMATION OF ROAD AGGREGATE QUANTITIES FOR THE FINAL STAGE OF OSDF CONSTRUCTION

FIGURE 14

Written by: DGP Date: 96/4/2 (YY MM DD) Reviewed by: K. Oliver Date: [illegible] (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3500 Task No.: 8.2



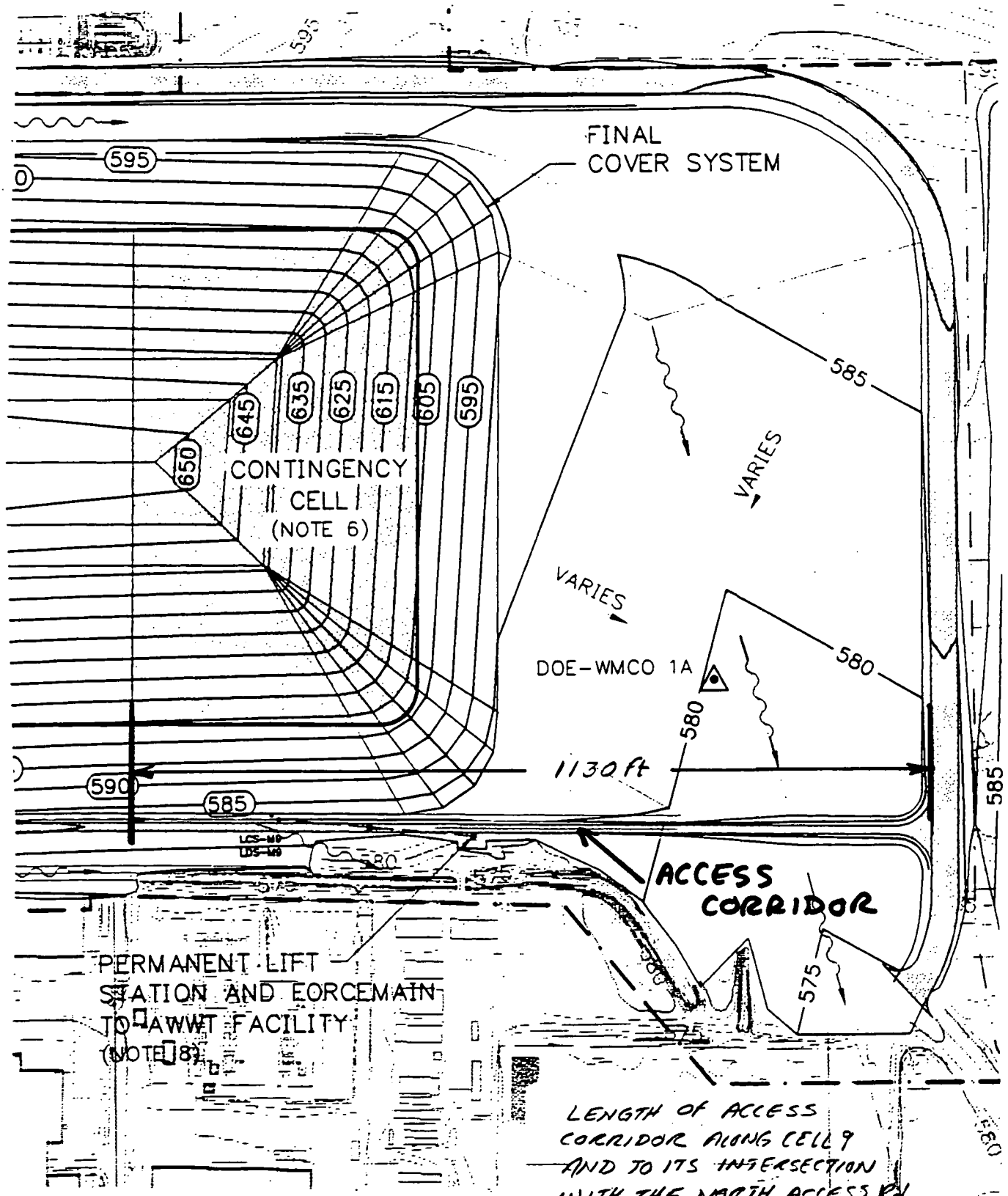
AREA FOR IMPACTED MATERIAL ACCESS RAMP FOR 1 CELL

50 ft
SCALE

FIGURE 15

Written by: DGP Date: 96/4/2 (YY MM DD) Reviewed by: K. Olsen Date: / / (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 8.11



FROM THE DESIGN DRAWING "SITE PLAN"

SCALE 1"=200'

FIGURE 16

3. GEOTECHNICAL - STATIC SLOPE STABILITY

3.1 OSDF Foundation
3.2 Liner System
3.3 Impacted Material Configurations
3.4 Intercell Berm
3.5 Final Cover System
3.6 Access Corridor
3.7 Borrow Area Cut Slopes

3.1 OSDF Foundation

COMPUTATION COVER SHEET

SUBJECT OF CALCULATION: OSDF FOUNDATION

Computations By: (Cognizant Engineer)
Signature: [signature] Date: 02/14/96
Printed Name and Title: R. David Espinoza, Assistant Project Engineer

Assumptions and Procedures Checked by: (Checker)
Signature: [signature] Date: 20 Feb '96
Printed Name and Title: SAAD QURESHI, PROJECT ENGINEER

Computations Checked by:
Signature: [signature] Date: 20 Feb '96
Printed Name and Title: SAAD QURESHI, PROJECT ENGINEER

Computations Backchecked by: (Cognizant Engineer)
Signature: [signature] Date: 2/20/96
Printed Name and Title: R. David Espinoza, Assistant Project Engineer

Approved by: (PDP)
Signature: Mark H. Gleason Date: 20 Feb 96
Printed Name and Title: MARK H. GLEASON, Assistant Project Engineer

Approved by: (DTL and TETL)
Signature: Rudolph Bonaparte Date: 22 Feb 96
Printed Name and Title: Rudolph Bonaparte, Principal (DTL)

Record of Revision (Number and initial all revisions)

NO.	REASON	DATE	BY	CHECKED	APPROVAL
C	Intermediate Design				
D	IDP - EPA Submittal	3Apr96	Kw		

Signature: _____
Number: _____
Registration Stamp (if applicable)

GE3900-09.4/F9530020.CD

Written by: D. Espinoza Date: 96 / 2 / 16 Reviewed by: SR. Date: 20 / Feb / 96

Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 09.4

OSDF FOUNDATION STABILITY

EXECUTIVE SUMMARY

Purpose

This calculation package contains analyses for static foundation stability of the OSDF for final and interim landfill configurations. The slope stability factor of safety of the OSDF is calculated for potential slip 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 properties of the impacted material and the foundation materials are considered. For the final OSDF configuration, only long-term properties of the impacted material and the foundation materials are considered. The stratigraphy of the foundation soils beneath the OSDF is selected based on available data and is considered to represent the worst case conditions.

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	2.8	acceptable

All factors of safety meet the established criteria.

Written by: D. Espinoza Date: 96 / 2 / 10 Reviewed by: _____ Date: ___/___/___

Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 09.4

FOUNDATION STABILITY

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Written by: D. Espinoza Date: 96/2/16 Reviewed by: SQ. Date: 20/Feb/96

Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 09.4

RB(DTL)16 FEB 96

OSDF FOUNDATION STABILITY

CALCULATION PACKAGE

PURPOSE: The purpose of the 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 potential slip surfaces that pass through the impacted material mass and the foundation soils beneath the OSDF. The analyses were performed for both interim and final configurations of the OSDF. The interim configurations model the conditions expected to occur while the OSDF is being filled. The interim configurations were analyzed for both short-term (undrained) and long-term (drained) soil strength parameters. For the long-term effective stress analysis, a perched water table in the brown till that corresponds to the elevation of the surface was considered.

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 slip surfaces were examined. Circular slip surfaces were analyzed using Bishop's Simplified Method (Bishop, 1955). Wedge slip surfaces were analyzed using Janbu's simplified method (Janbu, 1973) and Spencer's Method (Spencer, 1973).

ANALYSIS:

I. XSTABL Computer Model Notes

A. The stability of the foundation soils and the associated factors of safety against foundation failure were analyzed using the program XSTABL, Version 5.

B. For circular slip analysis, the program requires the analyst to provide 2 ranges of x-values delineating where the circular slip 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 initiation points and the number of circular slip surfaces to test for from each initiation point.

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Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 09.4

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OSDF FOUNDATION STABILITY

C. Wedge slip surface analyses require the operator to provide one or more "boxes" within the model through which all of the slip surfaces must pass.

II. Methodology for Critical Slip Surface Search

A. Circular Slip Surfaces

1. The number of initiation points for the circular slip surface search were 20 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 circular slip surfaces were allowed to terminate anywhere within the waste mass.

3. Forty to eighty slip surfaces were examined for each initiation point.

4. From the hundreds of slip surfaces generated, the 10 circular surfaces with the lowest factor of safety against failure were plotted. (Note: Since this was an examination of the foundation materials, any slip surfaces 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 number of initiation points and number of slip circles remain unchanged.

7. The slip circle with the lowest factor of safety generated in the second run was taken as the critical circle.

B. Wedge-Type Slip Surfaces

1. Two boxes were designated within the model. The first box was sized to contain as much of the foundation soils located under the impacted material 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 impacted material mass.

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OSDF FOUNDATION STABILITY

2. From 400 to 1,000 slip surfaces were then generated through the 2 initial boxes and the factor of safety for each slip surface computed using the Janbu's simplified method (Janbu, 1973).

3. The 10 most critical slip surfaces were plotted.

4. Both boxes were then reduced in size and repositioned to contain the inflection points of the 10 most critical slip surfaces.

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 slip surfaces were generated using both the Rankine and block failure generation.

7. The final factor of safety against a wedge slope instability was computed using Spencer's method (Spencer, 1973) on the wedge slip surface generated in steps 1 through 6.

III. Stratigraphy

The stratigraphy used for the foundation stability analysis represents the most critical condition based on all existing data for the site (Parsons, 1995). Various subsurface conditions were considered for the foundation stability analysis to identify the worst case.

For long-term conditions, the presence of a perched water table located in the brown till layer was considered. It was assumed that the perched water table had no effect on shear strength, and the buoyant unit weight of the bottom till was used. For the short-term, total stress analysis, the effect of the perched water table was not considered.

IV. Interim Landfill Conditions

A. OSDF Geometry

The interim conditions are expected to occur while the OSDF is being filled after capping of the existing cell and prior to placement of impacted materials in the adjacent cell. The geometry is taken from the Construction Drawings, is a North to South section, and is shown on Figure 1.

Written by: D. Espinoza Date: 96 / 2 / 16 Reviewed by: SDR Date: 20 / FEB / '96

Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 09.4

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OSDF FOUNDATION STABILITY

B. Material Strength Parameters

1. Short-Term Conditions

a) Stability analyses were performed for circular and wedge slip surfaces in the subgrade materials. The total stress analyses used undrained strengths for brown and gray tills.

b) Total Stress material parameters in the following table are established in the Data Verification section of this package.

Material	Total Unit Weight (γ) (pcf)	S_u (psf)	ϕ (degrees)
1) Impacted Material	125	200	25
2) Granular Soils of cover and liner system	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 Conditions

a) Stability analyses were performed for circular and wedge slip surfaces in the subgrade materials. The analysis was performed using the effective stress drained shear strengths for the brown and gray tills.

b) Effective Stress material parameters in the following table are established in the Data Verification section of this package.

Material	Total Unit Weight (γ) (pcf)	ϕ' (degrees)	c' (psf)
1) Impacted Material	125	25	0
2) Granular Soils of cover and liner system	125	30	0
3) Compacted Clay	130	25	0

Written by: D. Espinoza Date: 96 / 2 / 16 Reviewed by: SG Date: 20 / Feb / 96

Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 09.4

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OSDF FOUNDATION STABILITY

Material	Total Unit Weight (γ) (pcf)	ϕ' (degrees)	c' (psf)
4) Brown Till[1]	135	25	0
5) Gray Till	145	30	0
6) Great Miami Aquifer	135	35	0

Note [1]A perched water table was assumed for this material.

V. Final Landfill Conditions

A. Landfill Geometry

The final conditions examined will occur after the OSDF has been closed and capped. The geometry was obtained from the Construction Drawings is an East to West Section, and is shown on Figure 2.

B. Material Strength Parameters

1. Stability analyses were performed for circular and wedge slip surfaces in the subgrade materials. The analysis was performed using the effective stress drained strengths for the brown and gray tills.

2. Effective stress material parameters in the following table are established in the Data Verification Section of this package.

Material	Total Unit Weight (γ) (pcf)	ϕ' (degrees)	c' (psf)
1) Impacted Material	125	25	0
2) Granular Soils of Liner and Cover	125	30	0
3) Compacted Clay	130	25	0
4) Brown Till[1]	135	25	0

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OSDF FOUNDATION STABILITY

Material	Total Unit Weight (γ) (pcf)	ϕ' (degrees)	c' (psf)
5) Gray Till	145	30	0
6) Great Miami Aquifer	135	35	0

Note (1)A perched water table was assumed for this material.

VI. Summary of Results

The minimum acceptance factors of safety against slope failure are: (UMTRA, 1989) (Ref 7)

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
  1.6 Against wedge failure

- Interim conditions (long-term)
  1.8 Against circular failure
  2.0 Against wedge failure

- Final configuration
  2.8 Against circular failure
  3.5 Against wedge failure

All factors of safety meet the established criteria.

Written by: D. Espinoza Date: 96 / 2 / 16 Reviewed by: SQ. Date: 20 / Feb / 96

Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 09.4

RB (DTL) 16 FEB 96

OSDF FOUNDATION STABILITY

REFERENCES

Bishop, A.W., "*The Use of the Slip Circle in the Stability Analysis of Slopes*", Geotechnique, V.5, 1995, pp. 7-17.

Electric Power Research Institute, "*Ash Utilization Highways Delaware Demonstration Project*", prepared by Delmarva Power and Light Company, Wilmington, DE, EPRI project 2422-3, August 1989.

Janbu, N., "*Slope Stability Calculations in Embankment Dam Engineering*," Casagrande Memorial Volume, Hirschfield and Poulos, (Eds.) John Wiley, N.Y., 1973, pp. 47-86.

Kavazanjian, R., Matasovic, N., Bonaparte, R., and Schmertmann, G.R., "Evaluation of MSW Properties for Seismic Analysis", *Proceedings, Geoenvironment 2000*, New Orleans, LA, 1995.

Mitchel, J.K., "*Fundamentals of Soil Behavior*", John Wiley and Sons, New York, NY, 1976, 422 p.

Parsons, "*Disposal Facility Pre-Design Geotechnical Investigation, Soil Investigation Data Report*", Operable Unit 2, Project Order 132, July 1995, Fairfield Executive Center, 6120 South Gilmore Road, Fairfield, Ohio.

Peck, R.B., Hansen, W.E., and Thornburn, T.H., "*Foundation Engineering*", 2nd Ed., John Wiley and Sons, New York, 1974, page 310.

Sharma, S. "*XSTABL: An Integrated Slope Stability Analysis Program for Personal Computers*", Version 5, Interactive Software Designs, Moscow, ID, 1994.

Spencer, E., "The Thrust Line Criterion in Embankment Stability Analysis," *Geotechnique*, Vol. 23, No. 1, pp. 85-100, 1973.

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

Written by: M. GLEASON Date: 95/9/6 Reviewed by: [illegible] Date: 95/10/06
YY MM DD YY MM DD

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	Su	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.

Written by: M. Gleason Date: 95/9/16 (YY MM DD) Reviewed by: SR Date: 95/10/06 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GF 5900 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 Task 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	4898	10
11476	CL-ML	9.5-12.0	2635	15
11479	CL	18.5-21.0	1974	15

Written by: M. GLEASON Date: 95/9/6 Reviewed by: [illegible] Date: 95/10/06

Client: FEDMCO Project: CSDF Project/Proposal No.: GF 3300 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

Written by: M. GLEASON Date: 95/9/13 Reviewed by: [illegible] Date: 95/10/06

Client: FERMILAB Project: OSDF Project/Proposal No.: GE 2900 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 $w_L = 15.7$ @ 4% $w_L = 17.7\%$

Total unit weight $\gamma_T = \gamma_d(1+w_L)$

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%

Written by: M. GLEASON Date: 95/9/13 (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

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 ✓

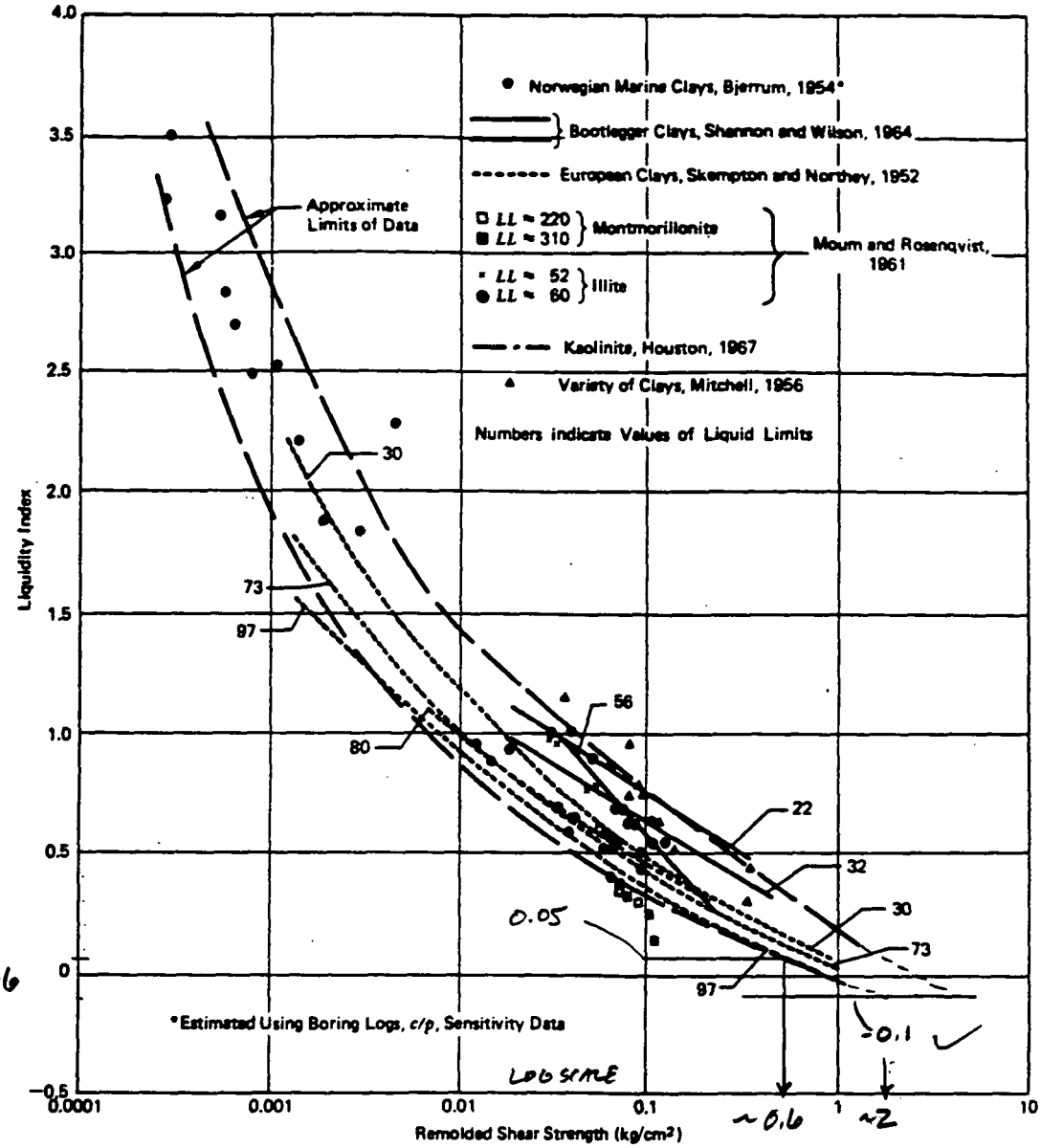
DRAINED STRENGTH - Presented below is a summary of consolidated-undrained triaxial tests on remolded Brown Till (Ref 1 Table 4-9).

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

∴ 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

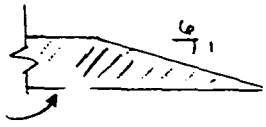
Written by: M BILEMON Date: 95/9/6 (YY MM DD) Reviewed by: [illegible] Date: 95/10/06 (YY MM DD)

Client: EEZ.WCO Project: OSDF Project/Proposal No.: 6F [illegible] Task No.: C9.4

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)
↗ based on tests performed for Delmarva Power similar to bottomash. (EPRI)

FOR ANALYSIS ASSUME THE FOLLOWING PROPERTIES

UNIT WEIGHT γ_{waste} = 125 pcf

SHORT-TERM STRENGTHS C = 200 psf $\phi = 25°$ ✓

LONG-TERM STRENGTHS $\bar{\phi} = 25°$

Written by: M. GLEASON Date: 95/9/14 Reviewed by: [illegible] Date: 95/10/06

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.4

RB 95/10/5

FOUNDATION STABILITY - DATA COLLECTION

PARAMETERS FOR DESIGN

GRANULAR COMPONENTS 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

PERCHED WATER TABLE

Based on site information (Parsons, 1995) it is assumed that a perched ground water table was present in the brown till layer. The top of the perched water table is assumed to correspond to the top of the existing ground surface. For the purposes of analyses, a hydraulic head of 10 ft is assumed for the Brown till. This condition is applied to the long-term effective stress stability analyses.

SQ. 20 Feb '96

FIGURE 1

INTERIM CONFIGURATION

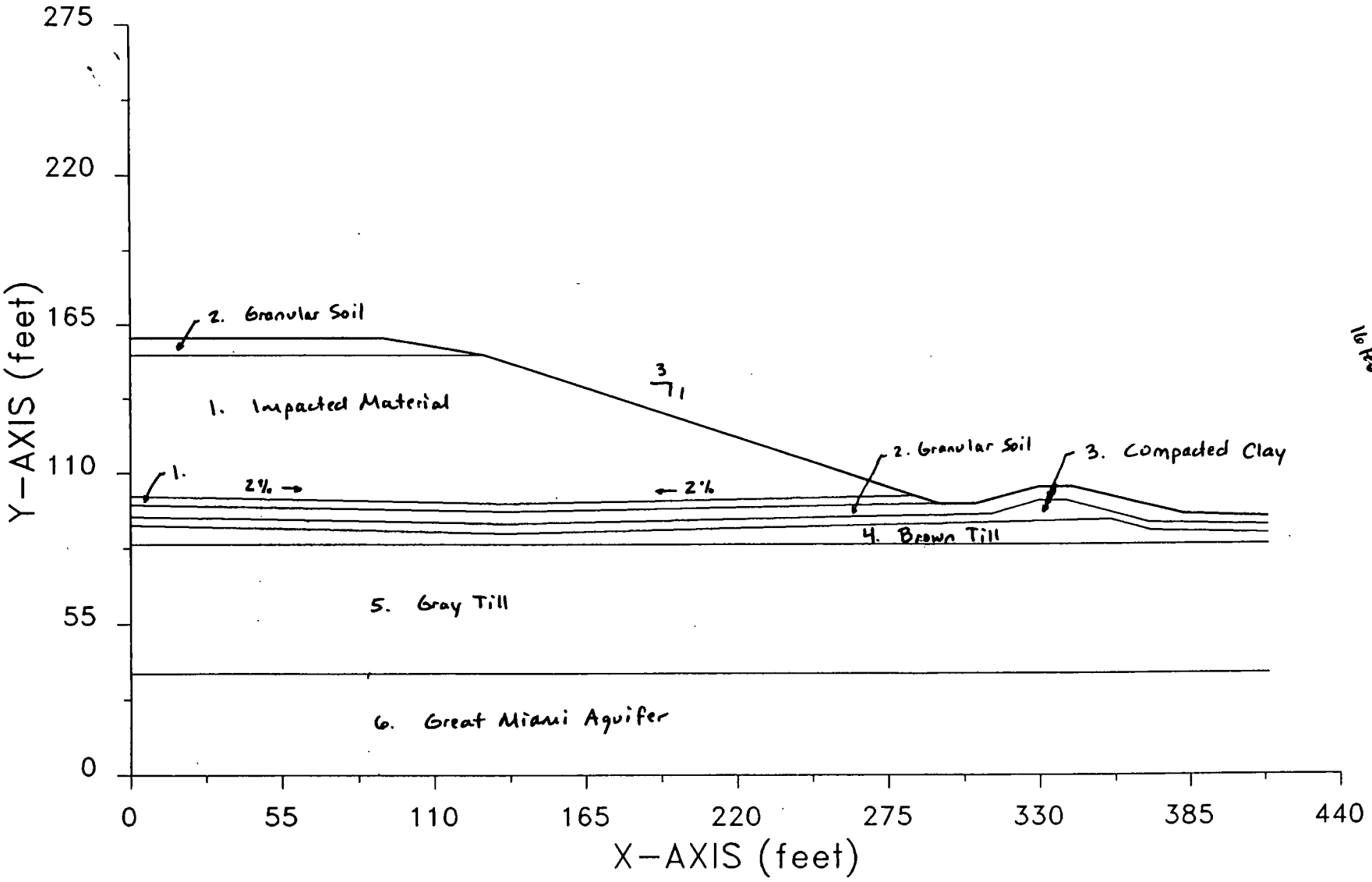


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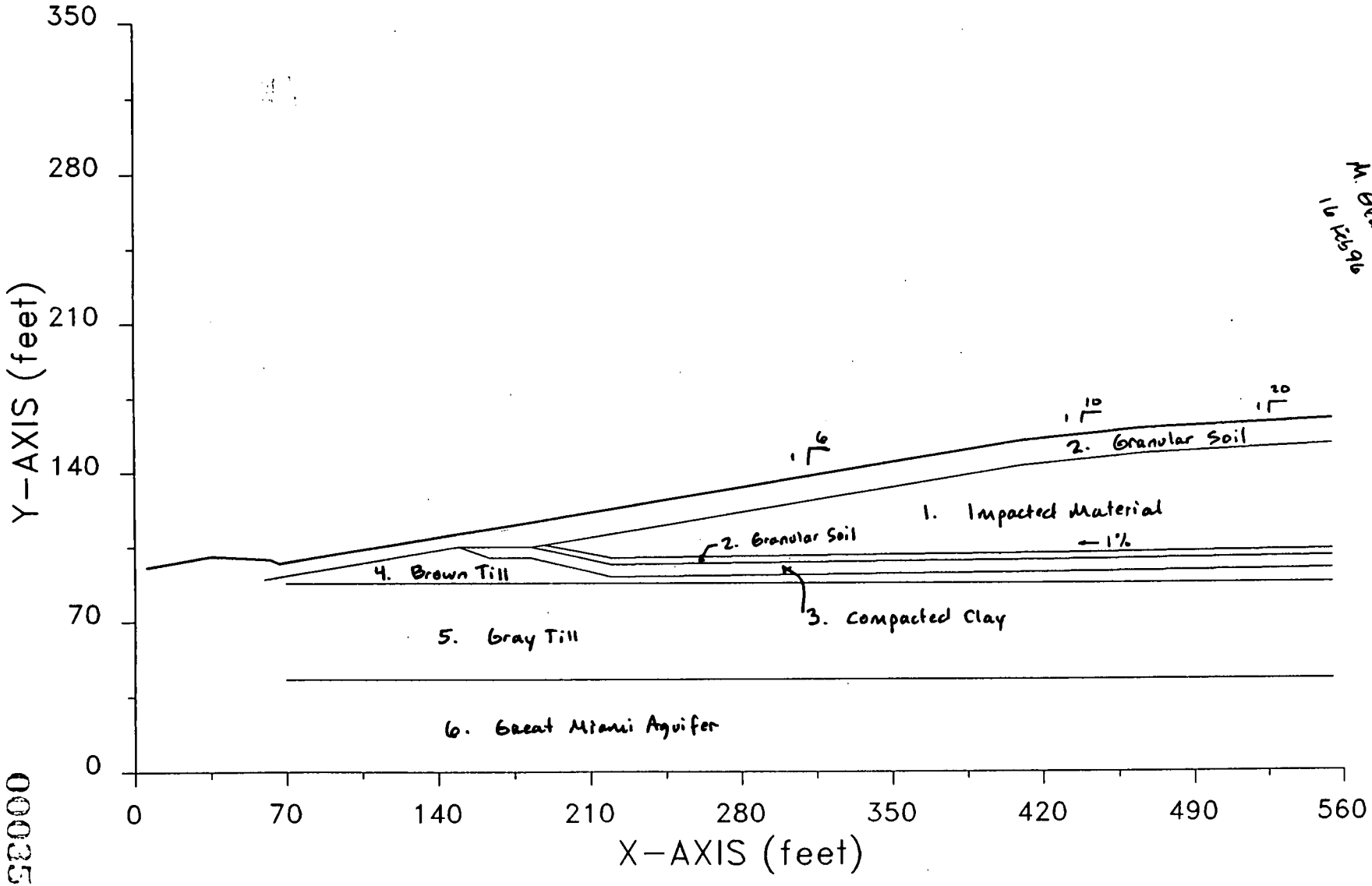
FIGURE 2

FINAL CONFIGURATION



M. Kruse
16 Feb 96

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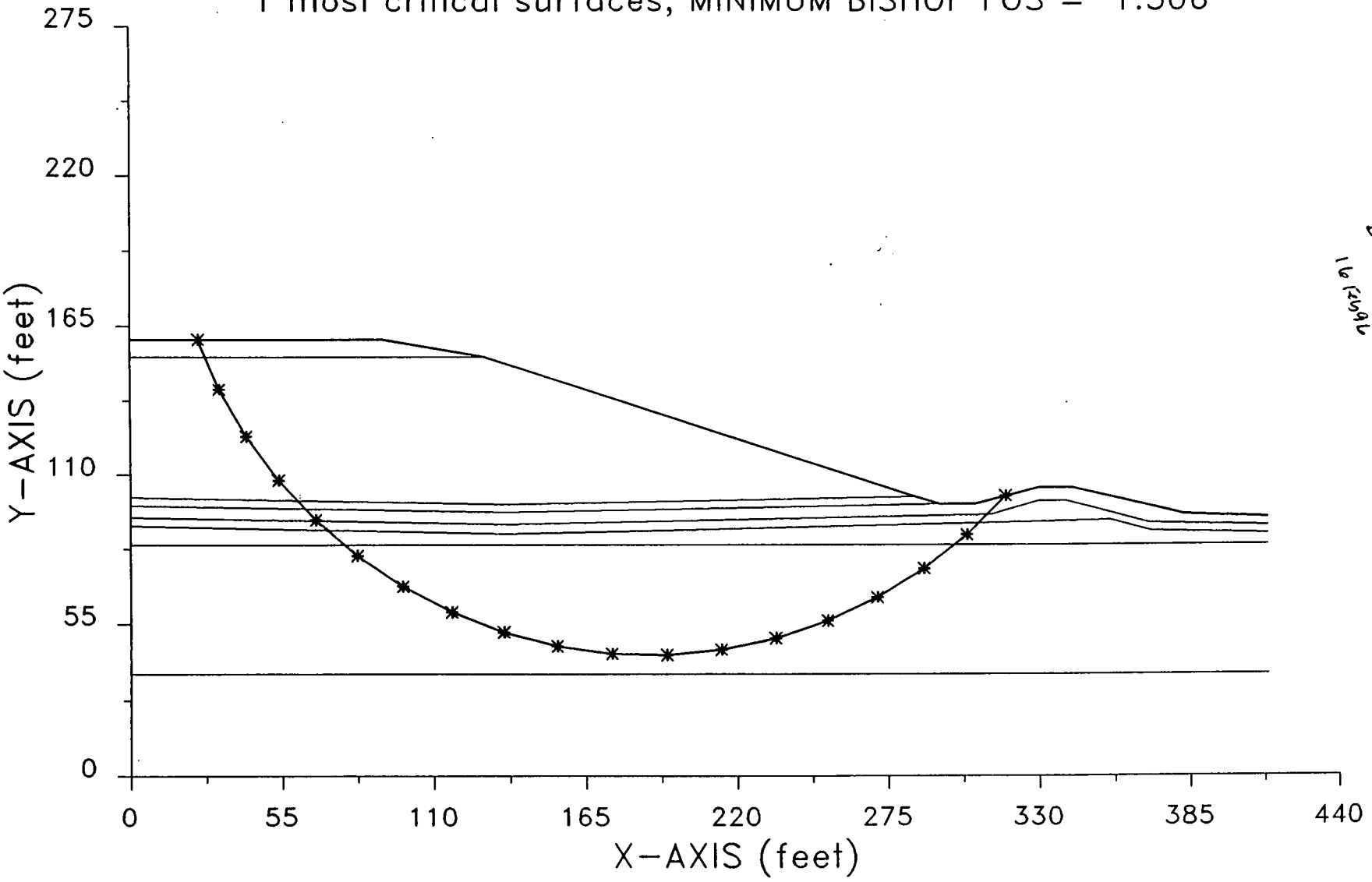
XSTABL OUTPUT FILES

OSDF Interim configuration-short term
1 most critical surfaces, MINIMUM BISHOP FOS = 1.506



E.D.E.
16 Aug 96

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*                                       *
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*           Method of Slices            *
*                                       *
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Problem Description : OSDF Interim Closure Short Term-Circ

SEGMENT BOUNDARY COORDINATES
---

10 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	92.0	160.0	2
2	92.0	160.0	129.0	153.6	2
3	129.0	153.6	150.0	146.6	2
4	150.0	146.6	285.0	101.6	1
5	285.0	101.6	294.0	99.0	2
6	294.0	99.0	307.0	99.0	2
7	307.0	99.0	330.0	105.0	2
8	330.0	105.0	342.0	105.0	2
9	342.0	105.0	383.0	95.0	2
10	383.0	95.0	414.0	94.0	2

17 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	153.6	129.0	153.6	1
2	.0	101.6	136.5	98.9	1
3	136.5	98.9	285.0	101.6	1
4	.0	98.6	136.5	95.9	2
5	136.5	95.9	294.0	99.0	2
6	.0	94.2	136.5	91.5	3
7	136.5	91.5	313.0	95.0	3
8	313.0	95.0	330.0	100.0	3
9	330.0	100.0	340.0	100.0	3
10	340.0	100.0	370.0	92.0	3
11	370.0	92.0	414.0	91.0	3
12	.0	91.0	136.5	88.0	4
13	136.5	88.0	356.0	93.0	4
14	356.0	93.0	371.0	89.0	4
15	371.0	89.0	414.0	88.0	4
16	.0	84.0	414.0	84.0	5
17	.0	37.0	414.0	37.0	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.

400 trial surfaces will be generated and analyzed.

20 Surfaces initiate from each of 20 points equally spaced along the ground surface between x = 318.0 ft
and x = 348.0 ft

Each surface terminates between x = 5.0 ft
and x = 30.0 ft

Unless further limitations were imposed, the minimum elevation at which a surface extends is y = .0 ft

20.0 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 19 coordinate points

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Point No.	x-surf (ft)	y-surf (ft)
1	318.00	101.87
2	303.86	87.73
3	288.18	75.31
4	271.17	64.78
5	253.07	56.28
6	234.11	49.93
7	214.54	45.80
8	194.62	43.95
9	174.63	44.41
10	154.82	47.17
11	135.46	52.19
12	116.81	59.41
13	99.12	68.74
14	82.61	80.04
15	67.52	93.16
16	54.05	107.94
17	42.36	124.17
18	32.62	141.64
19	25.01	160.00

**** Simplified BISHOP FOS = 1.506 ****

The following is a summary of the TEN most critical surfaces

Problem Description : OSDF Interim Closure Short Term-Circ

	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.	1.506	188.60	217.14	173.29	318.00	25.01	1.078E+08
2.	1.508	179.30	226.64	186.56	318.00	5.10	1.235E+08
3.	1.508	187.89	220.23	175.89	318.00	22.69	1.099E+08
4.	1.508	189.04	220.34	176.01	319.58	23.79	1.101E+08
5.	1.508	180.58	228.38	187.67	319.58	5.87	1.242E+08
6.	1.509	186.02	221.92	178.42	318.00	18.93	1.130E+08
7.	1.509	181.71	229.38	188.40	321.16	6.64	1.248E+08
8.	1.509	185.14	223.29	180.87	319.58	16.00	1.164E+08
9.	1.509	191.13	218.83	174.34	321.16	27.04	1.085E+08
10.	1.509	180.68	229.24	189.07	321.16	4.94	1.262E+08

* * * END OF FILE * * *

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16 Feb 96

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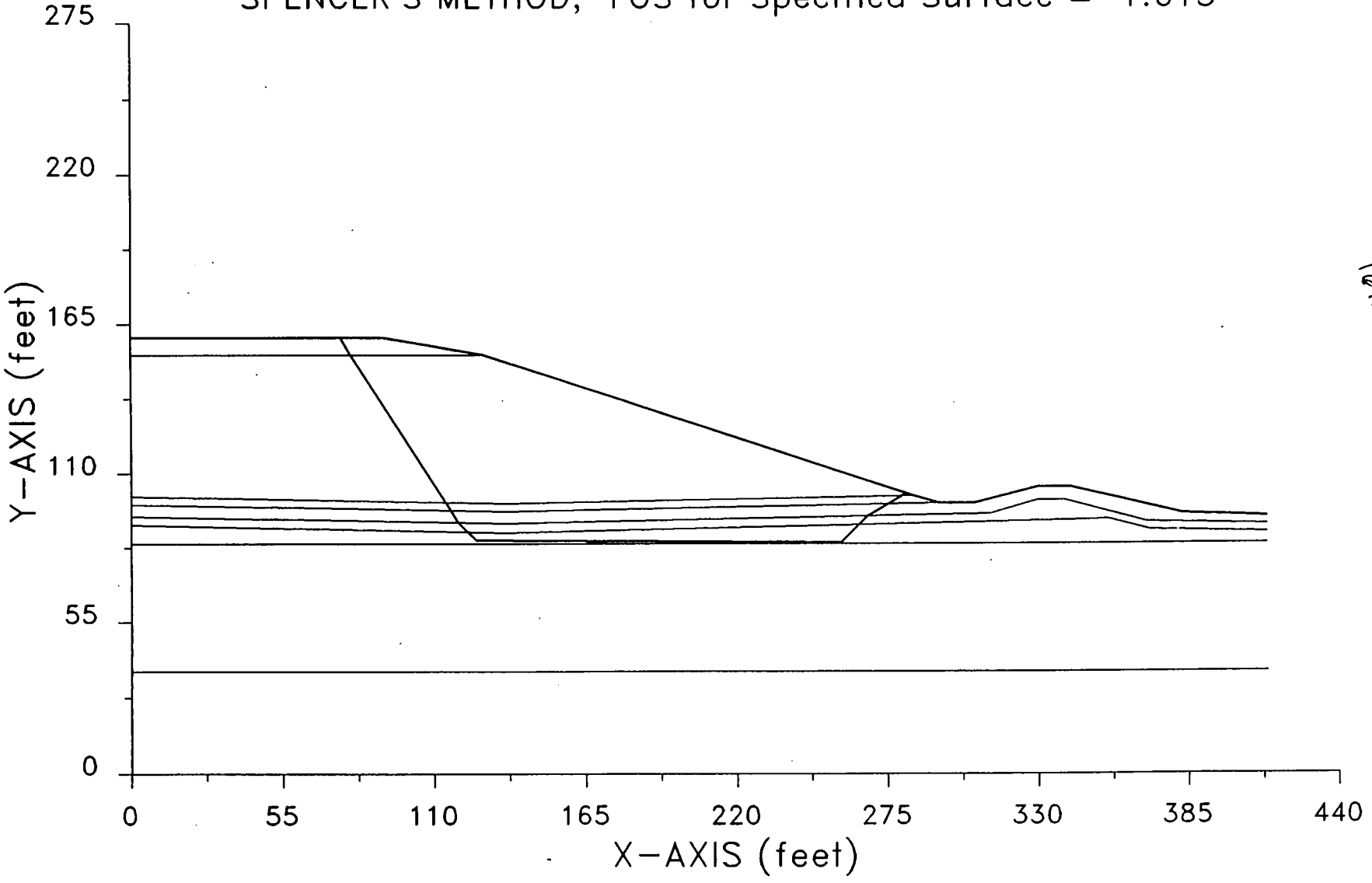
OSDF Interim Configuration-Short term
SPENCER'S METHOD, FOS for Specified Surface = 1.613



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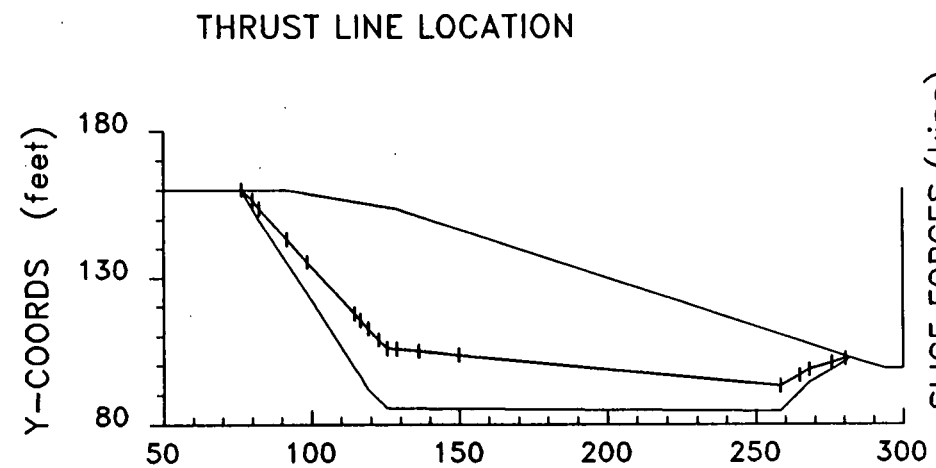

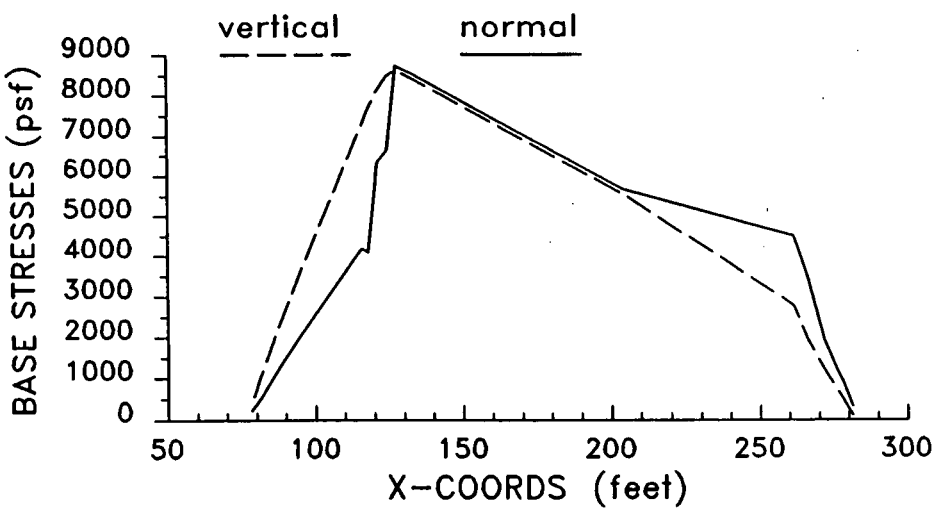

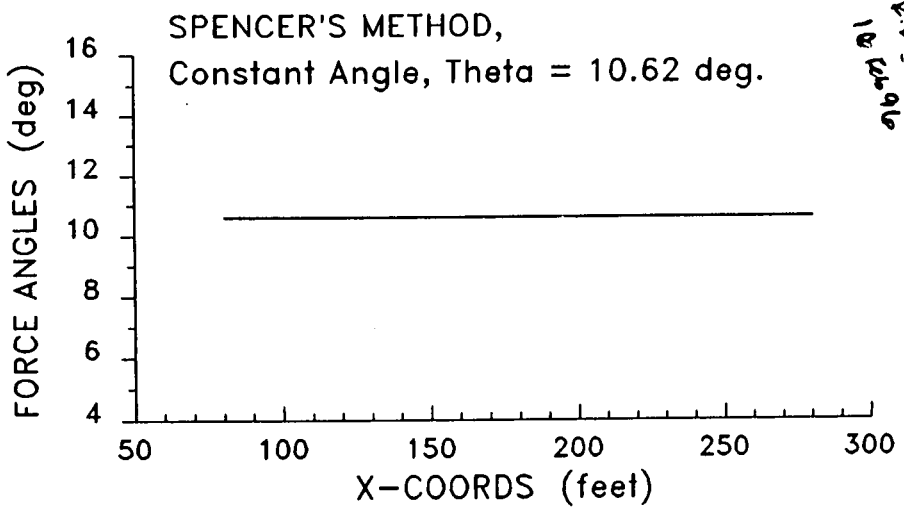

OSDF Interim Closure Short Term
SPENCER'S METHOD, FOS for Specified Surface = 1.613

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*              X S T A B L              *
*                                       *
*       Slope Stability Analysis        *
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* Ver. 5.100                95 - 1305   *
*****************************************
```

Problem Description : OSDF Interim Closure Short Term

SEGMENT BOUNDARY COORDINATES

10 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	92.0	160.0	2
2	92.0	160.0	129.0	153.6	2
3	129.0	153.6	150.0	146.6	2
4	150.0	146.6	285.0	101.6	1
5	285.0	101.6	294.0	99.0	2
6	294.0	99.0	307.0	99.0	2
7	307.0	99.0	330.0	105.0	2
8	330.0	105.0	342.0	105.0	2
9	342.0	105.0	383.0	95.0	2
10	383.0	95.0	414.0	94.0	2

17 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	153.6	129.0	153.6	1
2	.0	101.6	136.5	98.9	1
3	136.5	98.9	285.0	101.6	1
4	.0	98.6	136.5	95.9	2
5	136.5	95.9	294.0	99.0	2
6	.0	94.2	136.5	91.5	3
7	136.5	91.5	313.0	95.0	3
8	313.0	95.0	330.0	100.0	3
9	330.0	100.0	340.0	100.0	3
10	340.0	100.0	370.0	92.0	3
11	370.0	92.0	414.0	91.0	3
12	.0	91.0	136.5	88.0	4
13	136.5	88.0	356.0	93.0	4
14	356.0	93.0	371.0	89.0	4
15	371.0	89.0	414.0	88.0	4
16	.0	84.0	414.0	84.0	5
17	.0	37.0	414.0	37.0	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 SINGLE FAILURE SURFACE HAS BEEN SPECIFIED FOR ANALYSIS

Trial failure surface specified by
the following 15 coordinate points :

Point No.	x-surf (ft)	y-surf (ft)
1	282.15	102.55
2	280.52	101.52
3	276.01	98.65
4	268.16	94.11
5	264.98	90.93
6	258.41	84.36
7	125.76	85.38
8	122.84	88.30
9	119.30	91.84
10	116.73	96.29
11	114.80	99.33
12	98.68	124.63
13	82.56	149.93
14	80.22	153.60
15	76.53	160.00

B.D.E.
16 Feb 96

****
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	281.33	102.03	.79	1.63	-32.29	18.43	161.
2	278.26	100.08	3.76	4.51	-32.47	18.43	2119.
3	276.01	98.65	5.95	.01	-30.04	18.43	5.

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4	272.08	96.38	9.53	7.84	-30.04	18.43	9341.
5	266.57	92.52	15.23	3.18	-45.00	18.43	6084.
6	261.69	87.64	21.73	6.57	-45.00	18.43	18146.
7	204.21	84.78	43.75	108.41	.44	18.43	599888.
8	143.25	85.25	63.60	13.50	.44	18.43	107960.
9	132.75	85.33	67.02	7.50	.44	18.43	63172.
10	127.38	85.37	68.51	3.24	.44	9.81	27896.
11	124.30	86.84	67.57	2.92	45.00	9.81	24758.
12	121.07	90.07	64.90	3.54	45.00	9.81	28750.
13	118.01	94.07	61.43	2.57	59.99	9.81	19739.
14	115.76	97.81	58.08	1.93	57.59	9.81	14007.
15	106.74	111.98	45.47	16.12	57.50	9.81	91623.
16	95.34	129.87	29.55	6.68	57.50	9.81	24674.
17	87.28	142.52	17.48	9.44	57.50	.00	20624.
18	81.39	151.76	8.24	2.34	57.48	.00	2409.
19	78.38	156.80	3.20	3.69	60.03	.00	1476.

ITERATIONS FOR SPENCER'S METHOD

Iter #	Theta	FOS_force	FOS_moment
2	10.2849	1.6036	1.7804
3	10.6300	-----	1.6036
3	10.4575	1.6086	-----
4	10.6198	1.6133	1.6086
5	10.6150	1.6132	1.6133

SLICE INFORMATION ... continued :

Slice	Sigma (psf)	c-value (psf)	phi	U-base (lb)	U-top (lb)	P-top (lb)	Delta
1	310.3	200.0	25.00	0.	0.	0.	.00
2	890.6	200.0	25.00	0.	0.	0.	.00
3	1251.3	200.0	25.00	0.	0.	0.	.00
4	1928.7	.0	30.00	0.	0.	0.	.00
5	3438.8	1200.0	.00	0.	0.	0.	.00
6	4487.8	1200.0	.00	0.	0.	0.	.00
7	5659.1	1200.0	.00	0.	0.	0.	.00
8	8119.0	1200.0	.00	0.	0.	0.	.00
9	8544.4	1200.0	.00	0.	0.	0.	.00
10	8730.9	1200.0	.00	0.	0.	0.	.00
11	6631.0	1200.0	.00	0.	0.	0.	.00
12	6330.5	1200.0	.00	0.	0.	0.	.00
13	4090.9	.0	30.00	0.	0.	0.	.00
14	4178.3	200.0	25.00	0.	0.	0.	.00
15	3254.8	200.0	25.00	0.	0.	0.	.00
16	2079.8	200.0	25.00	0.	0.	0.	.00
17	1188.8	200.0	25.00	0.	0.	0.	.00
18	506.9	200.0	25.00	0.	0.	0.	.00
19	212.9	.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	281.33	310.3	98.5	.0	213.7
2	278.26	890.6	470.1	.0	381.4
3	276.01	1251.3	743.8	.0	485.7
4	272.08	1928.7	1191.0	.0	690.3
5	266.57	3438.8	1911.0	.0	743.9
6	261.69	4487.8	2763.4	.0	743.9
7	204.21	5659.1	5533.5	.0	743.9
8	143.25	8119.0	7997.0	.0	743.9
9	132.75	8544.4	8423.0	.0	743.9
10	127.38	8730.9	8609.8	.0	743.9
11	124.30	6631.0	8478.3	.0	743.9
12	121.07	6330.5	8121.4	.0	743.9
13	118.01	4090.9	7679.3	.0	1464.1
14	115.76	4178.3	7259.9	.0	1331.8
15	106.74	3254.8	5683.8	.0	1064.8
16	95.34	2079.8	3693.8	.0	725.2
17	87.28	1188.8	2184.7	.0	467.6
18	81.39	506.9	1029.4	.0	270.5
19	78.38	212.9	400.0	.0	76.2

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	280.52	10.62	681.	.67	1.58	.424
2	276.01	10.62	5029.	2.20	5.95	.370
3	276.00	10.62	5038.	2.20	5.95	.370
4	268.16	10.62	19446.	4.35	13.10	.332
5	264.98	10.62	32993.	5.57	17.35	.321
6	258.41	10.62	67946.	8.49	26.10	.325
7	150.00	10.62	145194.	18.27	61.41	.298
8	136.50	10.62	154554.	19.52	65.80	.297
9	129.00	10.62	159729.	20.21	68.24	.296
10	125.76	10.62	161960.	20.51	68.78	.298
11	122.84	10.62	144469.	20.47	66.37	.309
12	119.30	10.62	124348.	20.68	63.44	.326
13	116.73	10.62	109652.	19.21	59.43	.323
14	114.80	10.62	99348.	18.39	56.73	.324
15	98.68	10.62	33032.	10.66	34.21	.312
16	92.00	10.62	15776.	8.05	24.89	.323
17	82.56	10.62	2348.	3.71	10.07	.368
18	80.22	10.62	1099.	2.85	6.40	.446
19	76.53	.00	-1.	.09	.00	.000

AVERAGE VALUES ALONG FAILURE SURFACE

Total Normal Stress = 4511.92 (psf)
Pore Water Pressure = .00 (psf)
Shear Stress = 743.56 (psf)

Total Length of failure surface = 252.40 feet

For the single specified surface and the assumed angle of the interslice forces, the SPENCER'S (1973) procedure gives a

FACTOR OF SAFETY = 1.613

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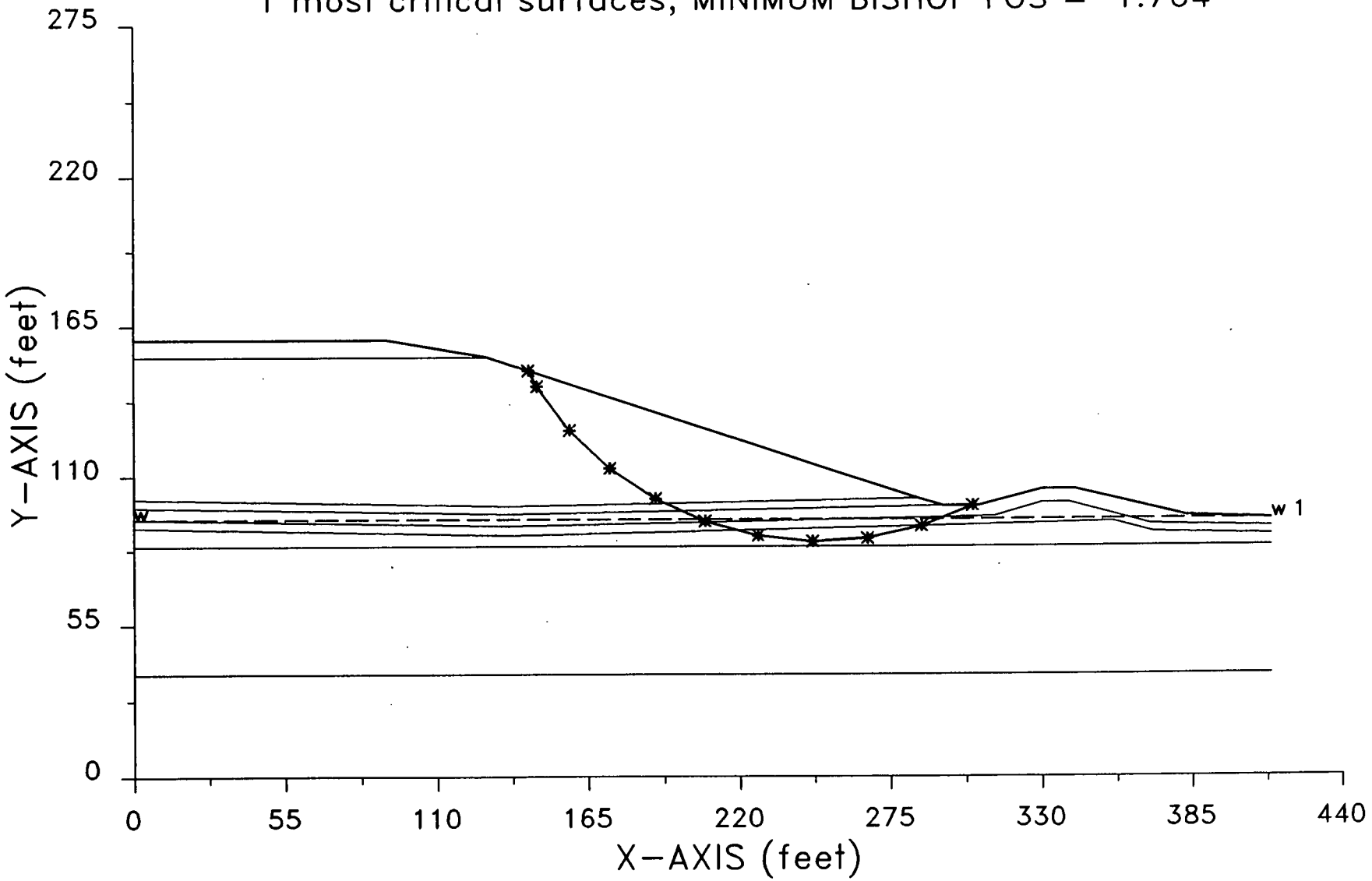
16 Feb 96

Total shear strength available
along specified failure surface = 302.75E+03 lb

OSDF Interim Configuration–Long term
1 most critical surfaces, MINIMUM BISHOP FOS = 1.764



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```

Problem Description : OSDF Interim Configuration-Long term

SEGMENT BOUNDARY COORDINATES
---

10 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	92.0	160.0	2
2	92.0	160.0	129.0	153.6	2
3	129.0	153.6	150.0	146.6	2
4	150.0	146.6	285.0	101.6	1
5	285.0	101.6	294.0	99.0	2
6	294.0	99.0	307.0	99.0	2
7	307.0	99.0	330.0	105.0	2
8	330.0	105.0	342.0	105.0	2
9	342.0	105.0	383.0	95.0	2
10	383.0	95.0	414.0	94.0	2

17 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	153.6	129.0	153.6	1
2	.0	101.6	136.5	98.9	1
3	136.5	98.9	285.0	101.6	1
4	.0	98.6	136.5	95.9	2
5	136.5	95.9	294.0	99.0	2
6	.0	94.2	136.5	91.5	3
7	136.5	91.5	313.0	95.0	3
8	313.0	95.0	330.0	100.0	3
9	330.0	100.0	340.0	100.0	3
10	340.0	100.0	370.0	92.0	3
11	370.0	92.0	414.0	91.0	3
12	.0	91.0	136.5	88.0	4
13	136.5	88.0	356.0	93.0	4
14	356.0	93.0	371.0	89.0	4
15	371.0	89.0	414.0	88.0	4
16	.0	84.0	414.0	84.0	5
17	.0	37.0	414.0	37.0	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	1
5	145.0	145.0	.0	30.00	.000	.0	0
6	135.0	135.0	.0	35.00	.000	.0	0

1 Water surface(s) have been specified

Unit weight of water = 62.40 (pcf)

Water Surface No. 1 specified by 2 coordinate points

P.DE, 16 Feb 96

```
**********************************
        PHREATIC SURFACE,
**********************************
```

Point No.	x-water (ft)	y-water (ft)
1	.00	94.00
2	414.00	94.00

A critical failure surface searching method, using a random technique for generating CIRCULAR surfaces has been specified.

1000 trial surfaces will be generated and analyzed.

10 Surfaces initiate from each of 100 points equally spaced along the ground surface between x = 280.0 ft
and x = 305.0 ft

Each surface terminates between x = 80.0 ft
and x = 150.0 ft

Unless further limitations were imposed, the minimum elevation at which a surface extends is y = .0 ft

20.0 ft line segments define each trial failure surface.

ANGULAR RESTRICTIONS :

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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 := -20.0 degrees

Factors of safety have been calculated by the :

* * * * * SIMPLIFIED BISHOP METHOD * * * * *

The most critical circular failure surface is specified by 11 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	304.75	99.00
2	286.24	91.42
3	266.74	86.98
4	246.78	85.79
5	226.89	87.90
6	207.61	93.25
7	189.48	101.69
8	172.98	112.98
9	158.55	126.84
10	146.60	142.87
11	143.57	148.74

**** Simplified BISHOP FOS = 1.764 ****

The following is a summary of the TEN most critical surfaces

Problem Description : OSDF Interim Configuration-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.	1.764	249.60	207.22	121.46	304.75	143.57	2.566E+07
2.	1.768	248.04	208.33	122.59	303.48	140.87	2.676E+07
3.	1.770	247.23	211.08	126.10	305.00	136.68	2.936E+07
4.	1.774	251.13	207.20	119.44	301.72	148.10	2.267E+07
5.	1.779	243.30	219.44	133.53	300.96	126.99	3.367E+07
6.	1.780	243.62	217.49	132.19	302.22	127.92	3.357E+07
7.	1.780	244.87	213.31	126.89	299.95	134.31	2.934E+07
8.	1.781	242.30	225.89	140.33	302.22	121.65	3.795E+07
9.	1.782	245.56	207.80	122.78	302.47	137.21	2.862E+07
10.	1.783	242.43	222.16	137.02	302.47	123.63	3.674E+07

* * * END OF FILE * * *

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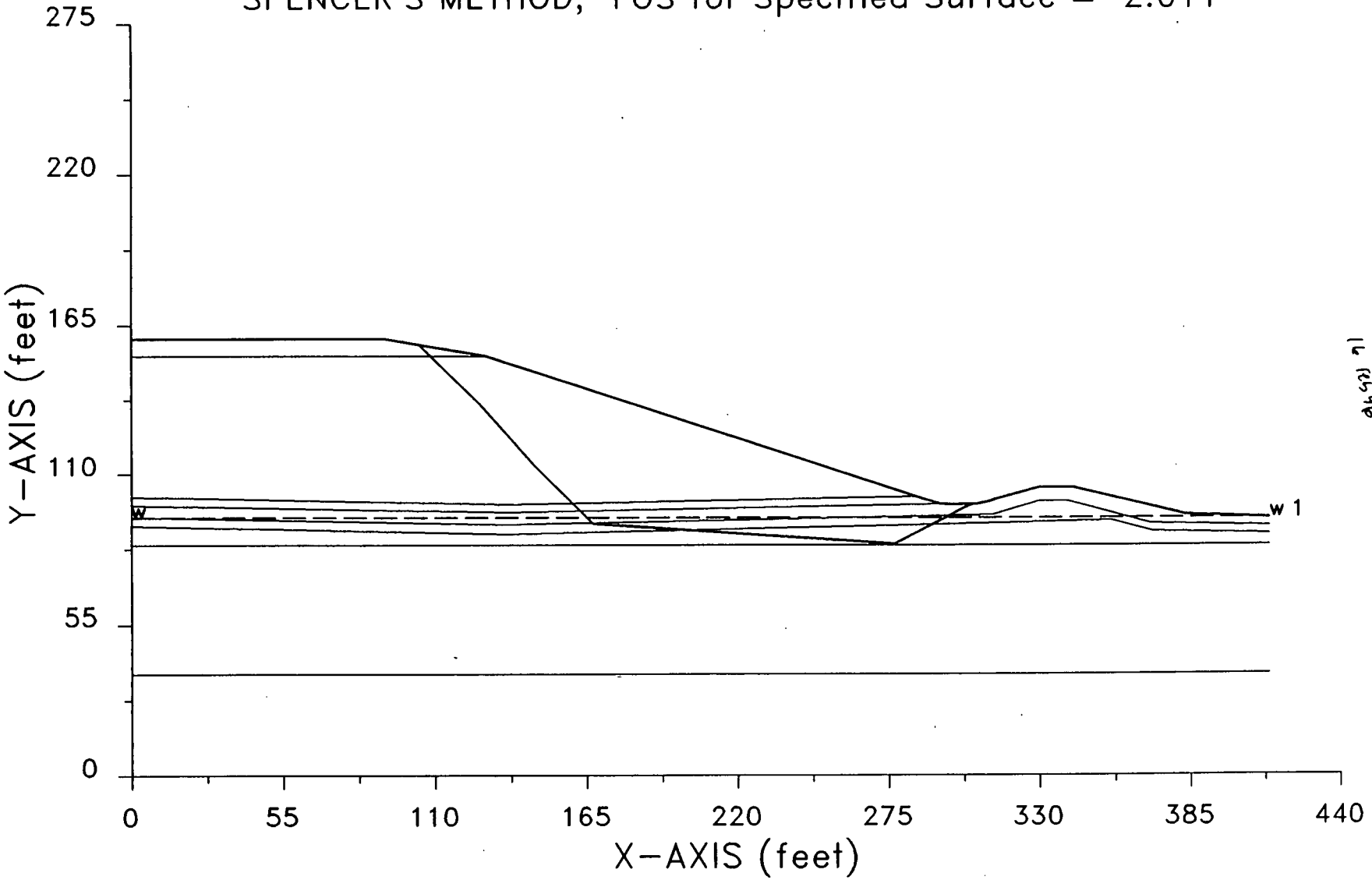
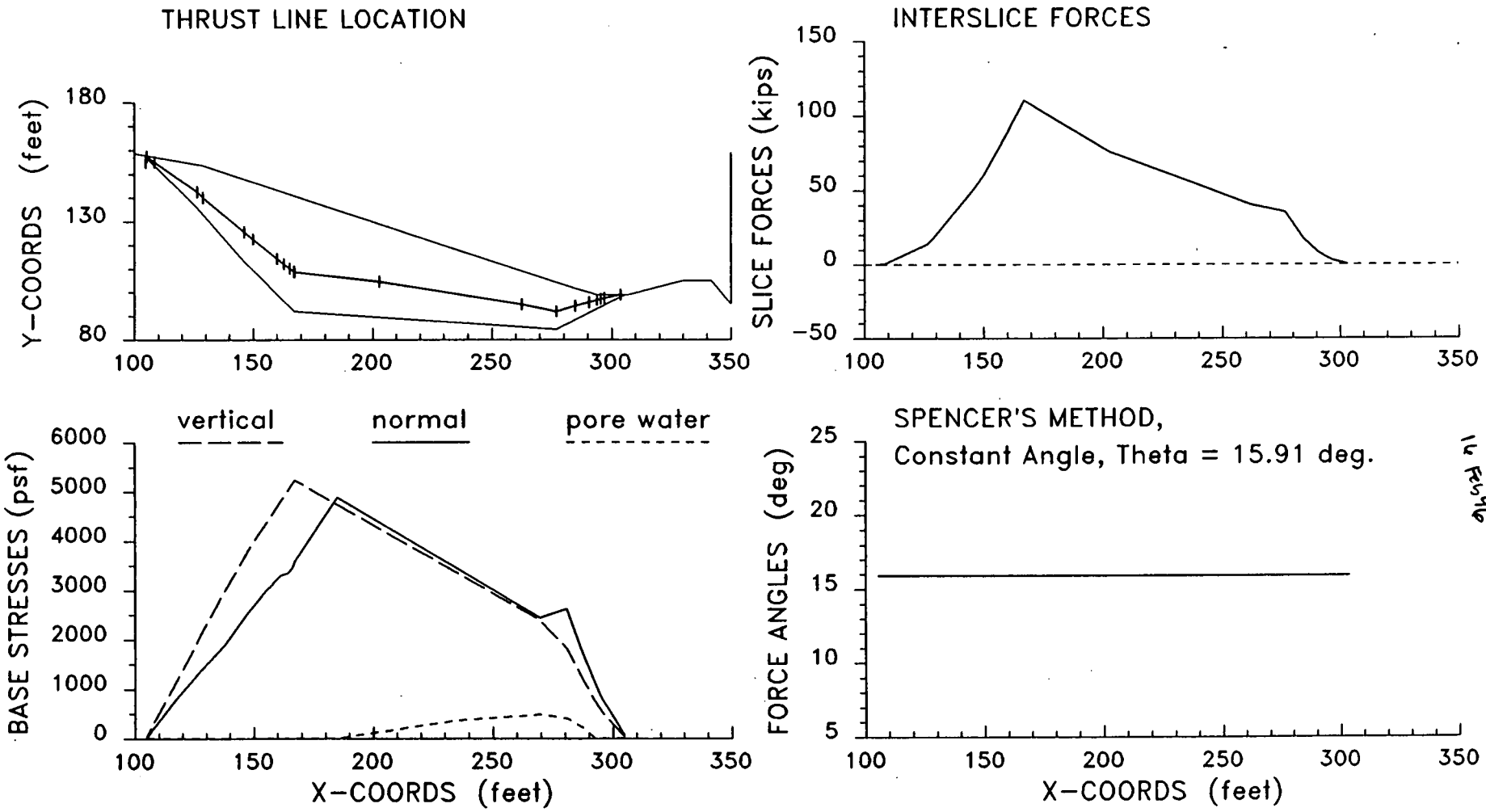
OSDF Interim Configuration–Long Term
SPENCER'S METHOD, FOS for Specified Surface = 2.011





OSDF Interim Configuration–Long Term
SPENCER'S METHOD, FOS for Specified Surface = 2.011

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```

Problem Description : OSDF Interim Configuration-Long Term

SEGMENT BOUNDARY COORDINATES
---

10 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	92.0	160.0	2
2	92.0	160.0	129.0	153.6	2
3	129.0	153.6	150.0	146.6	2
4	150.0	146.6	285.0	101.6	1
5	285.0	101.6	294.0	99.0	2
6	294.0	99.0	307.0	99.0	2
7	307.0	99.0	330.0	105.0	2
8	330.0	105.0	342.0	105.0	2
9	342.0	105.0	383.0	95.0	2
10	383.0	95.0	414.0	94.0	2

17 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	153.6	129.0	153.6	1
2	.0	101.6	136.5	98.9	1
3	136.5	98.9	285.0	101.6	1
4	.0	98.6	136.5	95.9	2
5	136.5	95.9	294.0	99.0	2
6	.0	94.2	136.5	91.5	3
7	136.5	91.5	313.0	95.0	3
8	313.0	95.0	330.0	100.0	3
9	330.0	100.0	340.0	100.0	3
10	340.0	100.0	370.0	92.0	3
11	370.0	92.0	414.0	91.0	3
12	.0	91.0	136.5	88.0	4
13	136.5	88.0	356.0	93.0	4
14	356.0	93.0	371.0	89.0	4
15	371.0	89.0	414.0	88.0	4
16	.0	84.0	414.0	84.0	5
17	.0	37.0	414.0	37.0	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	1
5	145.0	145.0	.0	30.00	.000	.0	0
6	135.0	135.0	.0	35.00	.000	.0	0

1 Water surface(s) have been specified

Unit weight of water = 62.40 (pcf)

Water Surface No. 1 specified by 2 coordinate points

```
***********************************
        PHREATIC SURFACE,
***********************************
```

Point No.	x-water (ft)	y-water (ft)
1	.00	94.00
2	414.00	94.00

A SINGLE FAILURE SURFACE HAS BEEN SPECIFIED FOR ANALYSIS

Trial failure surface specified by
the following 8 coordinate points :

Point No.	x-surf (ft)	y-surf (ft)
1	305.93	99.00
2	303.70	98.21
3	277.07	84.41
4	167.39	91.95
5	146.24	113.22
6	126.47	135.78
7	105.25	157.00
8	104.83	157.78

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*****************************************************
SELECTED METHOD OF ANALYSIS:  Spencer (1973)
*****************************************************
```

E.D.E. 16 Feb 96

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****
SUMMARY OF INDIVIDUAL SLICE INFORMATION
****

Slice	x-base (ft)	y-base (ft)	height (ft)	width (ft)	alpha	beta	weight (lb)
1	304.82	98.60	.40	2.23	-19.51	.00	110.
2	300.29	96.45	2.55	6.81	-27.39	.00	2175.
3	296.23	94.34	4.66	1.31	-27.39	.00	767.
4	294.79	93.59	5.41	1.58	-27.39	.00	1074.
5	292.39	92.35	7.12	3.22	-27.39	16.11	2901.
6	287.89	90.02	10.75	5.78	-27.39	16.11	7936.
7	281.04	86.46	16.46	7.93	-27.39	18.43	16818.
8	269.82	84.91	21.75	14.50	3.93	18.43	40534.
9	232.72	87.46	31.57	59.71	3.93	18.43	238221.
10	185.12	90.73	44.16	35.47	3.93	18.43	196105.
11	167.31	92.03	48.80	.16	45.16	18.43	967.
12	166.29	93.05	48.11	1.88	45.16	18.43	11307.
13	164.15	95.21	46.67	2.41	45.16	18.43	14042.
14	161.50	97.87	44.89	2.89	45.16	18.43	16225.
15	155.03	104.38	40.54	10.05	45.16	18.43	50947.
16	148.12	111.33	35.90	3.76	45.16	18.43	16872.
17	137.62	123.06	27.67	17.24	48.77	18.43	59629.
18	127.73	134.34	19.48	2.53	48.77	9.81	6161.
19	117.56	144.69	10.89	17.82	45.00	9.81	24255.
20	106.95	155.30	2.11	3.40	45.00	9.81	898.
21	105.04	157.39	.35	.42	61.72	9.81	19.

ITERATIONS FOR SPENCER'S METHOD

Iter #	Theta	FOS_force	FOS_moment
2	15.8803	2.0100	2.0195
3	15.9132	2.0107	2.0100

SLICE INFORMATION ... continued :

Slice	Sigma (psf)	c-value (psf)	phi	U-base (lb)	U-top (lb)	P-top (lb)	Delta
1	69.0	.0	30.00	0.	0.	0.	.00
2	513.7	.0	30.00	0.	0.	0.	.00
3	877.1	.0	25.00	0.	0.	0.	.00
4	1023.0	.0	25.00	0.	0.	0.	.00
5	1352.6	.0	25.00	0.	0.	0.	.00
6	1743.8	.0	25.00	1618.	0.	0.	.00
7	2582.8	.0	25.00	4200.	0.	0.	.00
8	2287.2	.0	25.00	8245.	0.	0.	.00
9	3686.1	.0	25.00	24429.	0.	0.	.00
10	5703.2	.0	25.00	0.	0.	0.	.00
11	4196.1	.0	25.00	0.	0.	0.	.00
12	4026.7	.0	30.00	0.	0.	0.	.00
13	3906.1	.0	30.00	0.	0.	0.	.00
14	3859.9	.0	25.00	0.	0.	0.	.00
15	3485.7	.0	25.00	0.	0.	0.	.00
16	3004.2	.0	30.00	0.	0.	0.	.00
17	2201.5	.0	30.00	0.	0.	0.	.00
18	1598.1	.0	25.00	0.	0.	0.	.00
19	938.1	.0	25.00	0.	0.	0.	.00
20	177.3	.0	30.00	0.	0.	0.	.00
21	23.6	.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	304.82	69.0	49.4	.0	19.8
2	300.29	513.7	319.3	.0	147.5
3	296.23	877.1	584.1	.0	203.4
4	294.79	1023.0	681.3	.0	237.2
5	292.39	1352.6	900.8	.0	313.7
6	287.89	1992.4	1373.1	248.5	404.4
7	281.04	3053.0	2120.8	470.2	599.0
8	269.82	2854.6	2795.7	567.3	530.4
9	232.72	4094.2	3989.5	408.1	854.8
10	185.12	5703.2	5528.8	.0	1322.6
11	167.31	4196.1	6100.4	.0	973.1
12	166.29	4026.7	6014.3	.0	1156.2
13	164.15	3906.1	5834.2	.0	1121.6
14	161.50	3859.9	5611.6	.0	895.1
15	155.03	3485.7	5067.6	.0	808.4
16	148.12	3004.2	4487.2	.0	862.6
17	137.62	2201.5	3458.8	.0	632.1
18	127.73	1598.1	2435.3	.0	370.6
19	117.56	938.1	1361.1	.0	217.6
20	106.95	177.3	264.3	.0	50.9
21	105.04	23.6	44.3	.0	6.8

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	303.70	15.91	103.	.71	.79	.902
2	296.89	15.91	3033.	2.85	4.32	.660
3	295.58	15.91	3931.	3.13	5.00	.627
4	294.00	15.91	5189.	3.49	5.82	.600
5	290.78	15.91	8587.	4.18	8.42	.497
6	285.00	15.91	17222.	5.56	13.08	.425
7	277.07	15.91	35207.	7.47	19.83	.376
8	262.57	15.91	40245.	9.47	23.67	.400
9	202.86	15.91	75846.	14.91	39.47	.378
10	167.39	15.91	110168.	16.74	48.85	.343
11	167.23	15.91	109633.	16.71	48.75	.343
12	165.35	15.91	103976.	16.23	47.48	.342
13	162.94	15.91	96952.	15.60	45.86	.340
14	160.05	15.91	87973.	15.01	43.92	.342
15	150.00	15.91	59777.	13.13	37.16	.353
16	146.24	15.91	51337.	12.36	34.63	.357
17	129.00	15.91	17634.	7.12	20.71	.344
18	126.47	15.91	13811.	6.63	18.26	.363
19	108.65	15.91	459.	1.27	3.52	.360
20	105.25	15.91	12.	.30	.71	.428
21	104.83	.00	-4.	-2.85	.00	.000

AVERAGE VALUES ALONG FAILURE SURFACE

P.D.E. 16 Feb 96

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Total Normal Stress = 3323.30 (psf)
Pore Water Pressure = 165.06 (psf)
Shear Stress = 756.73 (psf)

Total Length of failure surface = 233.19 feet

For the single specified surface and the assumed angle of the interslice forces, the SPENCER'S (1973) procedure gives a

FACTOR OF SAFETY = 2.011

Total shear strength available along specified failure surface = 336.87E+03 lb

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R.D.E.
16 Feb 96

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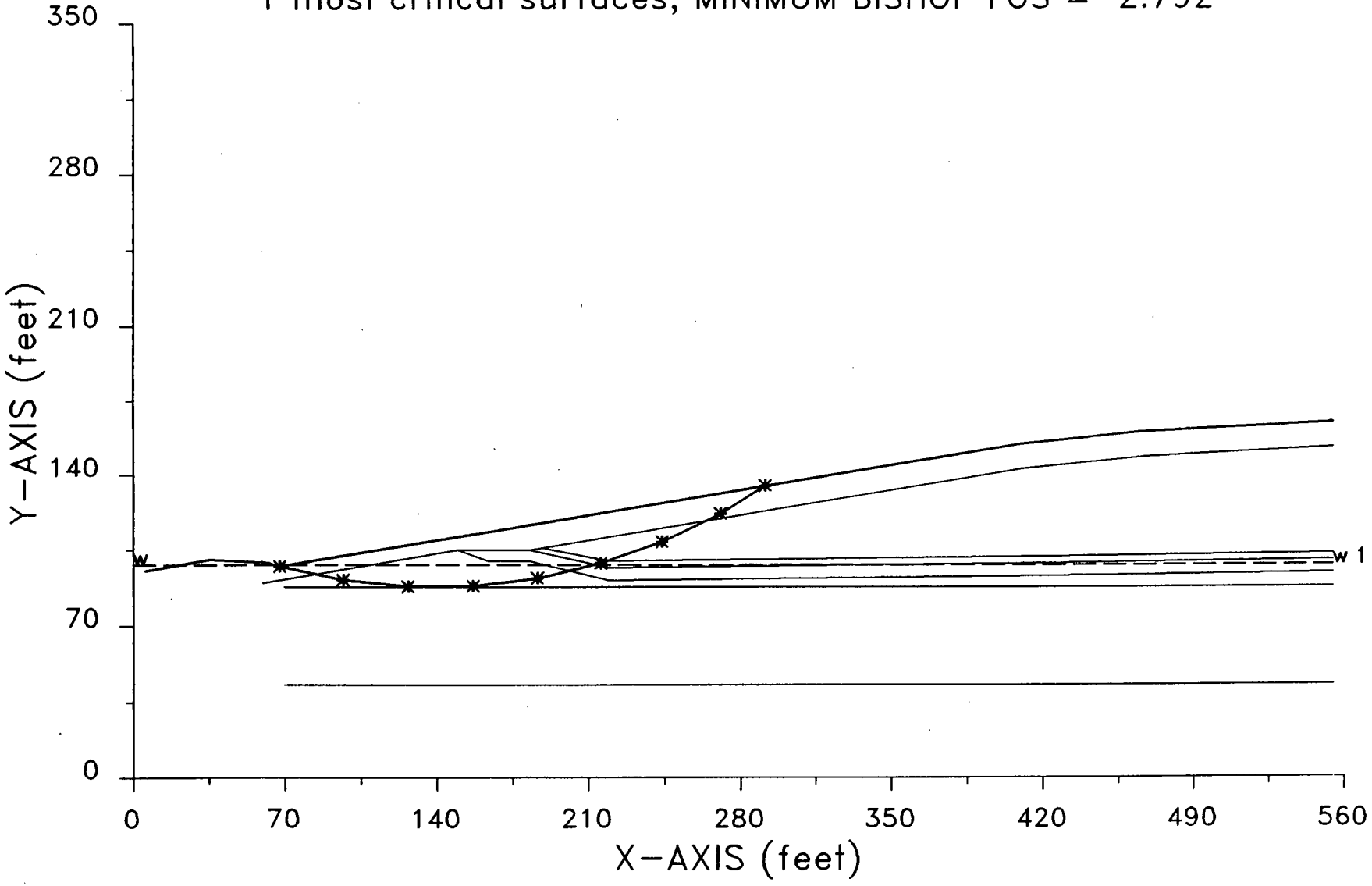
OSDF Final Configuration—Long Term

1 most critical surfaces, MINIMUM BISHOP FOS = 2.792



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16 Feb 96

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Problem Description : OSDF Final Configuration-Long Term

SEGMENT BOUNDARY COORDINATES
---

6 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	5.5	95.6	35.5	100.6	4
2	35.5	100.6	62.5	99.3	7
3	62.5	99.3	67.0	97.5	7
4	67.0	97.5	410.0	154.7	7
5	410.0	154.7	465.0	160.2	7
6	465.0	160.2	555.0	164.7	7

17 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	60.0	90.0	120.0	100.0	4
2	120.0	100.0	150.0	105.0	4
3	150.0	105.0	183.0	105.0	3
4	183.0	105.0	189.0	106.0	2
5	189.0	106.0	410.0	142.8	1
6	410.0	142.8	467.0	148.5	1
7	467.0	148.5	555.0	152.9	1
8	189.0	106.0	220.0	100.0	2
9	220.0	100.0	555.0	103.5	2
10	183.0	105.0	220.0	97.0	3
11	220.0	97.0	555.0	100.5	3
12	150.0	105.0	164.0	100.0	4
13	164.0	100.0	183.0	100.0	4
14	183.0	100.0	220.0	91.0	4
15	220.0	91.0	555.0	94.5	4
16	70.0	88.0	555.0	88.0	5
17	70.0	43.0	555.0	43.0	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	1
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	130.0	.0	30.00	.000	.0	0

1 Water surface(s) have been specified

Unit weight of water = 62.40 (pcf)

Water Surface No. 1 specified by 2 coordinate points

****
PHREATIC SURFACE,
****

Point No.	x-water (ft)	y-water (ft)
1	.00	98.00
2	555.00	98.00

A critical failure surface searching method, using a random technique for generating CIRCULAR surfaces has been specified.

1000 trial surfaces will be generated and analyzed.

20 Surfaces initiate from each of 50 points equally spaced along the ground surface between x = 50.0 ft
and x = 80.0 ft

Each surface terminates between x = 220.0 ft
and x = 440.0 ft

Unless further limitations were imposed, the minimum elevation at which a surface extends is y = .0 ft

30.0 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 :

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Lower angular limit := -45.0 degrees
Upper angular limit := -5.0 degrees

Factors of safety have been calculated by the :

* * * * * SIMPLIFIED BISHOP METHOD * * * * *

The most critical circular failure surface
is specified by 9 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	67.76	97.63
2	97.08	91.30
3	126.92	88.24
4	156.92	88.50
5	186.71	92.07
6	215.92	98.90
7	244.20	108.92
8	271.20	121.99
9	291.88	135.00

**** Simplified BISHOP FOS = 2.792 ****

The following is a summary of the TEN most critical surfaces

Problem Description : OSDF Final Configuration-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.	2.792	139.59	359.36	271.41	67.76	291.88	5.583E+07
2.	2.797	117.06	266.97	177.57	57.96	220.12	1.862E+07
3.	2.799	122.21	324.52	235.93	50.00	253.39	3.475E+07
4.	2.814	134.09	414.30	325.19	51.22	303.26	6.893E+07
5.	2.822	126.01	272.58	183.25	70.20	234.47	2.227E+07
6.	2.823	121.60	340.67	250.76	51.84	255.78	3.554E+07
7.	2.841	119.67	335.07	244.42	53.67	248.53	3.159E+07
8.	2.845	140.75	457.88	367.35	68.37	325.75	8.602E+07
9.	2.856	153.85	474.59	385.96	69.59	355.50	1.182E+08
10.	2.859	137.20	362.94	272.26	72.65	283.20	4.757E+07

* * * END OF FILE * * *

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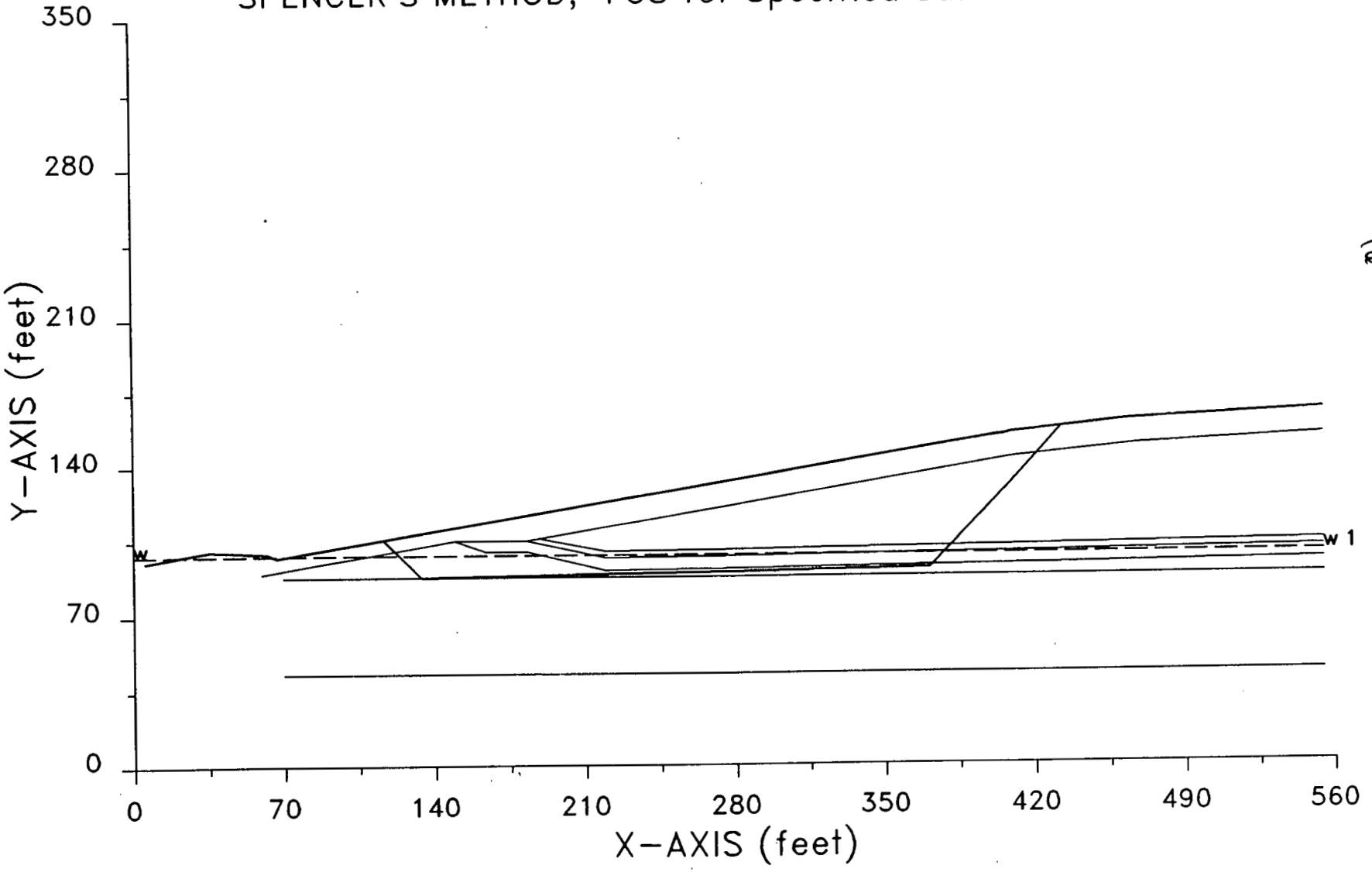
OSDF Final Configuration—Long Term
SPENCER'S METHOD, FOS for Specified Surface = 3.503



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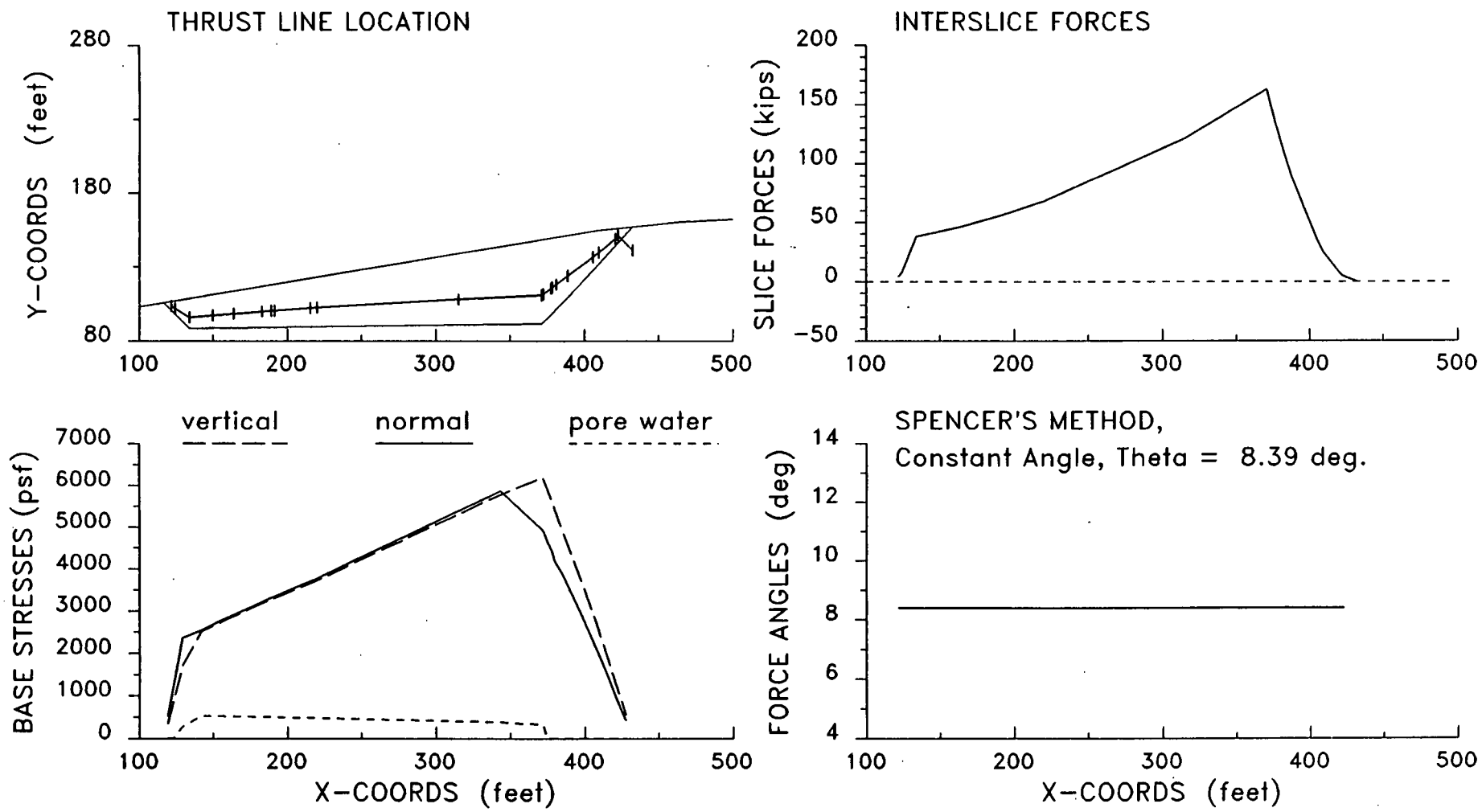

OSDF Final Configuration–Long Term
SPENCER'S METHOD, FOS for Specified Surface = 3.503

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*****************************************
*              X S T A B L              *
*                                       *
*        Slope Stability Analysis       *
*              using the                *
*           Method of Slices            *
*                                       *
*        Copyright (C) 1992 - 94        *
*   Interactive Software Designs, Inc.  *
*       Moscow, ID 83843, U.S.A.        *
*                                       *
*         All Rights Reserved           *
*                                       *
*  Ver. 5.100                95 - 1305  *
*****************************************
```

Problem Description : OSDF Final Configuration-Long Term

SEGMENT BOUNDARY COORDINATES
---

6 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	5.5	95.6	35.5	100.6	4
2	35.5	100.6	62.5	99.3	7
3	62.5	99.3	67.0	97.5	7
4	67.0	97.5	410.0	154.7	7
5	410.0	154.7	465.0	160.2	7
6	465.0	160.2	555.0	164.7	7

17 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	60.0	90.0	120.0	100.0	4
2	120.0	100.0	150.0	105.0	4
3	150.0	105.0	183.0	105.0	3
4	183.0	105.0	189.0	106.0	2
5	189.0	106.0	410.0	142.8	1
6	410.0	142.8	467.0	148.5	1
7	467.0	148.5	555.0	152.9	1
8	189.0	106.0	220.0	100.0	2
9	220.0	100.0	555.0	103.5	2
10	183.0	105.0	220.0	97.0	3
11	220.0	97.0	555.0	100.5	3
12	150.0	105.0	164.0	100.0	4
13	164.0	100.0	183.0	100.0	4
14	183.0	100.0	220.0	91.0	4
15	220.0	91.0	555.0	94.5	4
16	70.0	88.0	555.0	88.0	5
17	70.0	43.0	555.0	43.0	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	1
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	130.0	.0	30.00	.000	.0	0

1 Water surface(s) have been specified

Unit weight of water = 62.40 (pcf)

Water Surface No. 1 specified by 2 coordinate points

****
PHREATIC SURFACE,
****

Point No.	x-water (ft)	y-water (ft)
1	.00	98.00
2	555.00	98.00

A SINGLE FAILURE SURFACE HAS BEEN SPECIFIED FOR ANALYSIS

Trial failure surface specified by
the following 7 coordinate points :

Point No.	x-surf (ft)	y-surf (ft)
1	116.46	105.75
2	134.09	88.14
3	371.38	91.56
4	388.87	109.43
5	406.15	127.49
6	422.95	146.01
7	432.79	156.98

****
SELECTED METHOD OF ANALYSIS: Spencer (1973)
****

****
SUMMARY OF INDIVIDUAL SLICE INFORMATION

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****

Slice	x-base (ft)	y-base (ft)	height (ft)	width (ft)	alpha	beta	weight (lb)
1	119.18	103.03	3.17	5.44	-44.96	9.47	2155.
2	123.06	99.16	7.69	2.32	-44.96	9.47	2261.
3	129.15	93.07	14.80	9.87	-44.96	9.47	19092.
4	142.04	88.25	21.76	15.91	.83	9.47	45729.
5	157.00	88.47	24.04	14.00	.83	9.47	44207.
6	173.50	88.71	26.55	19.00	.83	9.47	65682.
7	186.00	88.89	28.46	6.00	.83	9.47	22118.
8	190.11	88.95	29.08	2.22	.83	9.47	8343.
9	203.30	89.14	31.09	24.15	.83	9.47	95972.
10	217.69	89.34	33.28	4.63	.83	9.47	19482.
11	267.86	90.07	40.93	95.71	.83	9.47	493914.
12	343.55	91.16	52.46	55.67	.83	9.47	367323.
13	371.89	92.08	56.27	1.01	45.62	9.47	7141.
14	375.04	95.30	53.57	5.29	45.62	9.47	35532.
15	378.00	98.33	51.04	.64	45.62	9.47	4085.
16	379.81	100.17	49.50	2.97	45.62	9.47	18354.
17	385.08	105.56	44.99	7.58	45.62	9.47	42626.
18	397.51	118.46	34.16	17.28	46.26	9.47	73779.
19	408.08	129.61	24.77	3.85	47.79	9.47	11919.
20	415.52	137.82	17.43	11.04	47.79	5.71	24057.
21	421.99	144.96	10.94	1.91	47.79	5.71	2613.
22	427.87	151.49	4.99	9.84	48.11	5.71	6141.

ITERATIONS FOR SPENCER'S METHOD

Iter #	Theta	FOS_force	FOS_moment
2	8.3299	3.4992	3.5531
3	8.3920	-----	3.4992
3	8.3610	3.5010	-----
4	8.3899	3.5028	3.5010
5	8.3889	3.5028	3.5028

SLICE INFORMATION ... continued :

Slice	Sigma (psf)	c-value (psf)	phi	U-base (lb)	U-top (lb)	P-top (lb)	Delta
1	596.8	.0	30.00	0.	0.	0.	.00
2	1392.3	.0	25.00	0.	0.	0.	.00
3	2387.6	.0	25.00	4292.	0.	0.	.00
4	2300.7	.0	25.00	9676.	0.	0.	.00
5	2602.3	.0	25.00	8326.	0.	0.	.00
6	2921.4	.0	25.00	11018.	0.	0.	.00
7	3165.9	.0	25.00	3412.	0.	0.	.00
8	3239.0	.0	25.00	1255.	0.	0.	.00
9	3473.5	.0	25.00	13358.	0.	0.	.00
10	3729.3	.0	25.00	2498.	0.	0.	.00
11	4738.1	.0	25.00	47380.	0.	0.	.00
12	6268.6	.0	25.00	23765.	0.	0.	.00
13	5243.0	.0	25.00	534.	0.	0.	.00
14	5298.3	.0	25.00	0.	0.	0.	.00
15	5036.3	.0	25.00	0.	0.	0.	.00
16	4778.4	.0	30.00	0.	0.	0.	.00
17	4438.1	.0	25.00	0.	0.	0.	.00
18	3352.3	.0	25.00	0.	0.	0.	.00
19	2400.5	.0	25.00	0.	0.	0.	.00
20	1689.6	.0	25.00	0.	0.	0.	.00
21	1036.2	.0	30.00	0.	0.	0.	.00
22	471.4	.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	119.18	596.8	396.2	.0	98.4
2	123.06	1392.3	974.8	.0	185.4
3	129.15	2695.2	1933.9	307.6	317.9
4	142.04	2908.8	2874.2	608.1	306.3
5	157.00	3196.9	3157.6	594.7	346.4
6	173.50	3501.3	3457.0	579.8	388.9
7	186.00	3734.5	3686.3	568.6	421.5
8	190.11	3803.9	3754.6	564.9	431.2
9	203.30	4026.5	3973.5	553.0	462.4
10	217.69	4269.4	4212.4	540.1	496.5
11	267.86	5233.1	5160.3	495.0	630.8
12	343.55	6695.5	6598.7	426.9	834.5
13	371.89	5612.7	7068.6	369.7	698.0
14	375.04	5298.3	6713.3	.0	705.3
15	378.00	5036.3	6381.2	.0	670.5
16	379.81	4778.4	6186.9	.0	787.6
17	385.08	4438.1	5623.3	.0	590.8
18	397.51	3352.3	4269.6	.0	446.3
19	408.08	2400.5	3095.9	.0	319.6
20	415.52	1689.6	2179.1	.0	224.9
21	421.99	1036.2	1367.8	.0	170.8
22	427.87	471.4	624.1	.0	77.7

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	121.90	8.39	3818.	3.12	6.34	.492
2	124.22	8.39	7512.	3.59	9.04	.397
3	134.09	8.39	37547.	7.51	20.55	.365
4	150.00	8.39	41798.	8.75	22.97	.381
5	164.00	8.39	46048.	9.72	25.11	.387
6	183.00	8.39	52549.	10.89	28.00	.389
7	189.00	8.39	54778.	11.23	28.91	.388
8	191.22	8.39	55624.	11.35	29.25	.388
9	215.38	8.39	65496.	12.61	32.93	.383
10	220.00	8.39	67530.	12.84	33.64	.382
11	315.71	8.39	121259.	17.06	48.22	.354
12	371.38	8.39	162786.	19.17	56.70	.338
13	372.39	8.39	157643.	18.90	55.84	.338
14	377.68	8.39	132454.	17.43	51.31	.340
15	378.32	8.39	129558.	17.25	50.76	.340
16	381.29	8.39	117280.	16.33	48.23	.339
17	388.87	8.39	87062.	14.21	41.75	.340
18	406.15	8.39	33660.	8.95	26.57	.337
19	410.00	8.39	24605.	7.89	22.97	.343
20	421.04	8.39	6330.	4.90	11.90	.412
21	422.95	8.39	4454.	4.76	9.98	.477
22	432.79	.00	0.	-16.04	.00	.000

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AVERAGE VALUES ALONG FAILURE SURFACE

Total Normal Stress = 4567.91 (psf)
Pore Water Pressure = 356.60 (psf)
Shear Stress = 563.76 (psf)

Total Length of failure surface = 351.97 feet

For the single specified surface and the assumed angle of the interslice forces, the SPENCER'S (1973) procedure gives a

FACTOR OF SAFETY = 3.503

Total shear strength available along specified failure surface = 636.52E+03 lb

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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.

See Section 1.2 of the Design Parameter Summary.

3.2 Liner System

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 Bonapalte, Principal

Record of Revision (Number and initial all revisions)

NO.	REASON	DATE	BY	CHECKED	APPROVAL	
Ø	30% Submitted	NA	NA	NA	NA	No changes
B	Exec. Summary	13 Dec 95	GRS	RCB	RB	
C	Intermediate Design	20 Feb 96	GRS			No changes
D	IDP, EPA Submitted	4 Apr 96				

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: _____ Date: _____ Reviewed by: _____ Date: _____

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 09.5

SHORT-TERM LINER SYSTEM STABILITY ON SIDE SLOPES

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		Page
1.	Calculation Procedures/Methods	1/10
2.	Data Verification Package	1/13
3.	Calculations	1/3

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

Written by: GES 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

BB 95/10/5
RCB 95/10/7

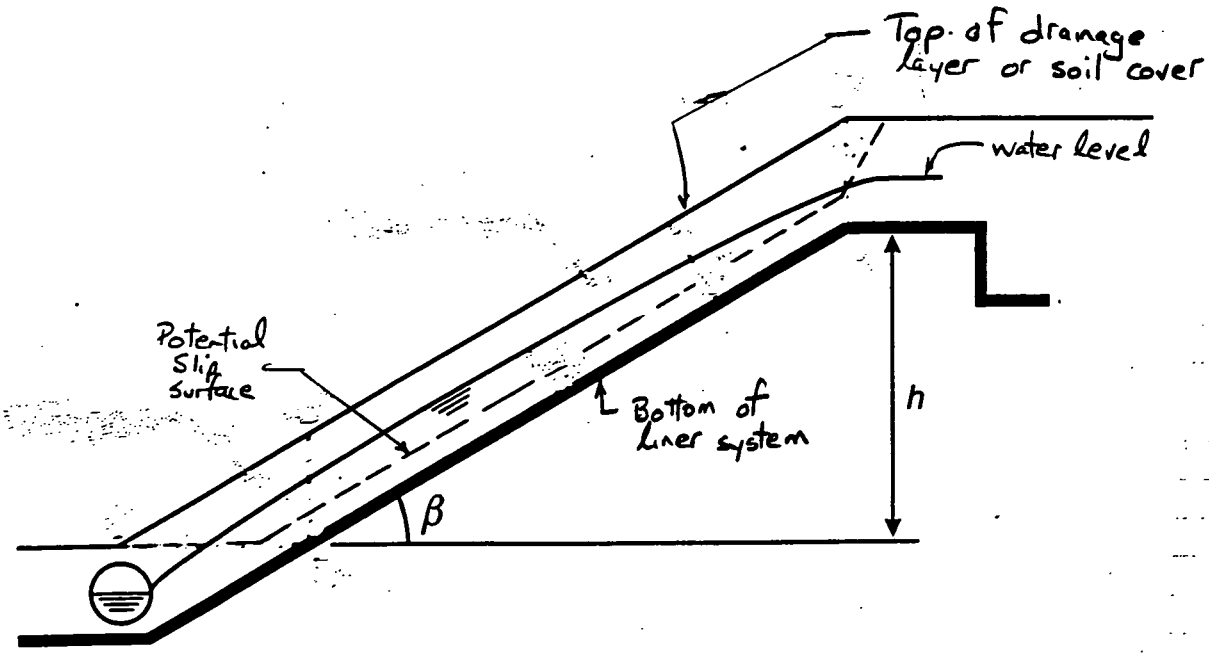
stability conditions will be considered:

[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.: 95

RB 95/10/5
RCB 95/10/7

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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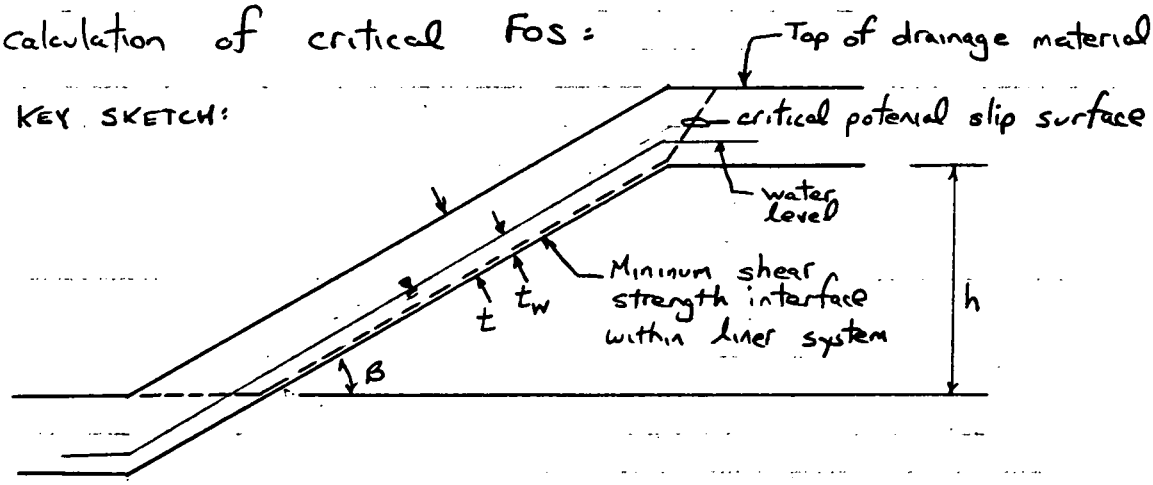
geosynthetic materials should be assessed using published information and project experience. Site-specific shear strength testing will be performed prior to final design to directly measure shear strength parameters. Assessment of shear strengths should consider the relatively low confining stresses 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

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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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(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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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 ≥ 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

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materials exceed the slope angle, β, 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 β from step (3A).

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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, Appendix 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.

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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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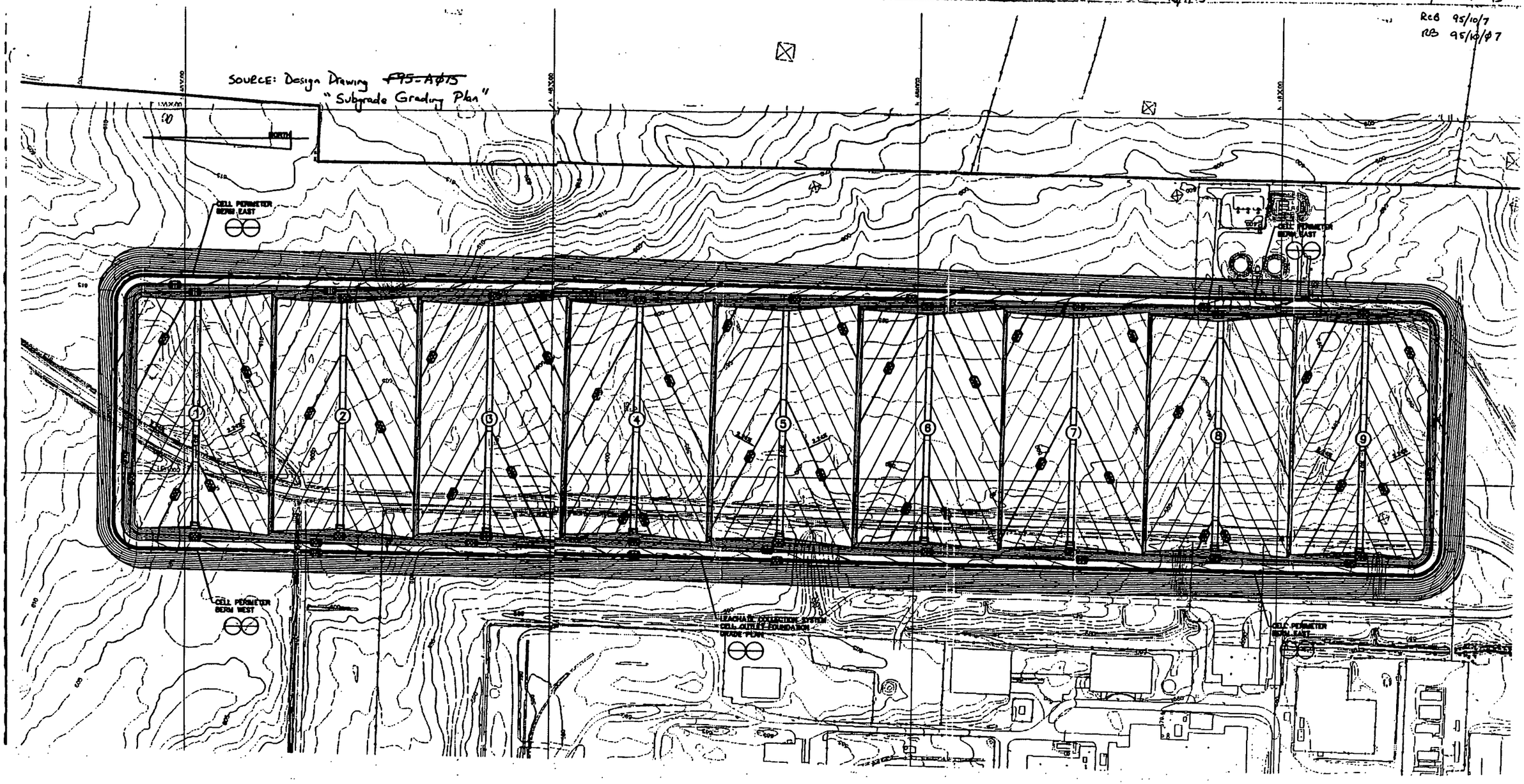
SOURCE: Design Drawing ~~F95-A015~~
"Subgrade Grading Plan"



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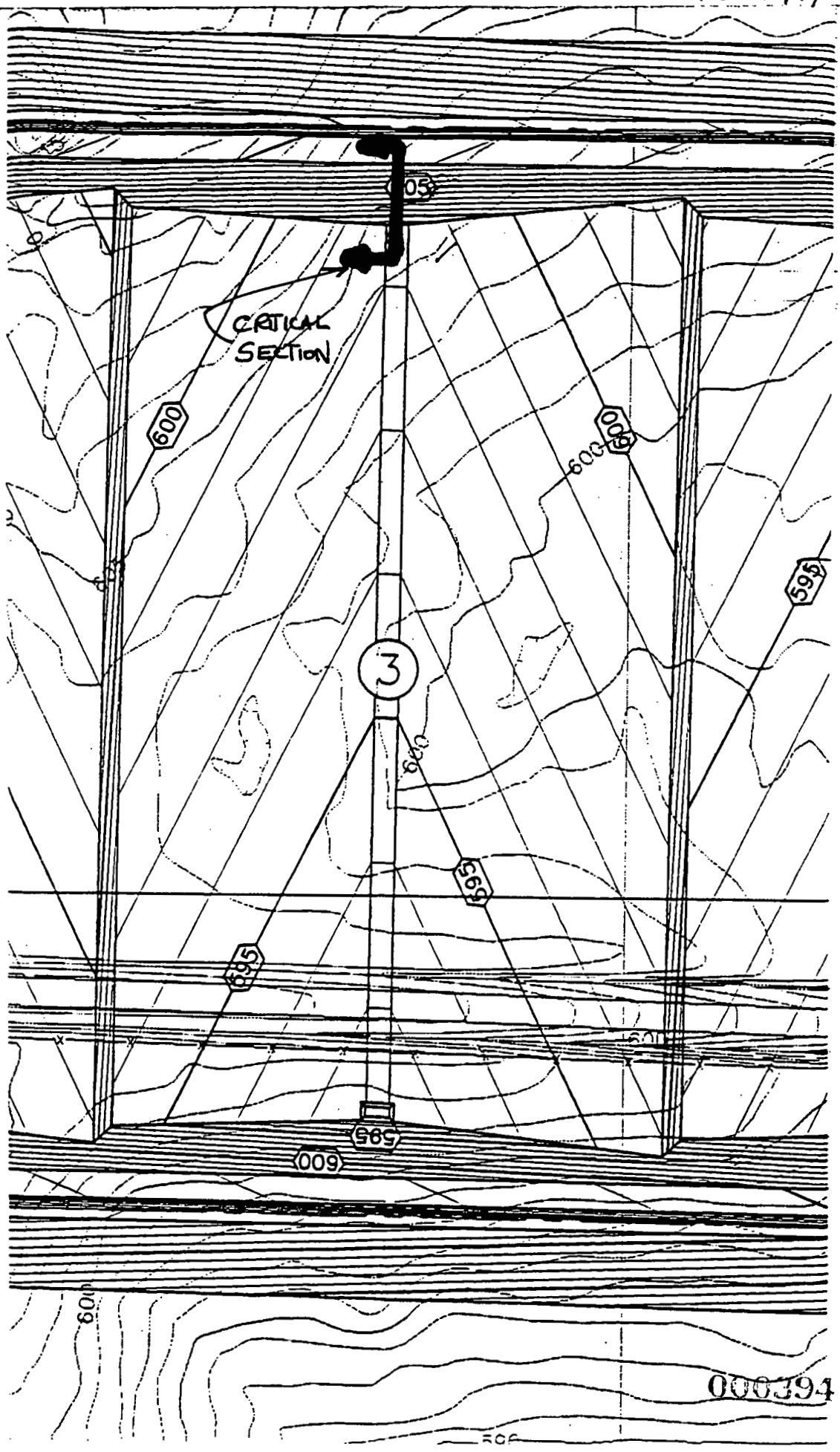

Source: Design Drawing No. ~~F95-A075~~
" Subgrade Grading Plan"

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.: 95

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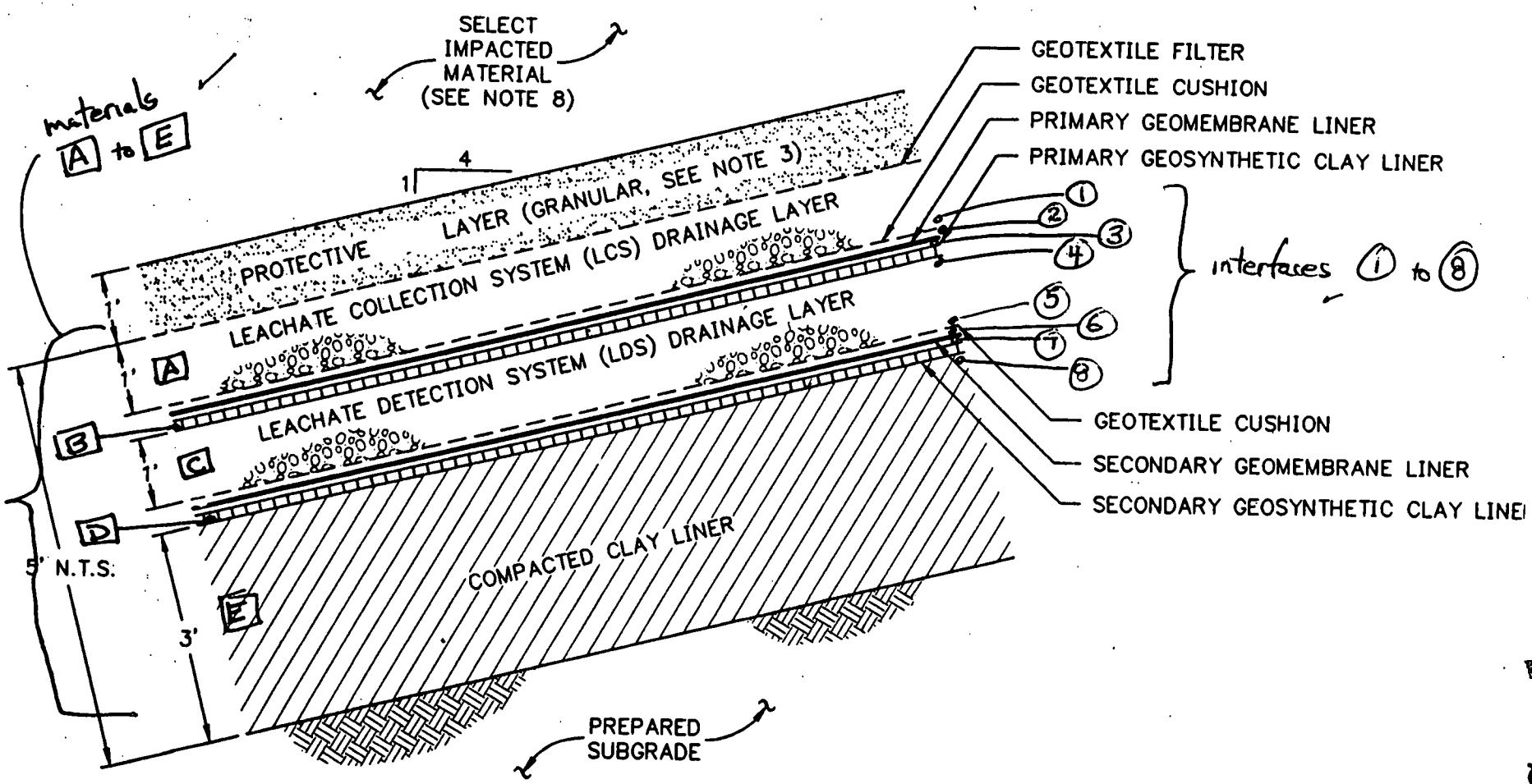
(2) Evaluate shear strength of all interfaces and materials within liner system:

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: ~~AREX 1/8"X1/8"~~

TAKEN FROM: Design Drawing ~~No. F95 A026~~
"Liner ~~Sy~~ and Cover System Details I"

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03 95/9/07

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Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.5

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MATERIALS

No.	Description	Shear Strength Parameters ϕ	c (psf)	Source
A	LCS Drainage Layer (gravel)			$\phi = 30°$ is a lower bound estimate for granular soil materials. (see page 8)
C	LDS Drainage Layer (gravel) For stability purposes, LCS and LDS are treated are taken as the same material	30°	0	
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 Consists of internally reinforced bentonite. Assume hydrated.	30°	0	See Cover System Stability Calculations (Doc # F953ØØ22.CDØ)
E	Compacted Clay Liner	23-29° use 25°	100-400 use 0	See Cover System Stability Calcs. (Doc. # F953ØØ22.CDØ

10^{-1} cm/sec

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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 # F9530022.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. # F9530022.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 # F9530022.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 # F9530022.CDO)

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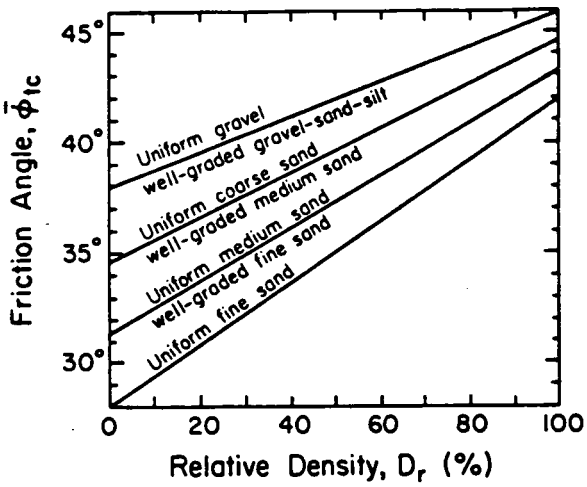

Figure 4-7. $\bar{\phi}_{tc}$ versus Relative Density

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

Authors
F. H. Kulhawy
P. W. Mayne

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.: GE3906 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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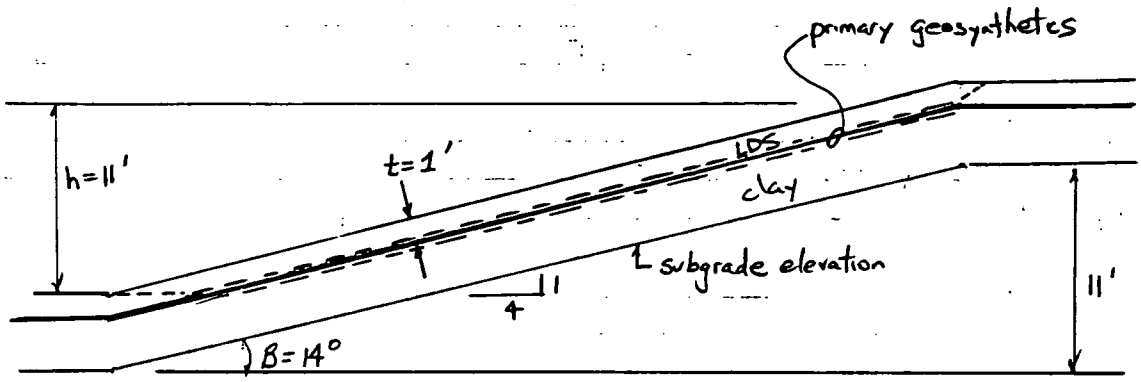
(3A) Select geometry and shear strength parameters for calculation of critical FOS.

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' β=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.

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(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 $\lambda = 0.022$) ✓

$\therefore\ T_{avg} = 0.24\ \text{ft}\,(0.94) = 0.23\ \text{ft}$ ✓

$t_w = t_{avg} = \underline{0.23\ \text{ft}}$ ✓

Source: Ref. 2 of calculation procedures/methods package

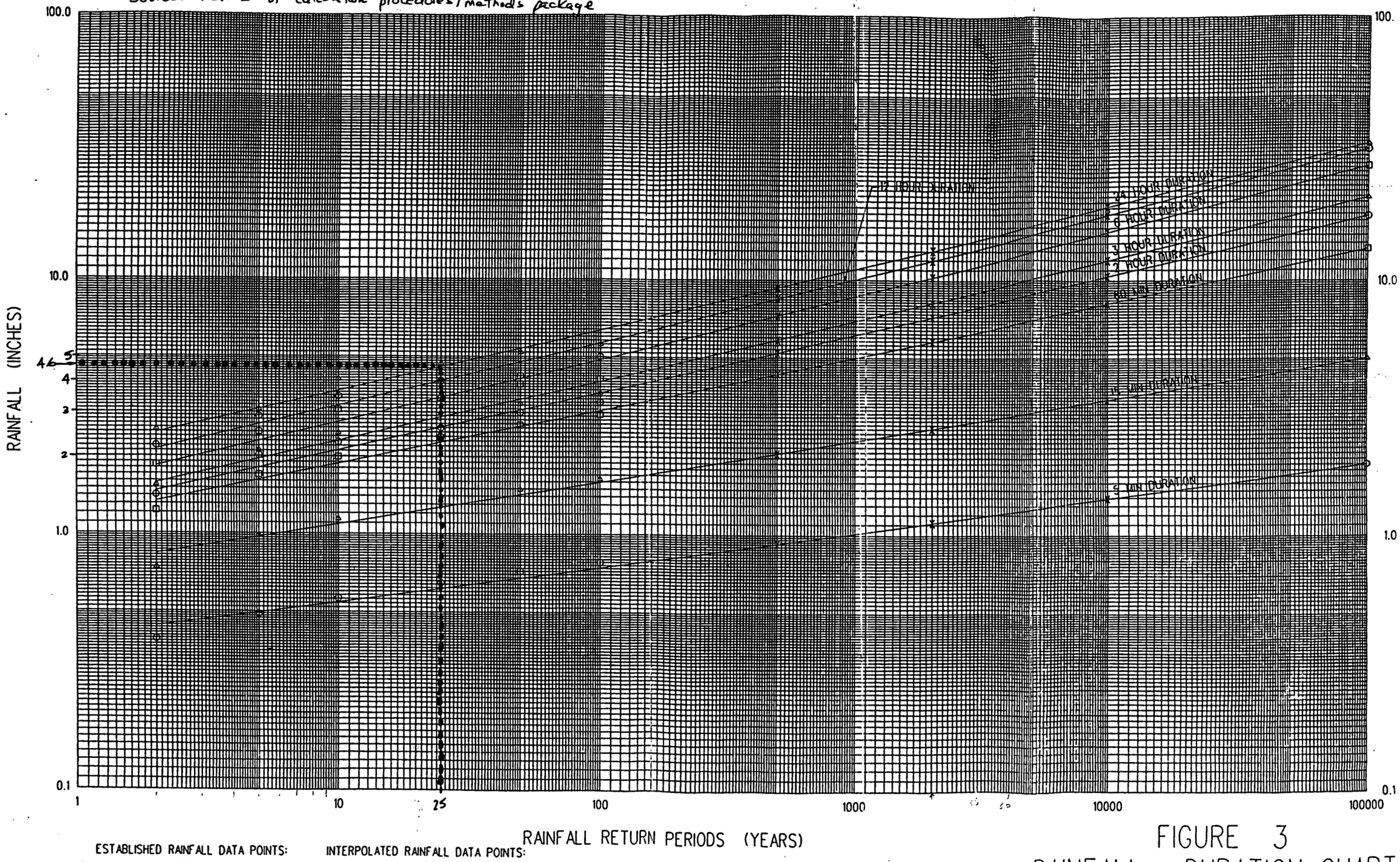

FIGURE 3
RAINFALL - DURATION CHART

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Client: FERMCO Project: OSDF Project/Proposal No.: GE3700 Task No.: 95

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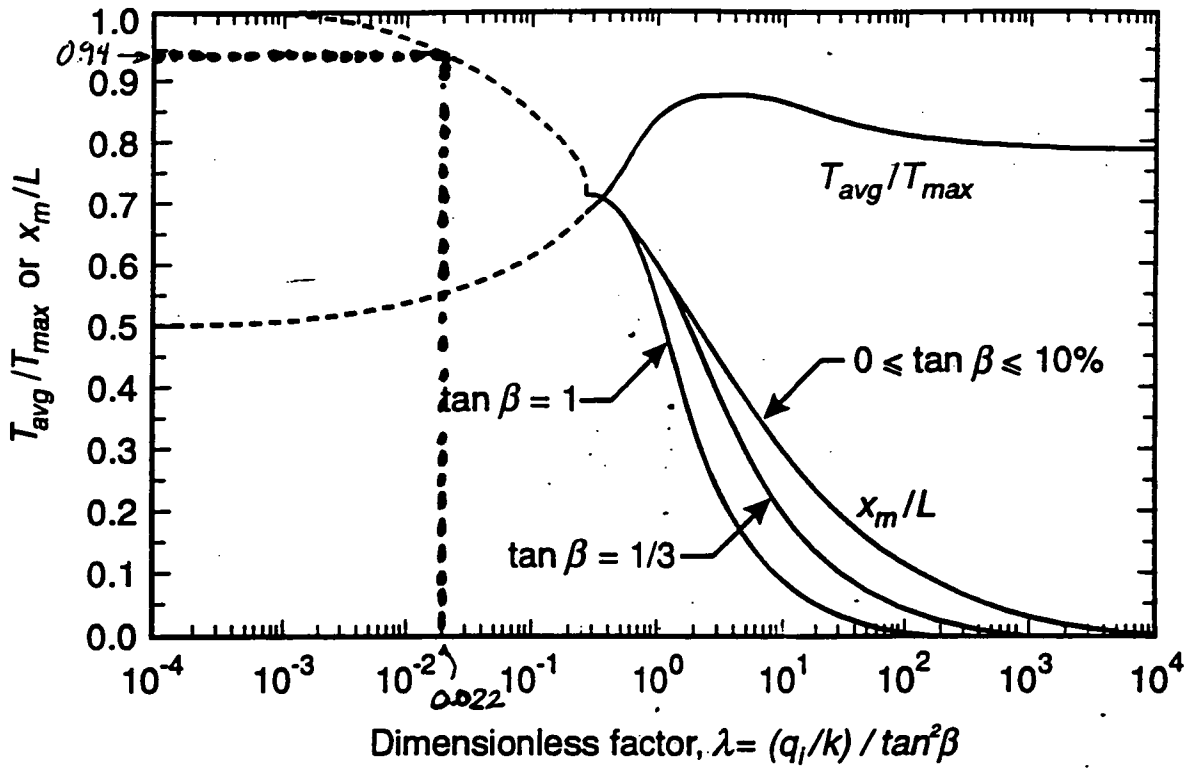

Source: Ref. 3 from Calculation Procedures/Methods Package

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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 ✓

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* 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

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(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 Impacted Material Configurations

COMPUTATION COVER SHEET

SUBJECT OF CALCULATION: IMPACTED MATERIAL CONFIGURATIONS

Computations By: (Cognizant Engineer)
Signature: [signature] Date: 02/16/96
Printed Name and Title: R. David Espinoza, Assistant Project Engineer

Assumptions and Procedures Checked by: (Checker)
Signature: [signature] Date: 20 Feb '96
Printed Name and Title: SAAD QURESHI, PROJECT ENGINEER

Computations Checked by:
Signature: [signature] Date: 20 Feb '96
Printed Name and Title: SAAD QURESHI, PROJECT ENGINEER

Computations Backchecked by: (Cognizant Engineer)
Signature: [signature] Date: 02/20/96
Printed Name and Title: R. David Espinoza, Assistant Project Engineer

Approved by: (PDP)
Signature: Mark H. Gleason Date: 20 Feb 96
Printed Name and Title: MARK H. GLEASON, Assistant Project Engineer

Approved by: (DTL and TETL)
Signature: Rudolph Bonaparte Date: 22 Feb 96
Printed Name and Title: Rudolph Bonaparte, Principal (DTL)

Record of Revision (Number and initial all revisions)

NO.	REASON	DATE	BY	CHECKED	APPROVAL
C	Intermediate Design				
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Registration Stamp (if applicable)

GE3900-09.6/F9530023.CD

IMPACTED MATERIAL CONFIGURATIONS (Interim and Final)

EXECUTIVE SUMMARY

Purpose

This calculation package contains analyses for static stability of the OSDF impacted material mass for final and interim configurations. The stability of the OSDF is calculated for slip surfaces that pass through the impacted material 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 $\geq$ 1.3. In addition, for potential slip surfaces involving the geosynthetic clay liner, the long-term slope stability factor of safety should be checked using large displacement shear strengths for the geosynthetic clay liner. The slope stability factor of safety for this condition should be at least 1.25 (Bonaparte, et al. [1996]).

The stability analyses are performed using established geotechnical procedures for calculating slope stability.

Results

	Factor of Safety
• Interim conditions	
· Dry unreinforced GCL/Geomembrane interface	FS = 2.0
· Hydrated reinforced (Internal strength) GCL	FS = 1.9
• Long-term conditions	
· Peak hydrated GCL strengths	FS = 1.8
· Large displacement hydrated GCL strengths	FS = 1.5

All factors of safety meet the established criteria and are conservative based on the variability of materials and shear strengths considered in this calculation.

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Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 09.6

IMPACTED MATERIAL CONFIGURATIONS (Interim and Final)

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IMPACTED MATERIAL CONFIGURATIONS (Interim and Final)

CALCULATION PACKAGE

Purpose: The purpose of this document is to provide the engineering calculations used in establishing that the OSDF liner system will be stable under static conditions with an adequate factor of safety. The calculations are used to obtain a minimum factor of safety of impacted material in the OSDF against sliding along the OSDF liner system. Analyses were performed for both the interim and final configurations of the impacted material in the OSDF landfill. The interim configurations model the conditions expected to occur while the landfill is being filled. The interim configurations were analyzed 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 system evaluation (i.e., unit weights, undrained shear strengths, and drained shear strengths) are provided in the Data Verification Package.

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 $\geq$ 1.3. In addition, for potential slip surfaces involving the geosynthetic clay liner, the long-term slope stability factor of safety should be checked using large displacement shear strengths for the geosynthetic clay liner. The slope stability factor of safety for this condition should be at least 1.25 (Bonaparte, et al. [1996]).

The computer program XSTABL (Sharma, 1994) was used to perform the stability analyses for slip surfaces that pass through the impacted material and along the OSDF liner system. The wedge-shaped potential slip surfaces were analyzed using Janbu's simplified method (Janbu, 1973) and Spencer's method (Spencer, 1973).

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.

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IMPACTED MATERIAL CONFIGURATIONS (Interim and Final)

B. For analyses involving wedge-shaped potential slip surfaces, the computer program requires the operator to designate one, or more, "boxes" within the model through which all of the potential slip surfaces must pass.

II. Methodology for Critical Slip Surface Search

A. The interface friction strengths and internal strength of each of the liner system components were examined and the interfaces and components with the lowest strengths were identified. (See Data Verification Package).

B. Based on the Construction Drawings, the OSDF geometry for both interim and final configurations was input into the computer model. Because these analyses are for slip surfaces that pass along the liner system, the foundation stratigraphy was not included.

C. To create the potential slip surfaces, two boxes were designated within the OSDF geometry. The first "box" consisted of a line (a box with no height) located in the layer of the liner system that was identified as having the lowest strength. 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. Four hundred potential slip surfaces were generated through the two initial boxes, and a factor of safety using Janbu's simplified method (Janbu, 1973) for each generated surface was calculated.

E. The 10 most critical potential slip surfaces were plotted.

F. Both lines were then shortened and repositioned to contain the inflection points of the 10 most critical potential slip surfaces.

G. Steps C through F were repeated until a single, minimum factor of safety against failure was obtained for two consecutive runs, or the factor of safety began to increase.

H. The final factor of safety against a wedge failure was then computed using Spencer's method (Spencer [1973]) for the wedge-shaped potential slip surface having the minimum factor of safety as calculated using Janbu's simplified method.

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IMPACTED MATERIAL CONFIGURATIONS (Interim and Final)

III. Interim OSDF Configuration

A. OSDF Geometry

The interim conditions are expected to occur, while the OSDF is being filled, after capping of the existing cell, and prior to placement of the impacted materials in the adjacent cell. The geometry of the interim landfill condition is taken from the Construction Drawings, is a north-to-south section, and is shown in Figure 1.

B. Material Strength Parameters

1. Based on the analyses presented in the Data Verification Section of this calculation package, the liner system interfaces were those associated with the geosynthetic clay liner (GCL). The stability of the OSDF interim configuration was calculated for the following two cases: (i) an unhydrated GCL/HDPE geomembrane liner interface for the GCL with a geomembrane backing; and (ii) the internal shear strength of a hydrated reinforced GCL.

2. For the hydrated reinforced GCL, the shear strength of the bentonite component of the GCL is a function of the normal stress induced by the overlying OSDF. Due to the variation in the normal stress, an average overburden stress is calculated for four sections of the hydrated GCL. The shear strength of the reinforced GCL for short-term conditions is assumed to be equal to approximately twice the hydrated shear strength of unreinforced bentonite, (Bonaparte, et al. [1996]) as presented in the Data Verification Section of this calculation.

3. The shear strength parameters used for the interim OSDF Configuration are presented below.

IMPACTED MATERIAL CONFIGURATIONS (Interim and Final)

INTERIM OSDF CONFIGURATION

	Material	Total Unit Weight γ	Overburden[1] Stress	Shear Strength Parameter - ϕ (degrees)		
				Dry	Peak Hydrated (unreinforced)	Peak Hydrated (reinforced)
1)	Impacted Material	125	N/A	ϕ = 25°, c = 200 psf	25	25
2)	Granular Cover System Soils	125	N/A	30	30	30
3)	GCL A	125	7700	20	8	15
4)	GCL B	125	5600	20	9	17
5)	GCL C	125	2000	20	12	23
6)	GCL D	125	400	20	16	30

[1]Assumes an average overburden total unit weight of 125 pcf.

IV. Final OSDF Configuration

A. OSDF Geometry

The final configuration conditions will occur after the OSDF has been closed and capped. The geometry was obtained from the Construction Drawings, is an east to west Section, and is shown on Figure 2. The section is taken along the leachate collection line and is considered to represent the most critical geometry for this case.

B. Material Strength Parameters

1. Based on the analyses presented in the Data Verification Section of this calculation package, the long-term hydrated shear strength of the bentonite component of the GCLs represents the material with the lowest shear strength.

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IMPACTED MATERIAL CONFIGURATIONS (Interim and Final)

This is based on the assumption that the bentonite in all GCLs will become hydrated and, for long-term conditions, the reinforcement will be ineffective. As in the interim configuration, the shear strength of the GCL will vary as a function of the normal stress induced by the overlying OSDF.

2. The shear strength parameters used for the final OSDF configuration are presented below.

3. The factor of safety for the final OSDF configuration is calculated for both peak GCL strength and for large displacement GCL strength.

FINAL OSDF CONFIGURATION

	Material	Weight γ (pcf)	Overburden[1] Stress (psf)	Shear Strength Parameter - ϕ (degrees)		
				Dry	Peak Hydrated	Large Displacement
1)	Impacted Material	125	N/A	25	25	25
2)	Granular Cover System Material	125	N/A	30	30	30
3)	GCL A	125	7700	-	8	5
4)	GCL B	125	6200	-	8	6
5)	GCL C	125	3500	-	10	8
6)	GCL D	125	2000	-	12	10

[1] Assumes an average overburden total unit weight of 125 pcf.

WASTE MASS STABILITY

The minimum acceptable factors of safety for slope stability as stated in UMTRA, 1989 (Ref 8) are:

- 1.5 for long-term conditions; and
- 1.3 for interim - end of construction conditions.

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IMPACTED MATERIAL CONFIGURATIONS (Interim and Final)

In addition, for long-term stability analyses using large displacement shear strengths for the geosynthetic clay liner, the slope stability factor of safety should be at least 1.25 (Bonaparte et al. [1996]).

The calculated factors of safety for the cases considered in this analysis are:

- Interim Conditions

  2.0 for dry GCL (unreinforced)
  1.9 for hydrated GCL (reinforced)

- Long-Term Conditions

  1.8 for peak hydrated GCL strengths
  1.5 for large displacement hydrated GCL strengths

All factors of safety meet the established criteria.

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IMPACTED MATERIAL CONFIGURATIONS (Interim and Final)

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., Matasovic, N., Bonaparte, R., and Schmertmann, G., "Evaluation of MSW Properties for Seismic Analysis", *Proceedings, Geoenvironmental 2000*, New Orleans, LA, 1995.

4. Electric Power Research Institute, "*Ash Utilization in Highways, Delaware Demonstration Product*", prepared by Delmarva Power and Light Company, Wilmington, DE, EPRI Project 24, 22-3, August 1989.

5. Data established from

   - Martin, J.P., Koerner, P.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, G.R., 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 '84*, New Orleans, LA Feb. 1987, pp. 616-627.

6. Bonaparte, R., Othman, M.A., Rad, N.R., Swan, R.H., and Vander Linde, D.L., "Evaluation of Various Aspects of GCL Performance," *Proceedings of Geosynthetic Clay Liner Workshop*, U.S. Environmental Protection Agency, Cincinnati, Ohio, August 1995, in press.

7. Spencer, E., "The Thrust Line Criterion in Embankment Stability Analyses," *Geotechnique*, Vol. 23, No. 1, pp. 85-100, 1973.

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Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 09.6

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IMPACTED MATERIAL CONFIGURATIONS (Interim and Final)

8. Janbu, N., "*Slope Stability Calculations in Embankment Dam Engineering*", Casagrande Memorial Volume, Hirschfield and Poulos (Eds.), John Wiley, N.Y., pp. 47-86, 1973.

9. U.S. Department of Energy, "Uranium Mine Tailings Remediation Control Act", *Remedial Action Design*, Technical Approach Document, Revision 2, December 1989.

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Client: FEMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.6

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IMPACTED MATERIAL CONFIGURATION

DATA VERIFICATION

Purpose — The purpose of this section is to describe the engineering procedures used to collect data for use in the analysis for impacted material stability of the On-Site Disposal Facility (OSDF). The data thus collected is provided for verification

SCOPE: Collect engineering data for the impacted material configuration stability analysis of the OSDF. Data required for the analysis includes engineering properties of the waste, engineering properties of the cover and liner system materials, and the shear strengths of the liner system interfaces. Also required for the analysis is the geometry of the OSDF for final and interim configurations. Data required includes base grades, berm heights and interim and final slopes.

DESIGN — Material properties are required for failure surfaces that pass through the impacted material 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 the slope stability computation.

PARAMETERS FOR DESIGN

COVER SYSTEM MATERIALS

Assume the granular components of the cover system have similar basic properties.

$\gamma_t = 125$ pcf $\phi = 30$ degrees.

Assume the compacted clay in the cover system has similar properties to the impacted material.

Assume the geosynthetics in the cover system are not relevant for this analysis

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Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.6

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IMPACTED MATERIAL CONFIGURATION — DATA VERIFICATION

PARAMETERS FOR DESIGN

IMPACTED MATERIAL

- Based on project scope of work, the impacted material is expected to include the following:
  - contaminated site soils
  - demolition debris
  - municipal solid waste (MSW)
  - lime sludge
  - fly ash / similar to most bottom ash.

Because of the variability, the impacted material properties may also vary. Assume the material will be placed under well controlled conditions

For the analysis, assume a range of properties

Unit weight low $\gamma_T = 80$ pcf
high $\gamma_T = 125$ pcf

Shear strength:
- assume lime sludge will be mixed with soil 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)
  - 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, 1982) (Ref 4)

FOR THE ANALYSIS ASSUME THE FOLLOWING

$\gamma_T = 125$ pcf

Short term shear strength $\phi = 25°$ $c = 200$ psf

long term shear strength $\phi = 25°$ $c = 0$ psf

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IMPACTED MATERIAL CONFIGURATION - DATA VERIFICATION

PARAMETERS FOR DESIGN

- GRANULAR DRAINAGE LAYERS - Assume $\gamma_T = 125$ pcf $\phi' = 30°$
- Recompacted Clay
  - The shear strength of the compacted clay liner was estimated in the Foundation Stability Calculation Package. The following strengths were assumed.

$\gamma_T = 130$ pcf $\phi' = 25°$

LINER SYSTEM	INTERFACE STRENGTHS ($= \delta$)	
Geotextile/Gravel Interface	$\tan\delta / \tan\phi = 0.7$ to 0.9 for angular soil For $\phi = 30$ for gravel $\delta = 22°$ to $27°$	(Ref 5)
Geotextile/HDPE interface	For textured HDPE assume $\delta = 25°$	(Ref 5)
Compacted Clay/Geotextile or Compacted Clay/Geotextile of GCL Interface	Assume $\tan\delta / \tan\phi = 0.8$ For clay $\phi = 25°$ ∴ Assume $\delta = 20°$ For short term conditions, bentonite in GCL not in contact with clay	(Ref 5)

GCL internal strength and GCL/HDPE geomembrane strength

- For short term conditions

Bentonite in GCL that is protected from hydration by a geomembrane backing remains dry.

Interface is unhydrated bentonite / textured HDPE
Assume ϕ of unhydrated bentonite = 25°
Bentonite / HDPE $\tan\delta / \tan\phi = 0.8$

Interface strength $\delta = 20°$

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INDEXED MATERIAL CONFIG. DATA VERIFICATION

GCL strengths

· Short term cond.

For reinforced GCLs, GCL will be placed against soil and is expected to become hydrated in short term conditions. Assume reinforcement for short term is intact.

Assume reinforced GCL $\tan\phi$ peak = 2 $\tan\phi$ peak unreinforced GCL

Use peak strengths for reinforced GCLs.

ϕ peak of reinforced GCL is dependent on normal stress as described in Bonaparte et al. (1996).

- For long term conditions, Assume Bentonite in all GCLs is hydrated and GCL reinforcement (if reinforced) is not effective.

GCL strengths (Bonaparte et al [1996]) see attached Figure 3

NORMAL STRESS (psf)	ϕ peak	ϕ large displacement	ϕ peak reinforced
7,700	8	15	5
6,200	8	-	6
5,600	9	17	-
3,500	10	-	8
2,000	12	23	10
400	16	-	30

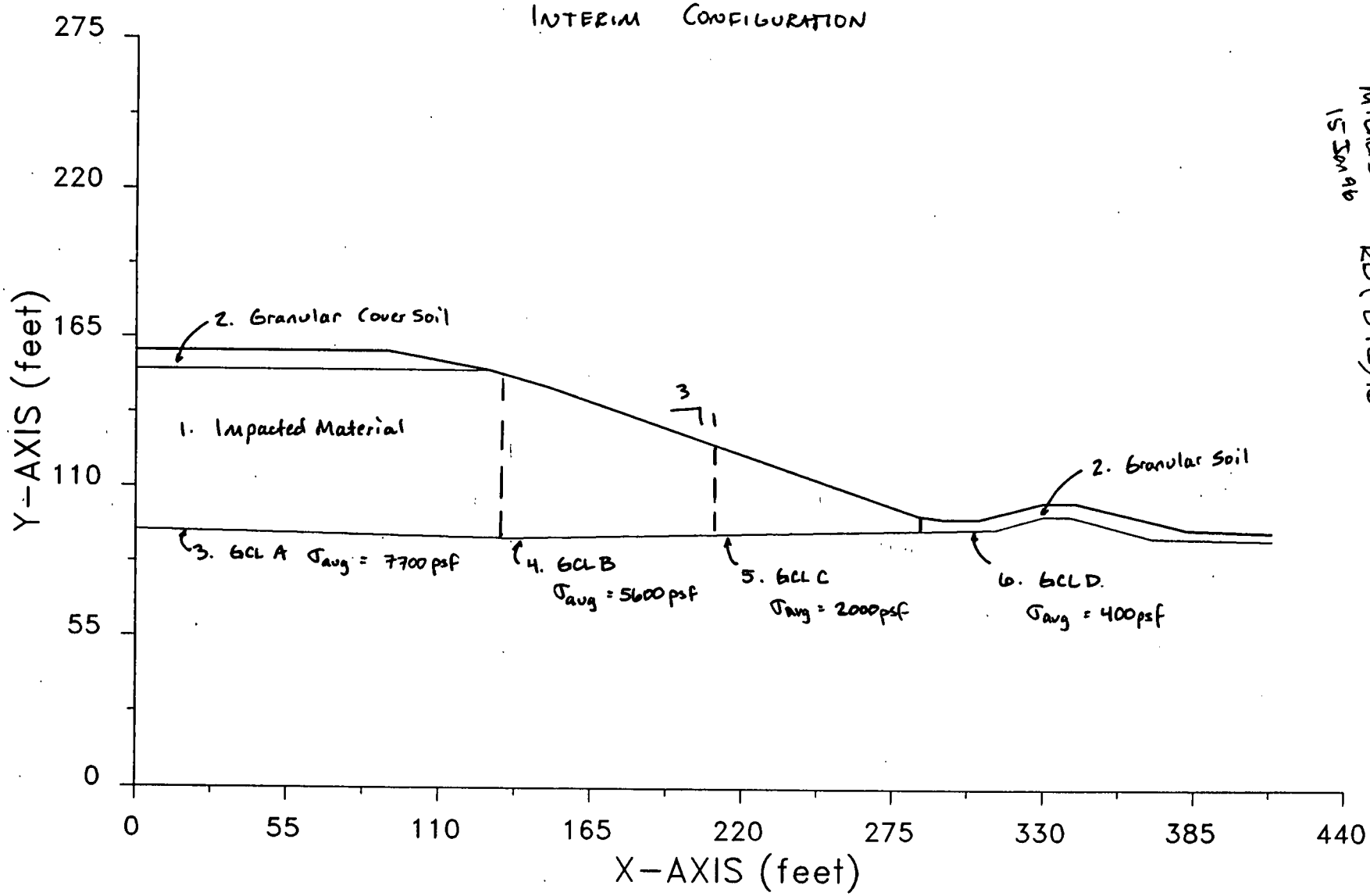
SUMMARY

- For short-term conditions, critical interface is either the dry GCL/HDPE interface ($\delta = 20°$) or the reinforced GCL internal shear strength where ϕpeak varies with normal stress. Both cases are considered.

- For long-term conditions, the critical interface is either GCL because both are assumed to be hydrated and the reinforcement is not effective. The shear strength varies with normal stress as in the previous table.

FIGURE 1

INTERIM CONFIGURATION



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15 Jan 96

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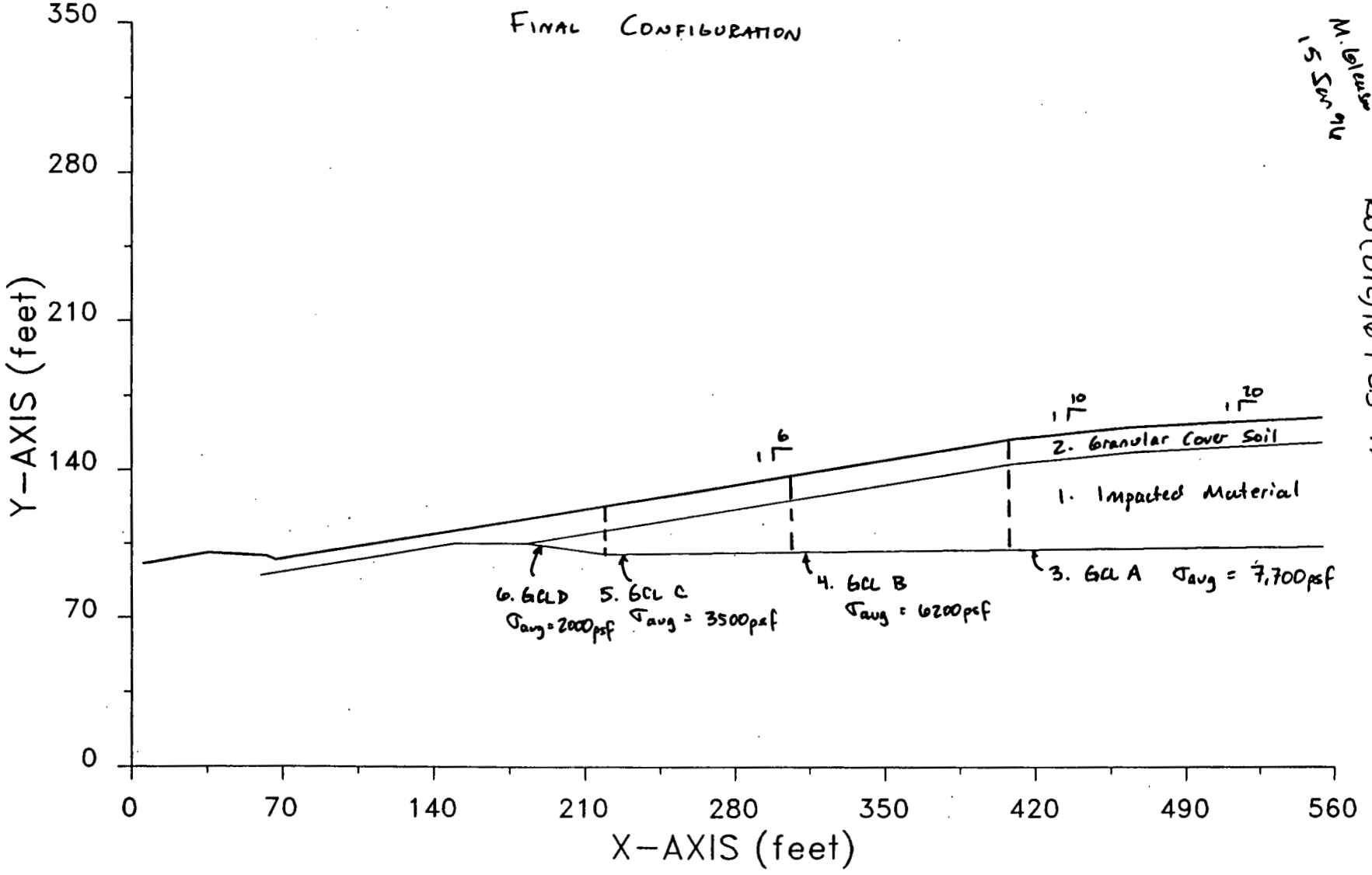
FIGURE 2

FINAL CONFIGURATION



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15 Sep 96

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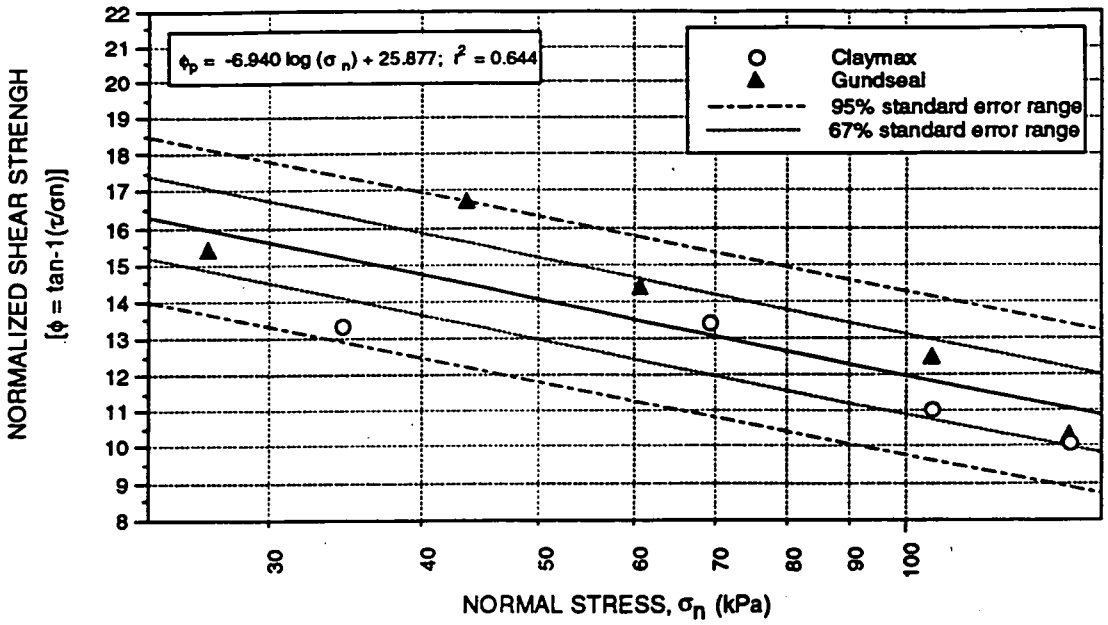

Figure 4. Log-linear regression analysis for peak CD conditions.

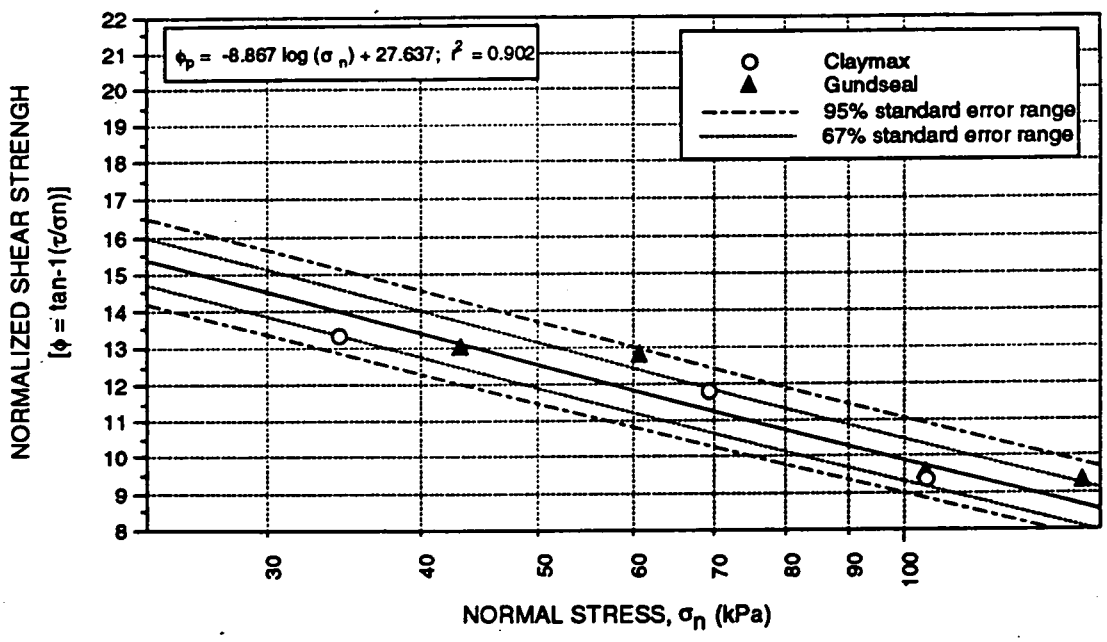

Figure 3. Log-linear regression analysis for large-displacement CD conditions. From Bonaparte et al. (1996)

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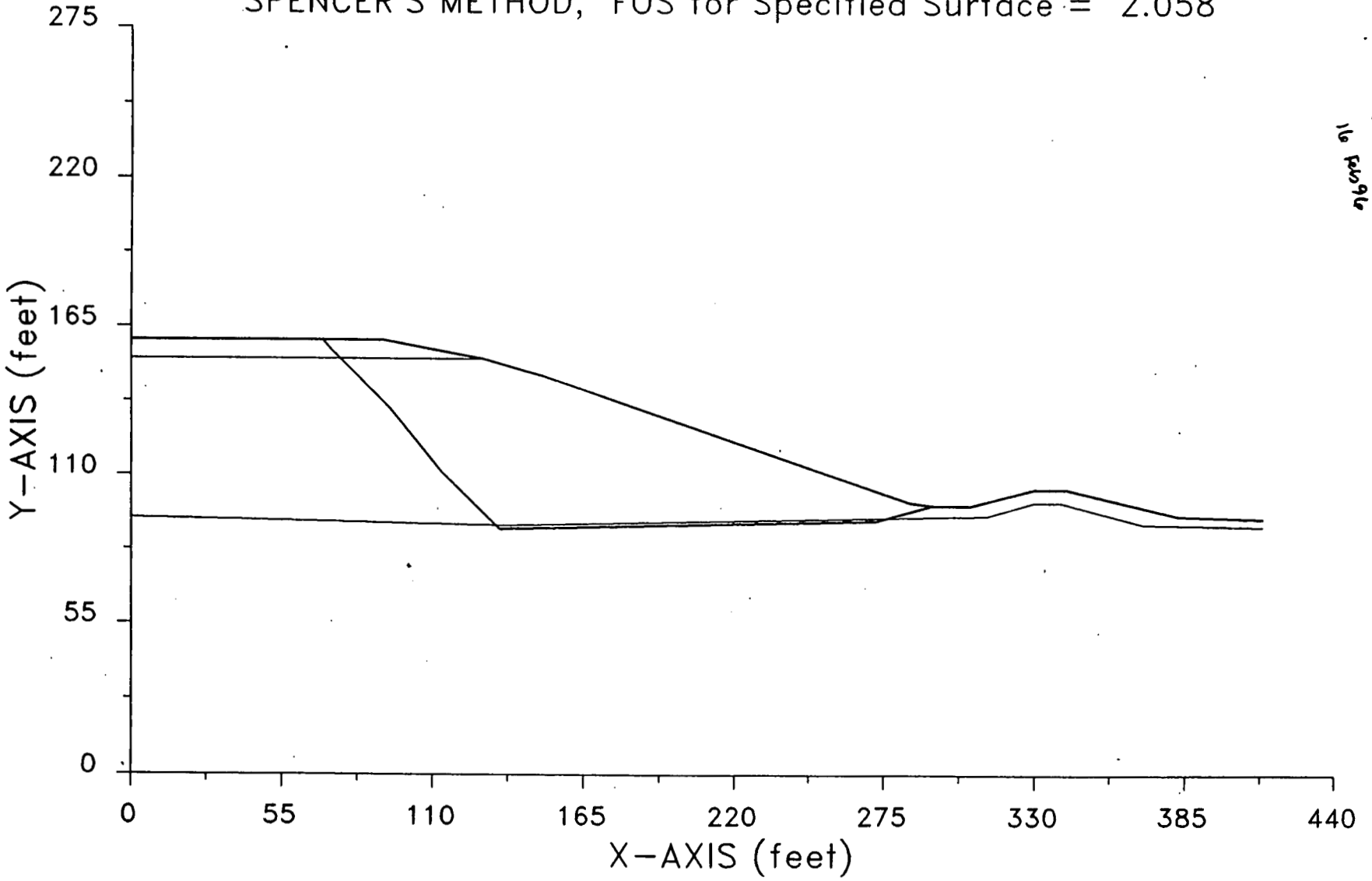
OSDF Interim Conditions–Dry Short term

SPENCER'S METHOD, FOS for Specified Surface = 2.058



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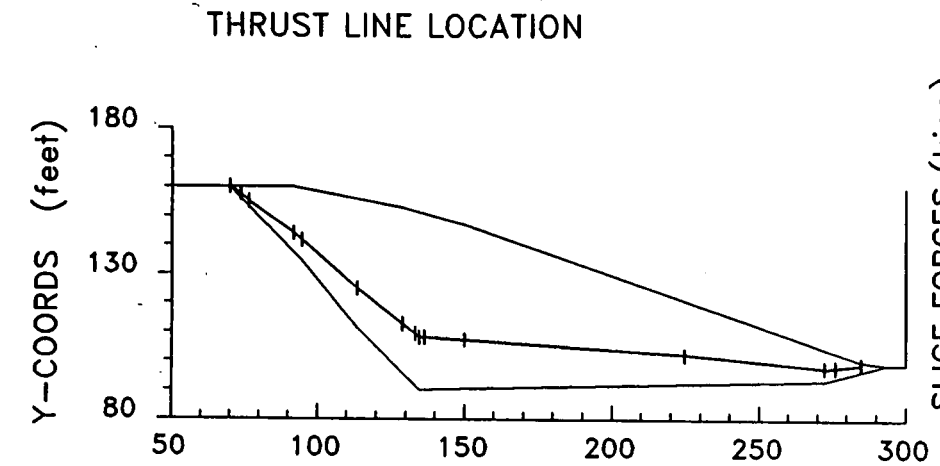

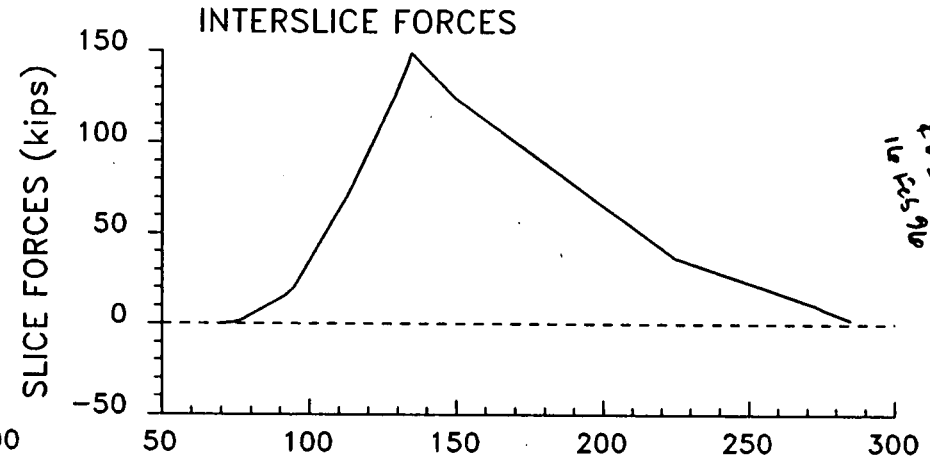

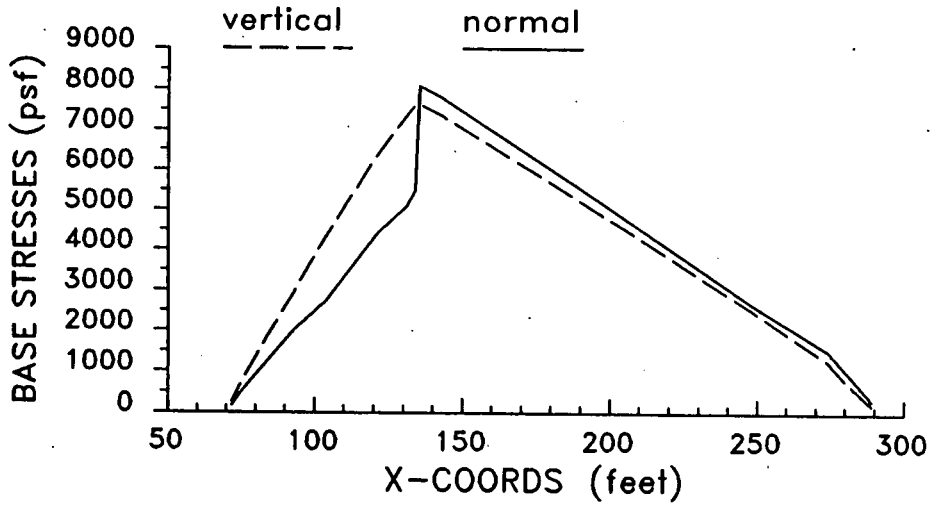

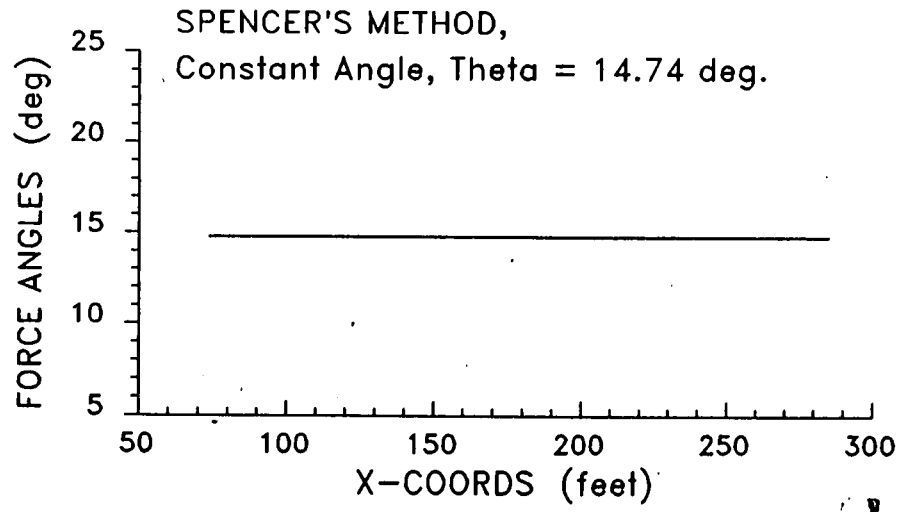

OSDF Interim Closure Short Term, DRY
SPENCER'S METHOD, FOS for Specified Surface = 2.058

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*   Interactive Software Designs, Inc.  *
*       Moscow, ID 83843, U.S.A.        *
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*         All Rights Reserved           *
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*  Ver. 5.100                95 - 1305  *
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Problem Description : OSDF Interim Closure Short Term, DRY

SEGMENT BOUNDARY COORDINATES

10 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	92.0	160.0	2
2	92.0	160.0	129.0	153.0	2
3	129.0	153.0	150.0	147.0	1
4	150.0	147.0	285.0	100.0	1
5	285.0	100.0	294.0	99.0	1
6	294.0	99.0	307.0	99.0	2
7	307.0	99.0	330.0	105.0	2
8	330.0	105.0	342.0	105.0	2
9	342.0	105.0	383.0	95.0	2
10	383.0	95.0	414.0	94.0	2

9 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	129.0	153.0	1
2	.0	94.1	136.5	91.4	3
3	136.5	91.4	224.8	93.2	4
4	224.8	93.2	285.0	94.4	5
5	285.0	94.4	313.0	95.0	6
6	313.0	95.0	330.0	100.0	6
7	330.0	100.0	340.0	100.0	6
8	340.0	100.0	370.0	92.0	6
9	370.0	92.0	414.0	91.0	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	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

A SINGLE FAILURE SURFACE HAS BEEN SPECIFIED FOR ANALYSIS

Trial failure surface specified by
the following 7 coordinate points :

Point No.	x-surf (ft)	y-surf (ft)
1	293.30	99.08
2	272.44	93.19
3	134.73	90.03
4	113.52	111.25
5	94.69	134.60
6	73.63	155.97
7	70.04	160.00

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	289.15	97.91	1.63	8.30	-15.76	6.34	1694.
2	280.55	95.48	6.07	8.90	-15.76	19.20	6755.
3	274.27	93.71	10.03	3.66	-15.76	19.20	4586.
4	248.62	92.64	20.02	47.64	-1.31	19.20	119232.
5	187.40	91.24	42.74	74.80	-1.31	19.20	399625.
6	143.25	90.23	58.70	13.50	-1.31	15.95	99061.
7	135.61	90.05	61.06	1.77	-1.31	15.95	13510.
8	134.01	90.75	60.82	1.43	45.01	15.95	10892.
9	131.15	93.61	58.77	4.30	45.01	15.95	31571.
10	121.26	103.51	50.96	15.48	45.01	10.71	98604.
11	104.10	122.93	34.78	18.83	51.12	10.71	81875.
12	93.35	135.96	23.78	2.69	45.42	10.71	7996.
13	84.28	145.16	14.84	15.44	45.42	.00	28638.
14	75.09	154.49	5.51	2.93	45.42	.00	2018.
15	71.84	157.98	2.02	3.59	48.30	.00	904.

ITERATIONS FOR SPENCER'S METHOD

F.7.E
16 Feb 96

SQ. 20 Feb 96

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Iter #	Theta	FOS_force	FOS_moment
2	14.7382	2.0578	2.0699
3	14.7443	2.0580	2.0578

SLICE INFORMATION ... continued :

Slice	Sigma (psf)	c-value (psf)	phi	U-base (lb)	U-top (lb)	P-top (lb)	Delta
1	320.5	200.0	25.00	0.	0.	0.	.00
2	1012.1	200.0	25.00	0.	0.	0.	.00
3	1511.8	.0	20.00	0.	0.	0.	.00
4	2653.1	.0	20.00	0.	0.	0.	.00
5	5663.4	.0	20.00	0.	0.	0.	.00
6	7778.5	.0	20.00	0.	0.	0.	.00
7	8090.7	.0	20.00	0.	0.	0.	.00
8	5455.0	.0	20.00	0.	0.	0.	.00
9	5086.1	200.0	25.00	0.	0.	0.	.00
10	4403.2	200.0	25.00	0.	0.	0.	.00
11	2748.1	200.0	25.00	0.	0.	0.	.00
12	2017.3	200.0	25.00	0.	0.	0.	.00
13	1239.3	200.0	25.00	0.	0.	0.	.00
14	466.5	.0	30.00	0.	0.	0.	.00
15	164.0	.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	289.15	320.5	204.1	.0	169.8
2	280.55	1012.1	758.8	.0	326.5
3	274.27	1511.8	1253.7	.0	267.4
4	248.62	2653.1	2502.8	.0	469.2
5	187.40	5663.4	5342.6	.0	1001.6
6	143.25	7778.5	7337.9	.0	1375.7
7	135.61	8090.7	7632.5	.0	1430.9
8	134.01	5455.0	7602.6	.0	964.8
9	131.15	5086.1	7346.6	.0	1249.6
10	121.26	4403.2	6369.8	.0	1094.9
11	104.10	2748.1	4348.1	.0	719.9
12	93.35	2017.3	2972.6	.0	554.3
13	84.28	1239.3	1854.4	.0	378.0
14	75.09	466.5	689.4	.0	130.9
15	71.84	164.0	251.9	.0	46.0

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	285.00	14.74	2234.	2.26	3.26	.693
2	276.10	14.74	7869.	3.76	8.88	.424
3	272.44	14.74	10494.	4.56	11.18	.408
4	224.80	14.74	36608.	10.08	28.86	.349
5	150.00	14.74	124132.	16.83	56.62	.297
6	136.50	14.74	145828.	17.90	60.79	.294
7	134.73	14.74	148786.	18.05	61.33	.294
8	133.30	14.74	142130.	17.81	60.31	.295
9	129.00	14.74	125072.	16.85	57.24	.294
10	113.52	14.74	72082.	13.64	44.68	.305
11	94.69	14.74	19746.	7.00	24.89	.281
12	92.00	14.74	15594.	6.58	22.67	.290
13	76.56	14.74	1548.	1.97	7.00	.282
14	73.63	14.74	512.	1.54	4.03	.383
15	70.04	.00	-1.	.00	.00	.000

AVERAGE VALUES ALONG FAILURE SURFACE

Total Normal Stress = 3712.57 (psf)
Pore Water Pressure = .00 (psf)
Shear Stress = 746.66 (psf)

Total Length of failure surface = 254.82 feet

For the single specified surface and the assumed angle of the interslice forces, the SPENCER'S (1973) procedure gives a

FACTOR OF SAFETY = 2.058

Total shear strength available along specified failure surface = 391.56E+03 lb

RDE 16 Feb 96

Sq. 20 Feb 96

22/34 253

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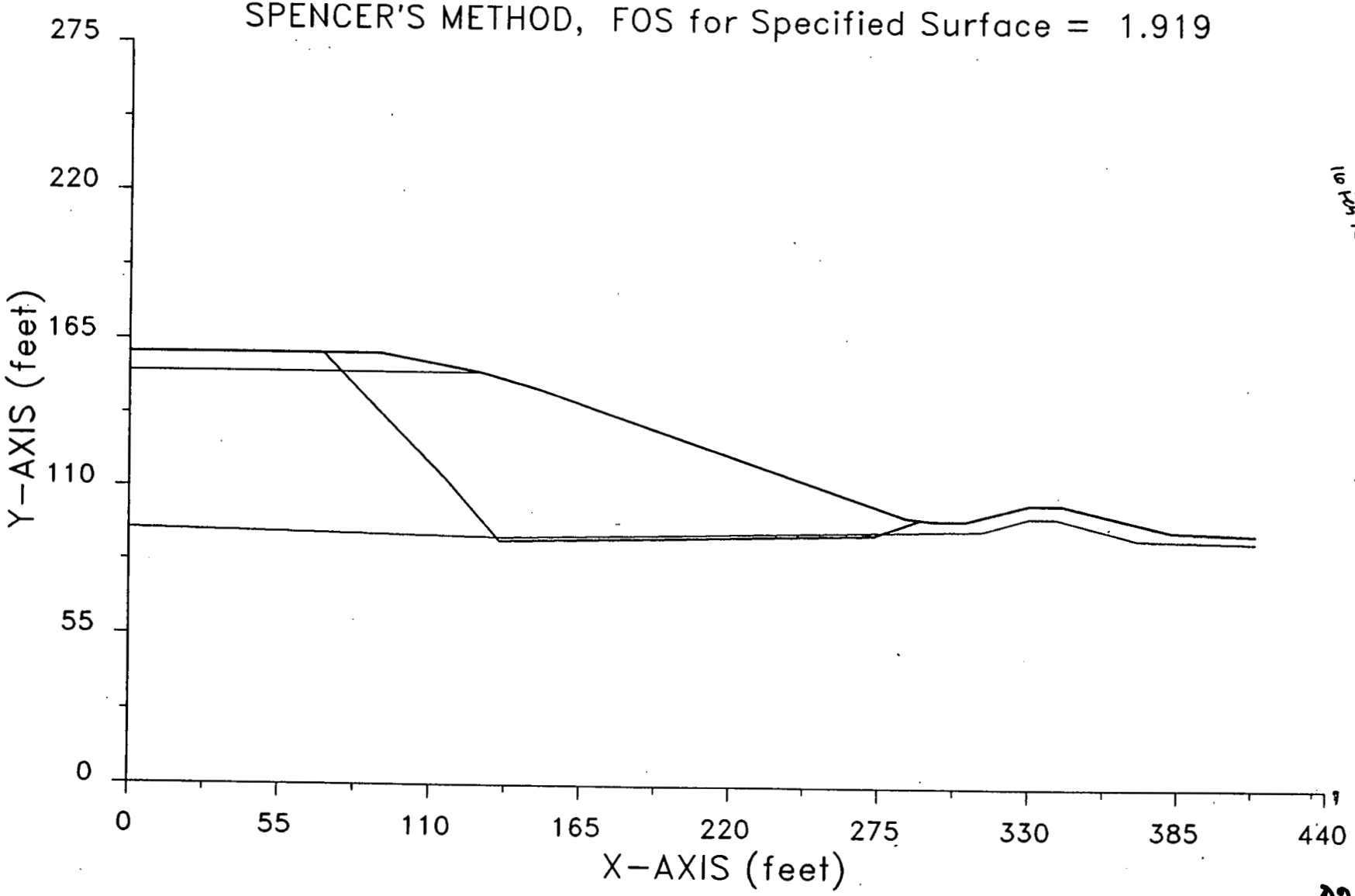
OSDF Interim Conditions–Peak Short Term

SPENCER'S METHOD, FOS for Specified Surface = 1.919



R.V.E. 16 Feb 96

SQ. 20 Feb 96

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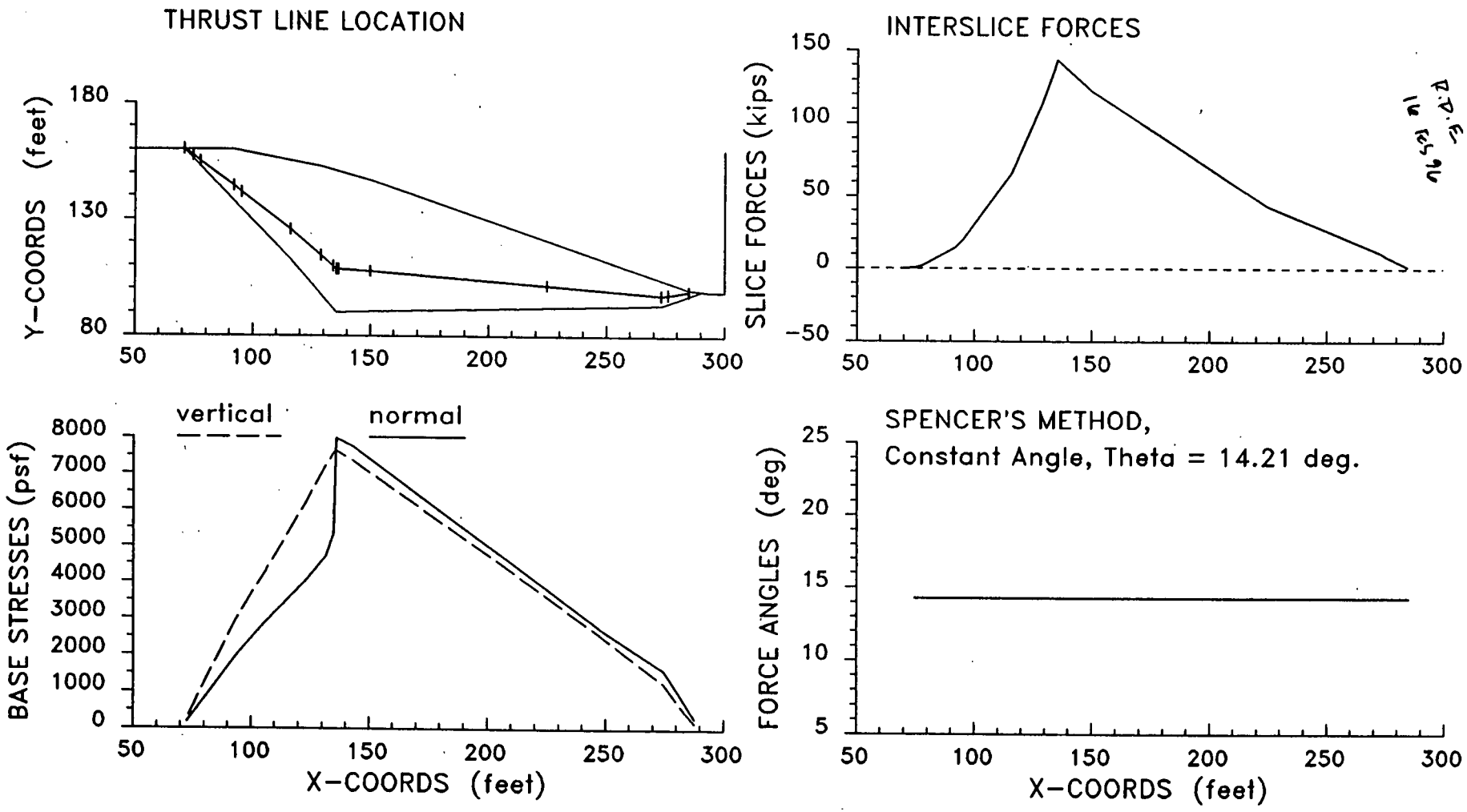

OSDF Interim Closure Short Term,PEAK
SPENCER'S METHOD, FOS for Specified Surface = 1.919

R.P.E.
16 Feb 96

SQ. 20 Feb 96
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*              X S T A B L              *
*                                       *
*       Slope Stability Analysis        *
*             using the                 *
*           Method of Slices            *
*                                       *
*       Copyright (C) 1992 - 94         *
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Problem Description : OSDF Interim Closure Short Term,PEAK

SEGMENT BOUNDARY COORDINATES

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10 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	92.0	160.0	2
2	92.0	160.0	129.0	153.0	2
3	129.0	153.0	150.0	147.0	1
4	150.0	147.0	285.0	100.0	1
5	285.0	100.0	294.0	99.0	1
6	294.0	99.0	307.0	99.0	2
7	307.0	99.0	330.0	105.0	2
8	330.0	105.0	342.0	105.0	2
9	342.0	105.0	383.0	95.0	2
10	383.0	95.0	414.0	94.0	2

9 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	129.0	153.0	1
2	.0	94.1	136.5	91.4	3
3	136.5	91.4	224.8	93.2	4
4	224.8	93.2	285.0	94.4	5
5	285.0	94.4	313.0	95.0	6
6	313.0	95.0	330.0	100.0	6
7	330.0	100.0	340.0	100.0	6
8	340.0	100.0	370.0	92.0	6
9	370.0	92.0	414.0	91.0	6

ISOTROPIC Soil Parameters

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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	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

A SINGLE FAILURE SURFACE HAS BEEN SPECIFIED FOR ANALYSIS

Trial failure surface specified by
the following 7 coordinate points :

Point No.	x-surf (ft)	y-surf (ft)
1	290.52	99.39
2	273.30	93.21
3	135.57	90.01
4	116.06	112.79
5	95.26	134.42
6	74.61	156.18
7	70.89	160.00

****

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	287.76	98.40	1.30	5.52	-19.73	6.34	895.
2	280.56	95.81	5.73	8.88	-19.73	19.20	6357.
3	274.71	93.72	9.87	2.82	-19.73	19.20	3483.
4	249.05	92.65	19.87	48.50	-1.33	19.20	120458.
5	187.40	91.21	42.77	74.80	-1.33	19.20	399853.
6	143.25	90.19	58.74	13.50	-1.33	15.95	99124.
7	136.04	90.02	60.97	.93	-1.33	15.95	7088.
8	134.96	90.73	60.57	1.23	49.42	15.95	9290.
9	131.67	94.56	57.67	5.34	49.42	15.95	38519.
10	122.53	105.24	48.99	12.94	49.42	10.71	79239.
11	105.66	123.60	33.81	20.80	46.12	10.71	87908.
12	93.63	136.14	23.55	3.26	46.50	10.71	9598.
13	84.81	145.43	14.57	14.37	46.50	.00	26180.
14	76.12	154.59	5.41	3.02	46.50	.00	2041.
15	72.75	158.09	1.91	3.72	45.76	.00	888.

ITERATIONS FOR SPENCER'S METHOD

R.P.E. 16 Feb 96

SQ. 20 Feb 96

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Iter #	Theta	FOS_force	FOS_moment
2	14.2040	1.9192	1.9455
3	14.2073	1.9193	1.9192

SLICE INFORMATION ... continued :

Slice	Sigma (psf)	c-value (psf)	phi	U-base (lb)	U-top (lb)	P-top (lb)	Delta
1	297.0	200.0	25.00	0.	0.	0.	.00
2	1025.6	200.0	25.00	0.	0.	0.	.00
3	1593.5	.0	23.00	0.	0.	0.	.00
4	2662.1	.0	23.00	0.	0.	0.	.00
5	5626.5	.0	17.00	0.	0.	0.	.00
6	7728.3	.0	17.00	0.	0.	0.	.00
7	7975.8	.0	15.00	0.	0.	0.	.00
8	5319.8	.0	15.00	0.	0.	0.	.00
9	4687.1	200.0	25.00	0.	0.	0.	.00
10	3971.8	200.0	25.00	0.	0.	0.	.00
11	2849.5	200.0	25.00	0.	0.	0.	.00
12	1957.7	200.0	25.00	0.	0.	0.	.00
13	1189.4	200.0	25.00	0.	0.	0.	.00
14	448.6	.0	30.00	0.	0.	0.	.00
15	160.0	.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	287.76	297.0	162.1	.0	176.4
2	280.56	1025.6	716.3	.0	353.4
3	274.71	1593.5	1233.1	.0	352.4
4	249.05	2662.1	2483.7	.0	588.8
5	187.40	5626.5	5345.6	.0	896.3
6	143.25	7728.3	7342.5	.0	1231.1
7	136.04	7975.8	7621.1	.0	1113.5
8	134.96	5319.8	7571.5	.0	742.7
9	131.67	4687.1	7209.3	.0	1243.0
10	122.53	3971.8	6123.6	.0	1069.2
11	105.66	2849.5	4226.3	.0	796.5
12	93.63	1957.7	2944.3	.0	579.9
13	84.81	1189.4	1821.6	.0	393.2
14	76.12	448.6	676.3	.0	134.9
15	72.75	160.0	238.8	.0	48.1

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	285.00	14.21	1611.	1.69	2.59	.651
2	276.12	14.21	8215.	3.58	8.87	.404
3	273.30	14.21	10907.	4.21	10.86	.388
4	224.80	14.21	43457.	9.44	28.88	.327
5	150.00	14.21	122700.	17.35	56.65	.306
6	136.50	14.21	142344.	18.43	60.83	.303
7	135.57	14.21	143590.	18.52	61.11	.303
8	134.34	14.21	136668.	18.31	60.03	.305
9	129.00	14.21	113356.	16.69	55.32	.302
10	116.06	14.21	65725.	12.66	42.66	.297
11	95.26	14.21	19237.	7.14	24.96	.286
12	92.00	14.21	14249.	6.57	22.14	.297
13	77.63	14.21	1497.	2.00	7.00	.286
14	74.61	14.21	445.	1.45	3.82	.378
15	70.89	.00	0.	.14	.00	.000

AVERAGE VALUES ALONG FAILURE SURFACE

Total Normal Stress = 3691.70 (psf)
Pore Water Pressure = .00 (psf)
Shear Stress = 745.01 (psf)

Total Length of failure surface = 251.39 feet

For the single specified surface and the assumed angle of the interslice forces, the SPENCER'S (1973) procedure gives a

FACTOR OF SAFETY = 1.919

Total shear strength available along specified failure surface = 359.46E+03 lb

R.D.E. 16 Feb 96

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SQ. 20 Feb 96

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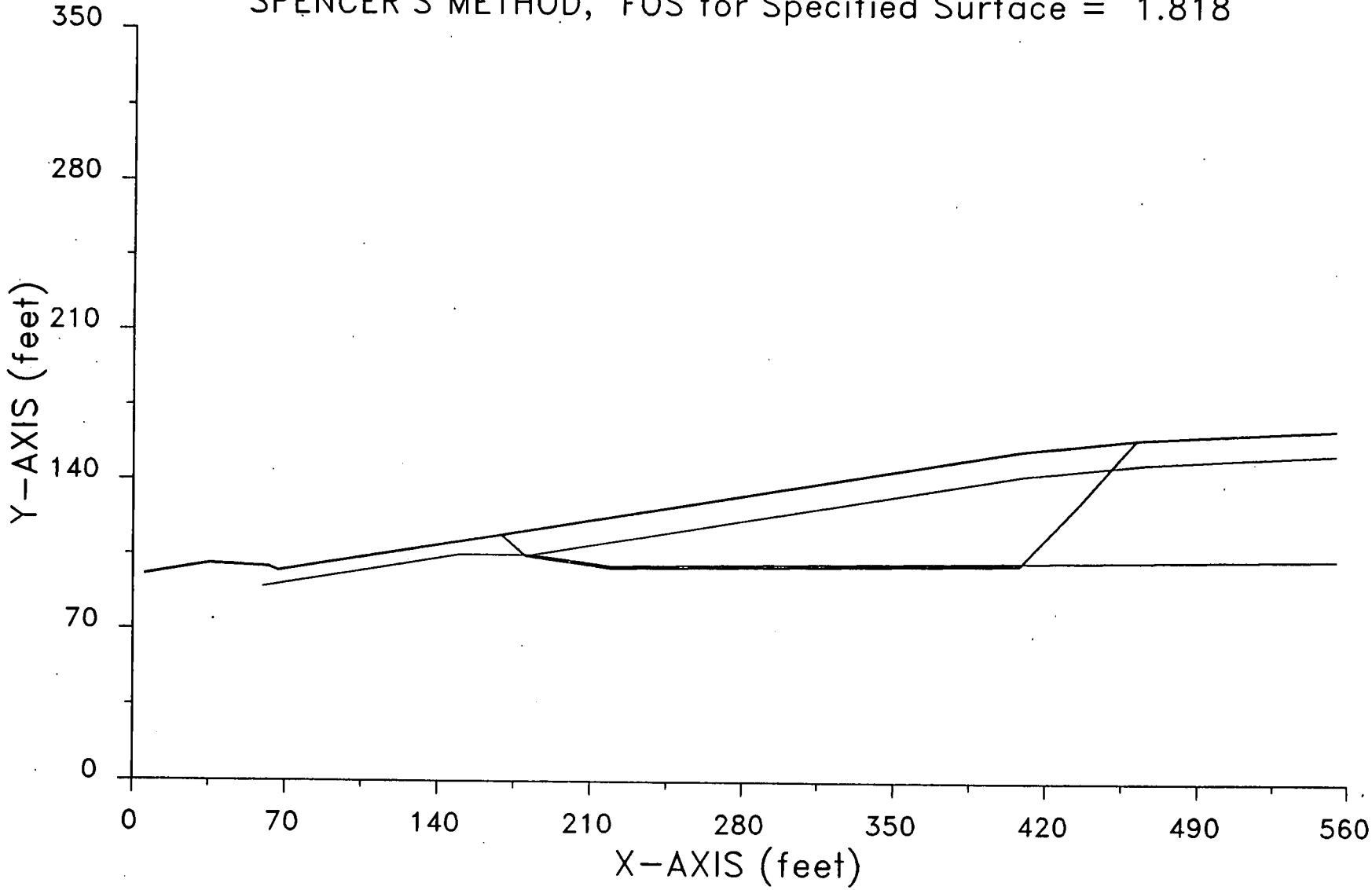
OSDF Final LOng Term–Peak Hydrated
SPENCER'S METHOD, FOS for Specified Surface = 1.818



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16 Feb 96

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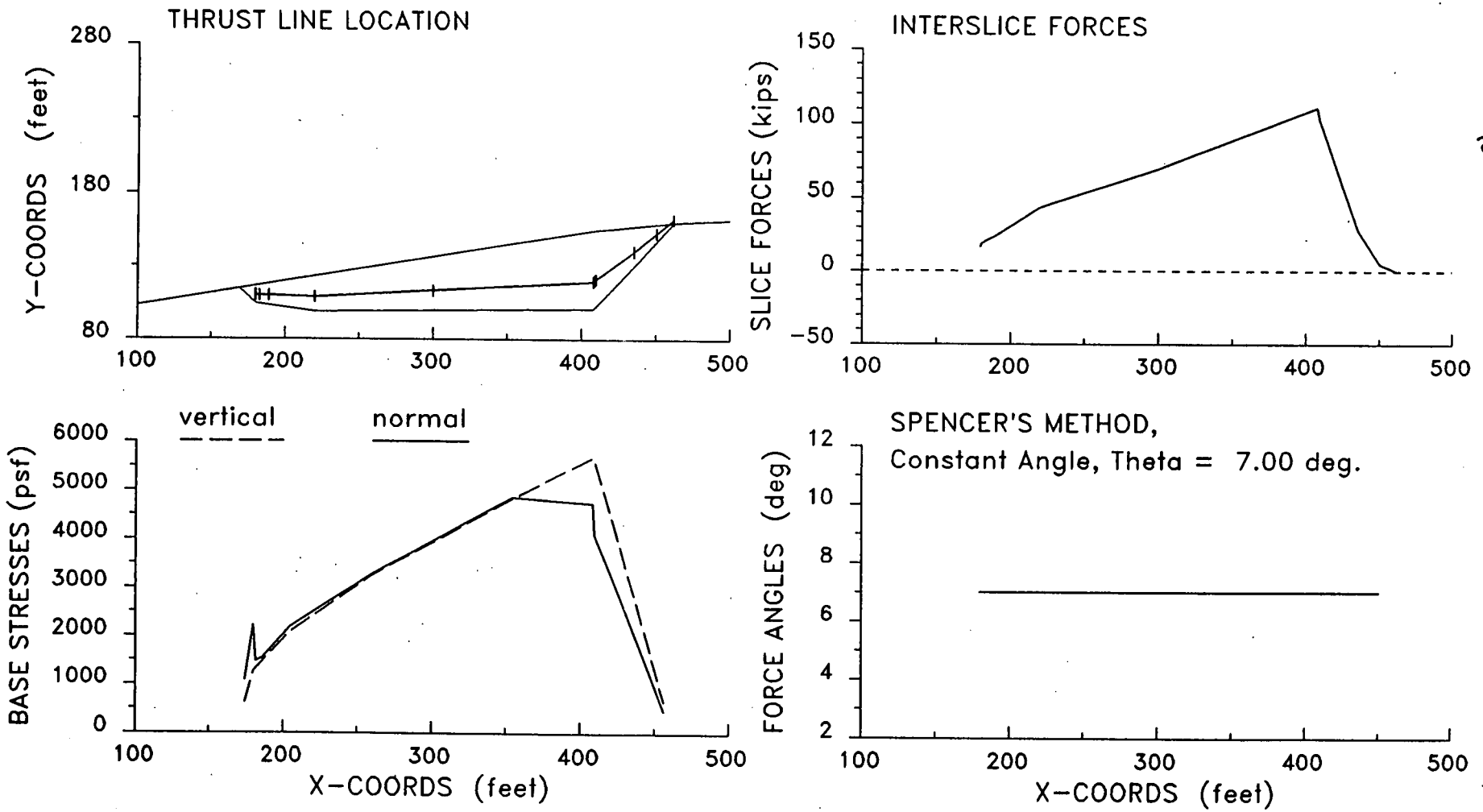

OSDF Final LOng Term-Peak Hydrated
SPENCER'S METHOD, FOS for Specified Surface = 1.818

R.D.E. 16 Feb 96

SR. 20 Feb 96
24/34

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*****************************************
*              X S T A B L              *
*                                       *
*       Slope Stability Analysis        *
*             using the                 *
*           Method of Slices            *
*                                       *
*        Copyright (C) 1992 - 94        *
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*       Moscow, ID 83843, U.S.A.        *
*                                       *
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*                                       *
* Ver. 5.100                95 - 1305   *
*****************************************
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Problem Description : OSDF Final LOng Term-Peak Hydrated

SEGMENT BOUNDARY COORDINATES

6 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	5.5	95.6	35.5	100.6	2
2	35.5	100.6	62.5	99.3	2
3	62.5	99.3	67.0	97.5	2
4	67.0	97.5	410.0	154.7	2
5	410.0	154.7	465.0	160.2	2
6	465.0	160.2	555.0	164.7	2

11 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	60.0	90.0	120.0	100.0	2
2	120.0	100.0	150.0	105.0	2
3	150.0	105.0	183.0	105.0	2
4	183.0	105.0	189.0	106.0	1
5	189.0	106.0	410.0	142.8	1
6	410.0	142.8	467.0	148.5	1
7	467.0	148.5	555.0	152.9	1
8	183.0	105.0	220.0	100.0	6
9	220.0	100.0	300.0	100.8	5
10	300.0	100.8	410.0	102.0	4
11	410.0	102.0	555.0	103.5	3

ISOTROPIC Soil Parameters

6 Soil unit(s) specified

Soil	Unit Weight	Cohesion	Friction	Pore Pressure	Water
Unit No.	Moist (pcf)	Sat. (pcf)	Intercept (psf)	Angle (deg)	Parameter Ru	Constant (psf)	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	12.00	.000	.0	0

A SINGLE FAILURE SURFACE HAS BEEN SPECIFIED FOR ANALYSIS

Trial failure surface specified by
the following 6 coordinate points :

Point No.	x-surf (ft)	y-surf (ft)
1	169.27	114.55
2	180.38	104.53
3	220.00	99.00
4	408.24	100.97
5	435.73	130.03
6	462.24	159.92

Z.P.E. 16 Feb 96

****
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	174.56	109.78	5.66	10.59	-42.06	9.47	7492.
2	180.12	104.76	11.60	.52	-42.06	9.47	755.
3	181.69	104.35	12.28	2.62	-7.95	9.47	4021.
4	186.00	103.75	13.60	6.00	-7.95	9.47	10199.
5	204.50	101.16	19.27	31.00	-7.95	9.47	74658.
6	260.00	99.42	30.27	80.00	.60	9.47	302668.
7	354.12	100.40	44.98	108.24	.60	9.47	608547.
8	408.72	101.48	53.01	.97	46.59	9.47	6402.
9	409.60	102.41	52.22	.79	46.59	9.47	5182.
10	422.86	116.43	39.56	25.73	46.59	5.71	127223.
11	443.20	138.45	19.57	14.93	48.43	5.71	36526.
12	456.45	153.39	5.95	11.58	48.43	5.71	8612.

ITERATIONS FOR SPENCER'S METHOD

Iter #	Theta	FOS_force	FOS_moment
2	6.9008	1.8153	1.8623
3	6.9992	-----	1.8153
3	6.9500	1.8165	-----
4	6.9968	1.8176	1.8165

SB. 20 Feb 96

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5	6.9956	1.8176	1.8176

SLICE INFORMATION ... continued :

Slice	Sigma (psf)	c-value (psf)	phi	U-base (lb)	U-top (lb)	P-top (lb)	Delta
1	1255.3	.0	30.00	0.	0.	0.	.00
2	2572.3	.0	30.00	0.	0.	0.	.00
3	1706.3	.0	30.00	0.	0.	0.	.00
4	1785.2	.0	12.00	0.	0.	0.	.00
5	2529.2	.0	12.00	0.	0.	0.	.00
6	3820.0	.0	10.00	0.	0.	0.	.00
7	5664.1	.0	8.00	0.	0.	0.	.00
8	5512.5	.0	8.00	0.	0.	0.	.00
9	4766.8	.0	25.00	0.	0.	0.	.00
10	3610.6	.0	25.00	0.	0.	0.	.00
11	1752.2	.0	25.00	0.	0.	0.	.00
12	510.3	.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	174.56	1255.3	707.6	.0	398.7
2	180.12	2572.3	1449.9	.0	817.1
3	181.69	1706.3	1534.9	.0	542.0
4	186.00	1785.2	1699.9	.0	208.8
5	204.50	2529.2	2408.3	.0	295.8
6	260.00	3820.0	3783.4	.0	370.6
7	354.12	5664.1	5622.2	.0	438.0
8	408.72	5512.5	6625.8	.0	426.2
9	409.60	4766.8	6527.9	.0	1223.0
10	422.86	3610.6	4944.5	.0	926.3
11	443.20	1752.2	2446.4	.0	449.5
12	456.45	510.3	743.8	.0	162.1

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	179.86	7.00	16338.	5.43	11.32	.479
2	180.38	7.00	17985.	5.44	11.88	.458
3	183.00	7.00	20044.	5.53	12.68	.436
4	189.00	7.00	22812.	6.34	14.52	.437
5	220.00	7.00	43076.	9.58	24.01	.399
6	300.00	7.00	69724.	13.18	36.52	.361
7	408.24	7.00	111021.	18.16	53.44	.340
8	409.21	7.00	105764.	18.14	52.58	.345
9	410.00	7.00	102711.	17.93	51.87	.346
10	435.73	7.00	27781.	9.81	27.24	.360
11	450.66	7.00	4822.	5.82	11.90	.489
12	462.24	.00	0.	12.62	.00	.000

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AVERAGE VALUES ALONG FAILURE SURFACE

Total Normal Stress = 3805.09 (psf)
Pore Water Pressure = .00 (psf)
Shear Stress = 448.41 (psf)

Total Length of failure surface = 323.18 feet

For the single specified surface and the assumed angle of the interslice forces, the SPENCER'S (1973) procedure gives a

FACTOR OF SAFETY = 1.818

Total shear strength available along specified failure surface = 263.39E+03 lb

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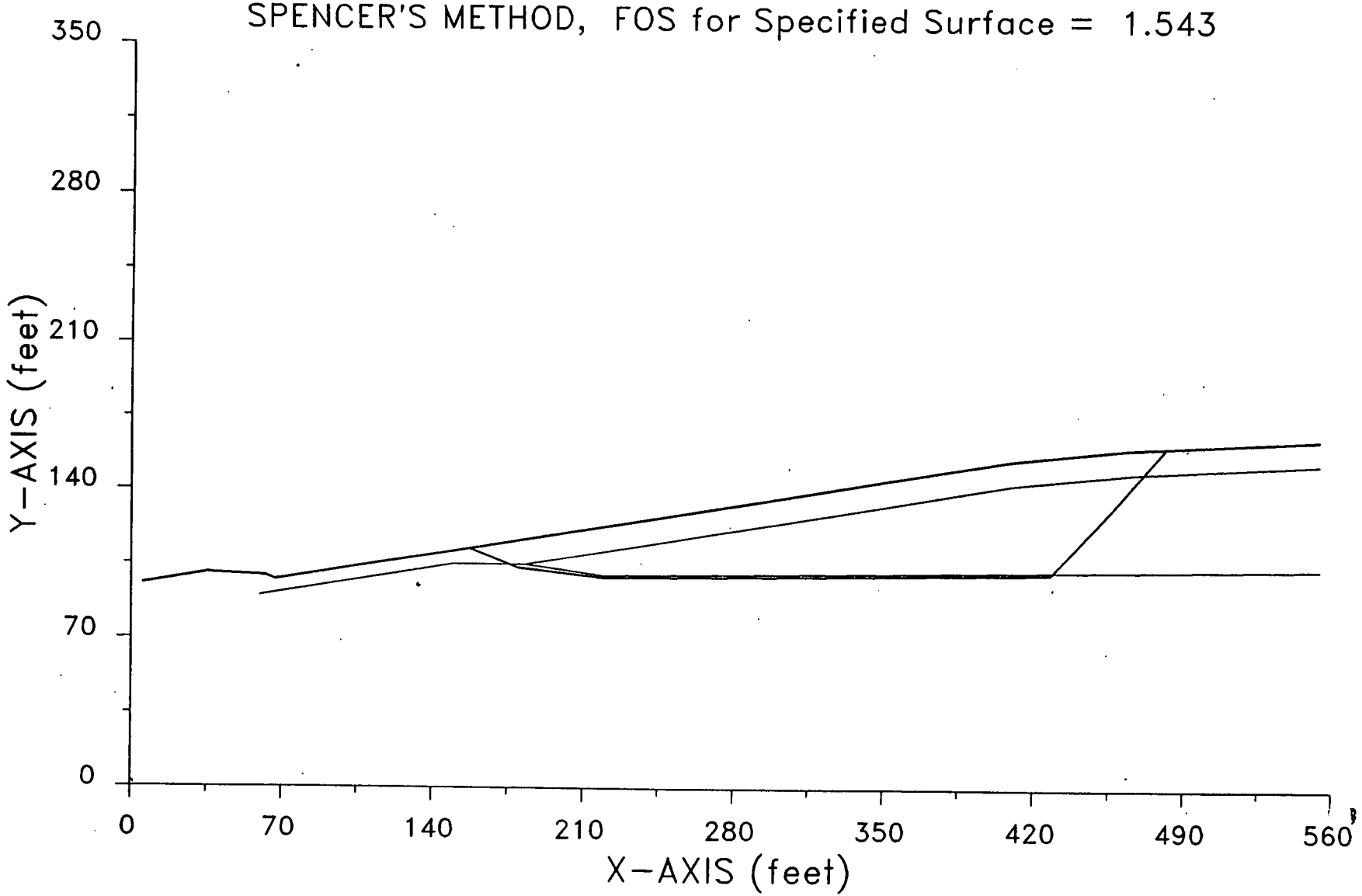
OSDF Final Long Term – Large Disp.
SPENCER'S METHOD, FOS for Specified Surface = 1.543



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16 Feb 96

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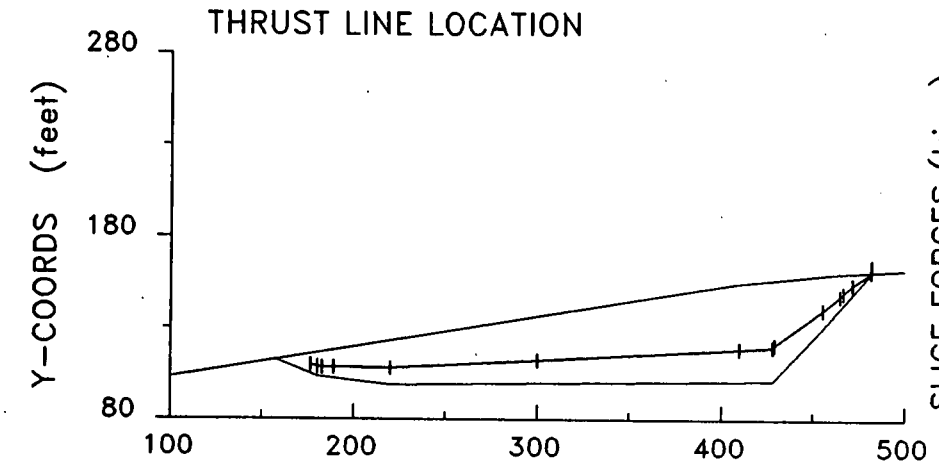

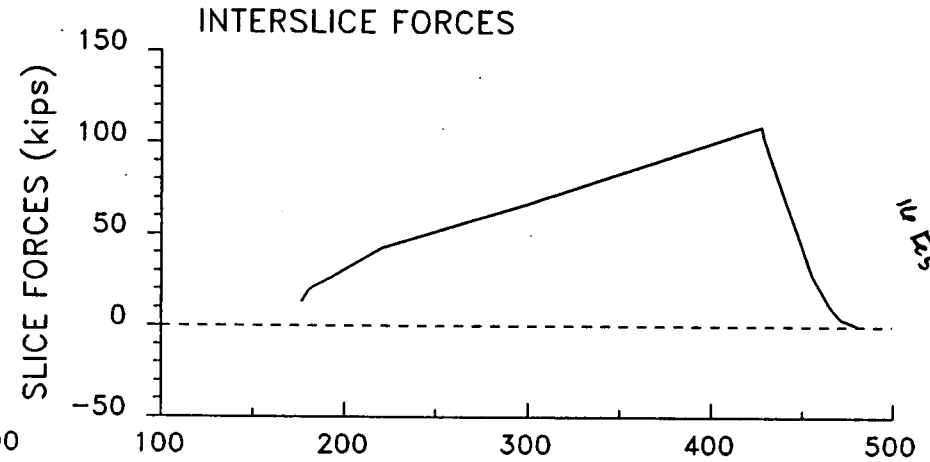

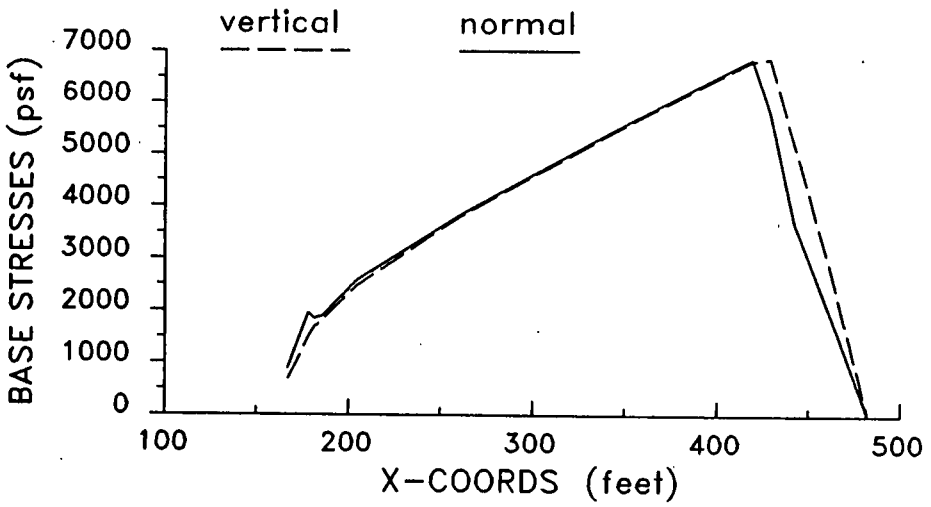

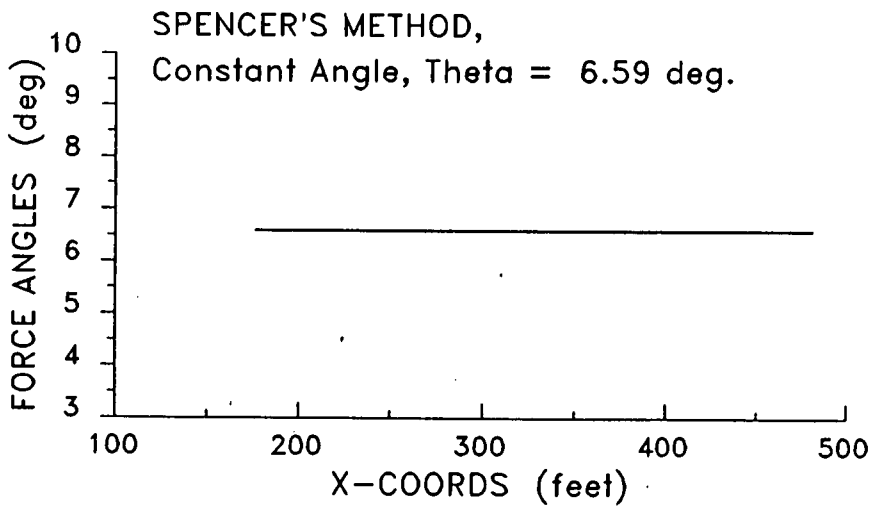

OSDF Final Long Term – Large Disp.
SPENCER'S METHOD, FOS for Specified Surface = 1.543

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10 Feb 96

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*       Slope Stability Analysis        *
*             using the                 *
*           Method of Slices            *
*                                       *
*        Copyright (C) 1992 - 94        *
*   Interactive Software Designs, Inc.  *
*       Moscow, ID 83843, U.S.A.        *
*                                       *
*         All Rights Reserved           *
*                                       *
*  Ver. 5.100                95 - 1305  *
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Problem Description : OSDF Final Long Term - Large Disp.

SEGMENT BOUNDARY COORDINATES
---

6 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	5.5	95.6	35.5	100.6	2
2	35.5	100.6	62.5	99.3	2
3	62.5	99.3	67.0	97.5	2
4	67.0	97.5	410.0	154.7	2
5	410.0	154.7	465.0	160.2	2
6	465.0	160.2	555.0	164.7	2

11 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	60.0	90.0	120.0	100.0	2
2	120.0	100.0	150.0	105.0	2
3	150.0	105.0	183.0	105.0	2
4	183.0	105.0	189.0	106.0	1
5	189.0	106.0	410.0	142.8	1
6	410.0	142.8	467.0	148.5	1
7	467.0	148.5	555.0	152.9	1
8	183.0	105.0	220.0	100.0	6
9	220.0	100.0	300.0	100.8	5
10	300.0	100.8	410.0	102.0	4
11	410.0	102.0	555.0	103.5	3

ISOTROPIC Soil Parameters
---

6 Soil unit(s) specified

Soil No.	Unit Weight (pcf)	Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Water Constant (psf)	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	8.00	.000	.0	0
6	125.0	125.0	.0	10.00	.000	.0	0

A SINGLE FAILURE SURFACE HAS BEEN SPECIFIED FOR ANALYSIS

Trial failure surface specified by
the following 7 coordinate points :

Point No.	x-surf (ft)	y-surf (ft)
1	157.53	112.60
2	180.25	103.47
3	220.00	99.00
4	428.25	101.18
5	455.60	130.37
6	481.96	160.45
7	482.22	161.06

E.D.E. 16 Feb 96

****
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	166.99	108.80	5.38	18.91	-21.89	9.47	12707.
2	178.35	104.24	11.83	3.81	-21.89	9.47	5634.
3	181.63	103.32	13.30	2.75	-6.42	9.47	4572.
4	186.00	102.82	14.52	6.00	-6.42	9.47	10891.
5	204.50	100.74	19.69	31.00	-6.42	9.47	76287.
6	260.00	99.42	30.27	80.00	.60	9.47	302667.
7	355.00	100.41	45.11	110.00	.60	9.47	620328.
8	419.13	101.08	54.53	18.25	.60	5.71	124392.
9	428.73	101.69	54.88	.95	46.86	5.71	6548.
10	442.40	116.28	41.66	26.40	46.86	5.71	137441.
11	460.30	135.73	24.00	9.40	48.77	5.71	28196.
12	466.00	142.24	18.01	2.00	48.77	2.86	4503.
13	469.35	146.06	14.36	4.69	48.77	2.86	8425.
14	476.83	154.59	6.20	10.27	48.77	2.86	7955.
15	482.09	160.76	.30	.26	66.95	2.86	10.

ITERATIONS FOR SPENCER'S METHOD

Iter #	Theta	FOS_force	FOS_moment

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2	6.5387	1.5423	1.5719
3	6.5854	1.5430	1.5423

SLICE INFORMATION ... continued :

Slice	Sigma (psf)	c-value (psf)	phi	U-base (lb)	U-top (lb)	P-top (lb)	Delta
1	884.0	.0	30.00	0.	0.	0.	.00
2	1946.0	.0	30.00	0.	0.	0.	.00
3	1843.6	.0	30.00	0.	0.	0.	.00
4	1888.9	.0	10.00	0.	0.	0.	.00
5	2560.8	.0	10.00	0.	0.	0.	.00
6	3815.2	.0	8.00	0.	0.	0.	.00
7	5673.1	.0	6.00	0.	0.	0.	.00
8	6848.5	.0	5.00	0.	0.	0.	.00
9	5827.8	.0	5.00	0.	0.	0.	.00
10	3690.7	.0	25.00	0.	0.	0.	.00
11	2080.6	.0	25.00	0.	0.	0.	.00
12	1561.7	.0	25.00	0.	0.	0.	.00
13	1245.1	.0	25.00	0.	0.	0.	.00
14	511.3	.0	30.00	0.	0.	0.	.00
15	18.7	.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	166.99	884.0	671.9	.0	330.8
2	178.35	1946.0	1479.2	.0	728.1
3	181.63	1843.6	1662.5	.0	689.8
4	186.00	1888.9	1815.2	.0	215.9
5	204.50	2560.8	2460.9	.0	292.6
6	260.00	3815.2	3783.3	.0	347.5
7	355.00	5673.1	5639.3	.0	386.4
8	419.13	6848.5	6816.0	.0	388.3
9	428.73	5827.8	6860.4	.0	330.4
10	442.40	3690.7	5207.0	.0	1115.3
11	460.30	2080.6	2999.6	.0	628.8
12	466.00	1561.7	2251.5	.0	472.0
13	469.35	1245.1	1795.1	.0	376.3
14	476.83	511.3	774.9	.0	191.3
15	482.09	18.7	37.4	.0	7.0

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	176.44	6.59	13057.	4.89	10.75	.455
2	180.25	6.59	18846.	5.06	12.92	.391
3	183.00	6.59	21329.	5.06	13.68	.370
4	189.00	6.59	23916.	5.80	15.36	.378
5	220.00	6.59	42034.	8.84	24.01	.368
6	300.00	6.59	66802.	12.40	36.52	.340
7	410.00	6.59	103015.	17.56	53.71	.327
8	428.25	6.59	108831.	18.49	55.35	.334
9	429.20	6.59	103173.	18.57	54.42	.341
10	455.60	6.59	28147.	9.44	28.89	.327
11	465.00	6.59	11630.	6.36	19.10	.333
12	467.00	6.59	8993.	5.88	16.92	.347
13	471.69	6.59	4058.	5.28	11.80	.447
14	481.96	6.59	5.	.29	.60	.481
15	482.22	.00	-5.	2.84	.00	.000

AVERAGE VALUES ALONG FAILURE SURFACE

Total Normal Stress = 3900.77 (psf)
Pore Water Pressure = .00 (psf)
Shear Stress = 450.05 (psf)

Total Length of failure surface = 353.41 feet

For the single specified surface and the assumed angle of the interslice forces, the SPENCER'S (1973) procedure gives a

FACTOR OF SAFETY = 1.543

Total shear strength available along specified failure surface = 245.42E+03 lb

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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.

See Section 1.2 of the Design Parameter Summary.

3.4 Intercell Berm

COMPUTATION COVER SHEET

SUBJECT OF CALCULATION: INTERCELL BERM

Computations By: (Cognizant Engineer)
Signature: [signature] Date: 02/16/96
Printed Name and Title: R. David Espinoza, Assistant Project Engineer.

Assumptions and Procedures Checked by: (Checker)
Signature: [signature] Date: 20 Feb '96
Printed Name and Title: SAAD QURESHI, PROJECT ENGINEER

Computations Checked by:
Signature: [signature] Date: 20 Feb '96
Printed Name and Title: SAAD QURESHI, PROJECT ENGINEER

Computations Backchecked by: (Cognizant Engineer)
Signature: [signature] Date: 02/20/96
Printed Name and Title: R. David Espinoza, Assistant Project Engineer

Approved by: (PDP)
Signature: Mark H. Gleason Date: 20 Feb 96
Printed Name and Title: MARK H. GLEASON, Assistant Project Engineer

Approved by: (DTL and TETL)
Signature: Rudolph Bonaparte Date: 22 Feb 96
Printed Name and Title: Rudolph Bonaparte, Principal (DTL)

Record of Revision (Number and initial all revisions)

NO.	REASON	DATE	BY	CHECKED	APPROVAL
C	Intermediate Design				
D	IDP, EPA Submittal	4 Apr 96	[illegible]		

Signature: _____
Number: _____
Registration Stamp (if applicable)

GE3900-09.4/F9630086.CD

Written by: D. Espinoza Date: 96 / 02 / 07 Reviewed by: SQ Date: 20 / Feb '96

Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 9.4

INTERCELL BERM STABILITY

EXECUTIVE SUMMARY

Purpose:

These calculations are performed to evaluate the slope stability factor of safety of the intercell berm. The specific case considered in the evaluation is for slope stability of the upgradient side of the intercell berm when it contains the stormwater runoff from the existing cell for the 25-year, 24-hour storm event. The foundation stability and the stability against lateral thrust of the intercell berm are considered in this calculation.

Procedure:

Bishop's simplified method (Bishop, [1955]) was used to calculate the factor of safety for foundation stability of the intercell berm. A hand calculation, using traditional geotechnical analyses, was used to calculate the factor of safety of the intercell berm against lateral thrust.

Data Verification:

The following information was used for this calculation package: (i) the intercell berm cross section was obtained from the Construction Drawings; (ii) the contained stormwater level from the 25-year, 24-hour storm event was used; (iii) the calculations were for short term conditions; and (iv) appropriate shear strength of the different components of the intercell berm were obtained from the "Foundation Stability" package.

The computed minimum factor of safety is compared to the target factor of safety given in the Design Criteria Package (i.e. 1.3 for short-term conditions). The slope stability is considered adequate if the calculated minimum factor of safety is equal to or greater than the target value.

Conclusions:

The calculated minimum foundation slope stability factor of safety for short-term conditions without the water load applied is 3.9. The calculated foundation slope stability factor of safety with the water load is 3.85. The calculated factor of safety of the intercell berm for lateral thrust due to the water load is approximately 40. These values exceed the target value of 1.3. Therefore, the short-term stability of the intercell berm is acceptable.

Written by: _____ Date: _____ Reviewed by: _____ Date: _____

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.4

INTERCELL BERM STABILITY

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		Page
1.	Purpose	2/10
2.	Procedure	2/10
3.	Data Verification	2/10
4.	Analysis	3/10
5.	Results	3/10

Written by: D. Espinoza Date: 96 / 02 / 07 Reviewed by: SQ. Date: 20 / Feb / 96

Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 9.4

RB (DTL) 16 FEB 96

INTERCELL BERM STABILITY

Purpose:

The purpose of these calculations is to evaluate the stability factor of safety of the intercell berm. The specific case considered in the evaluation is for slope stability of the upgradient side of the intercell berm when it contains the stormwater runoff from the existing cell for the 25-year, 24-hour storm event. The foundation stability and the stability against lateral thrust of the intercell berm are considered in this calculation.

Procedure:

The computer program XSTABL (Sharma, 1994) was used to perform the foundation stability analysis. Circular failure surfaces were analyzed along with the simplified Bishop's method (Bishop, [1955]), as coded in XSTABL.

A hand calculation, using traditional geotechnical analyses, was used to calculate the factor of safety of the intercell berm against lateral thrust.

Data Verification:

The unit weights and undrained shear strengths used in the analysis assumed for this analysis are provided in the data verification package of the OSDF Foundation Stability Calculation Package (Package Number 3.1). The foundation was conservatively assumed to be uniform brown till. Gray till, although present at greater depth, has a greater shear strength that the brown till and is not used in this calculation. Presented on Figure 1 are the geometric and stratigraphic characteristics of the temporary intercell berm as well as the material properties used for the analysis.

The additional resisting force provided by the geosynthetic components of the liner system were neglected in the analysis.

The analysis considers the stability of the intercell berm when subjected to stress associated with the ponding of stormwater runoff in the landfill cell upgradient of the berm from the 25-year, 24-hour storm event. The runoff is assumed to be contained above the primary geomembrane component of the liner system (Figure 2).

Written by: D. Espinoza Date: 96 / 02 / 07 Reviewed by: SQ. Date: 20 / FEB / 96

Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 9.4

RB (DR) 16 FEB 96

Analysis:

The analysis is performed for short term conditions because the loading from the stormwater runoff occurs for only brief time periods after storm events. Therefore, the stormwater runoff is considered to be an additional load applied to the intercell berm.

For foundation stability, the termination points of the circular potential slip surfaces were constrained to exit below the ponded water.

For stability against lateral thrust, the passive resisting force of the material on the opposite side of the intercell berm was ignored. The active lateral force of the contained stormwater is resisted by the length of the potential slip surface and the shear strength along the slip surface.

Results:

Foundation stability factor of safety without water = 3.90;
Foundation stability factor of safety with water = 3.85; and
Lateral thrust factor of safety = 40.

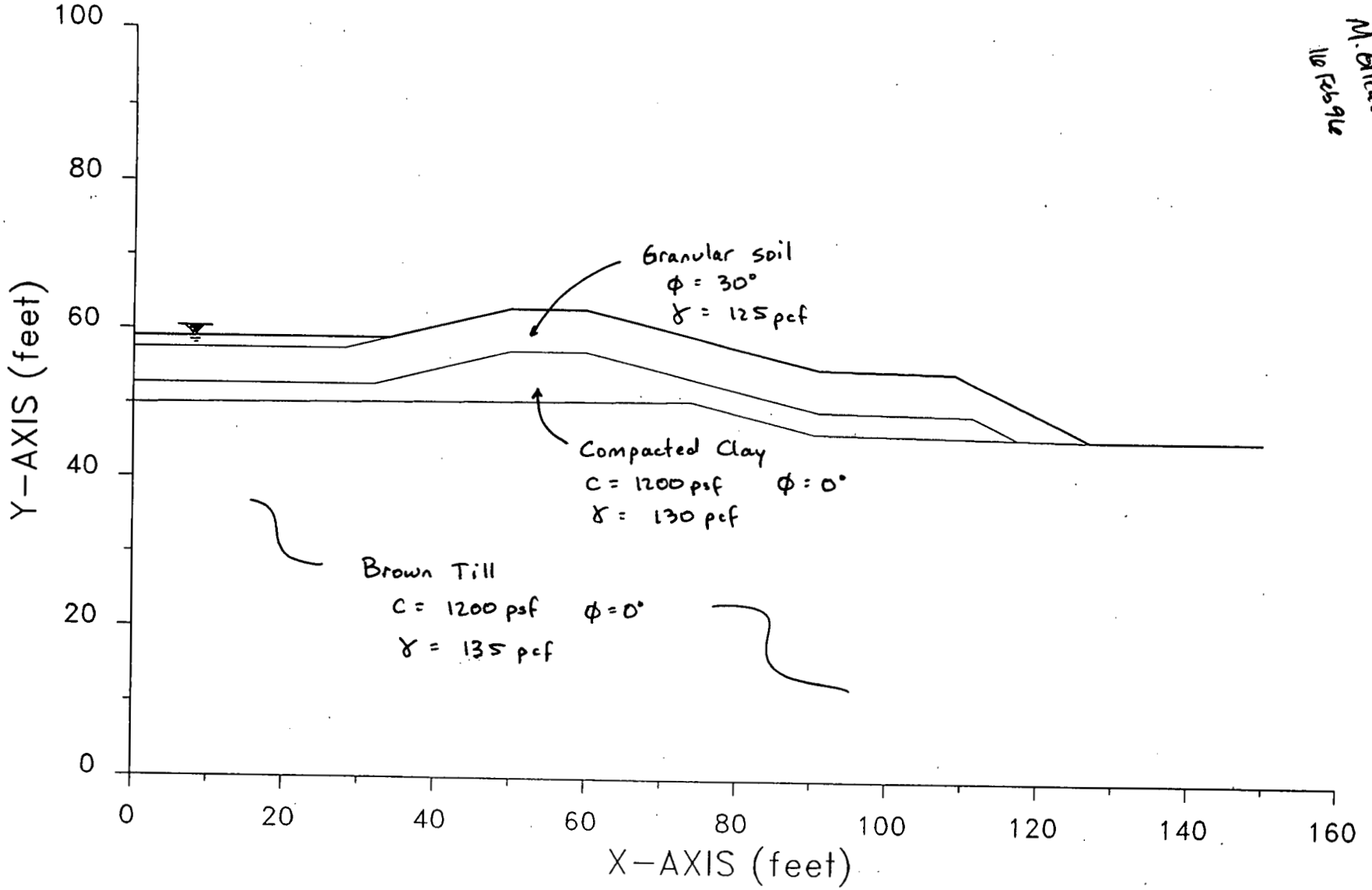
The short-term stability of the intercell berm is adequate (i.e. FS > 1.3).

References:

Bishop, A.W., "The Use of the Slip Circle in the Stability Analysis of Slopes", *Geotechnique*, Vol. 5, 1955, pp. 7-17.

Sharma, S., "*XSTABL: An Integrated Slope Stability Analysis Program for Personal Computers*", Version 5, Interactive Software Designs, Moscow, ID, 1994.

FIGURE 1



M. Bilcasin
16 Feb 96

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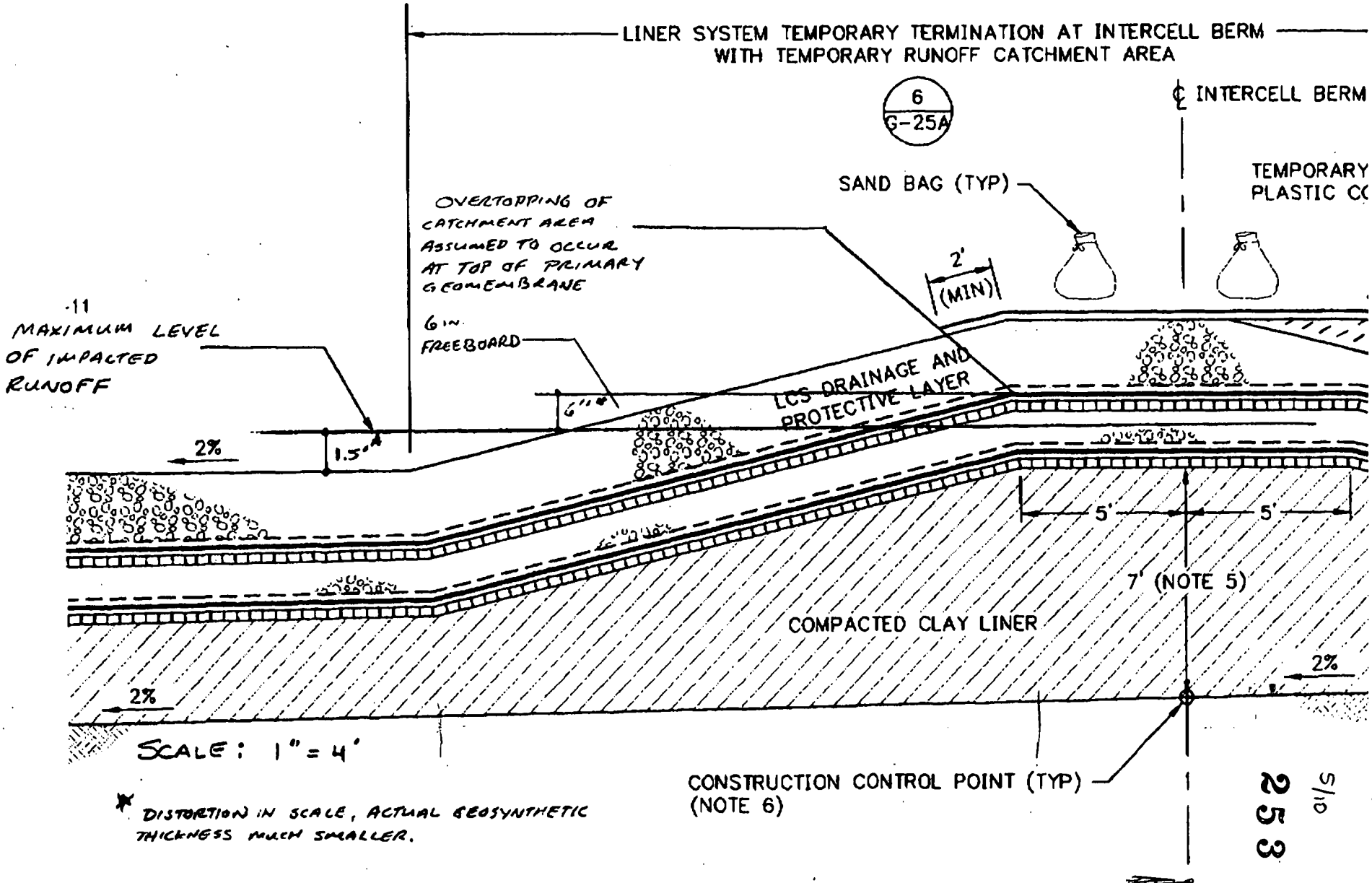
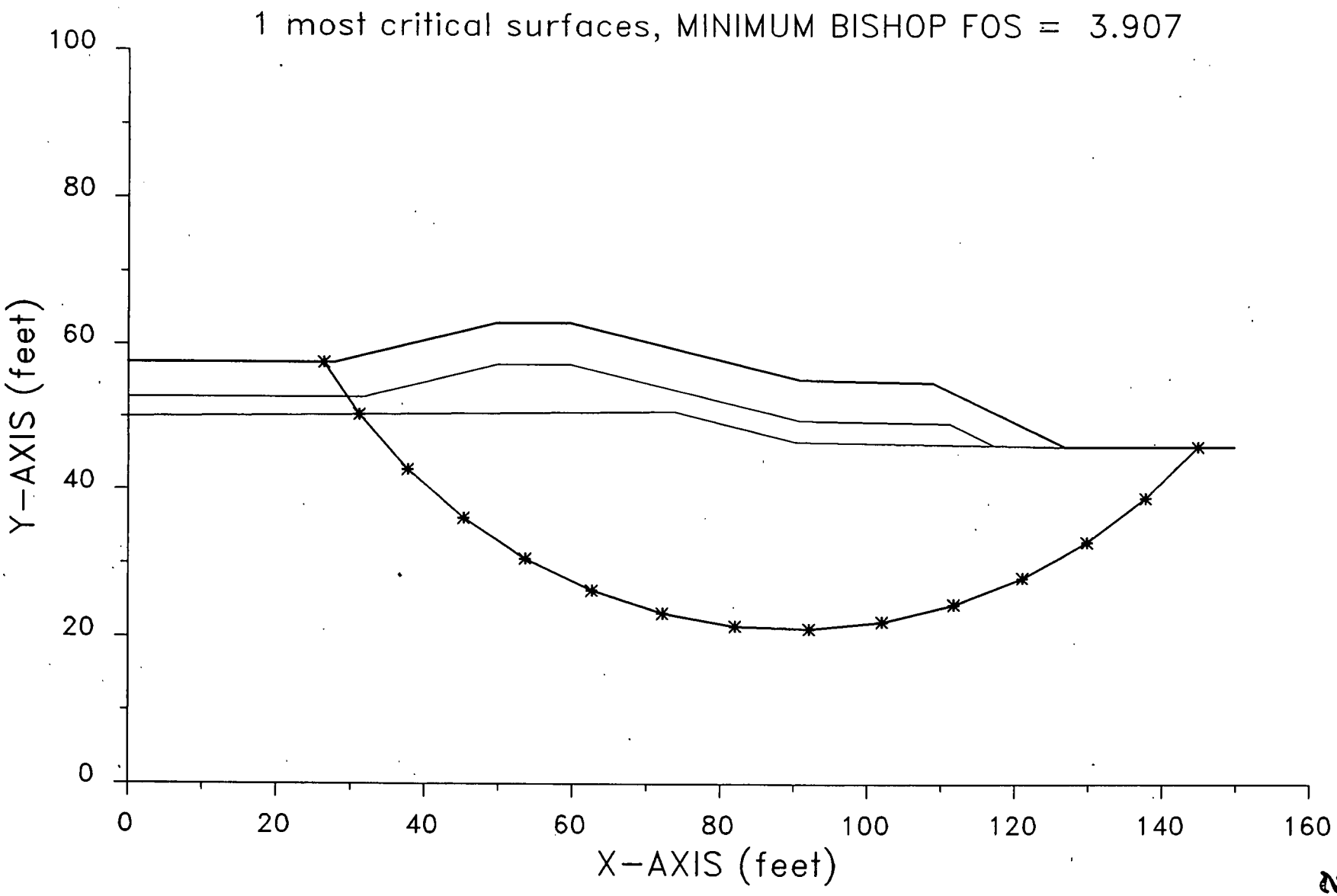
MAXIMUM LEVEL OF IMPACTED RUNOFF FOR CATCHMENT

FIGURE 2



* DISTORTION IN SCALE, ACTUAL GEOSYNTHETIC THICKNESS MUCH SMALLER.

Intercell Berm Stability (no runoff water)



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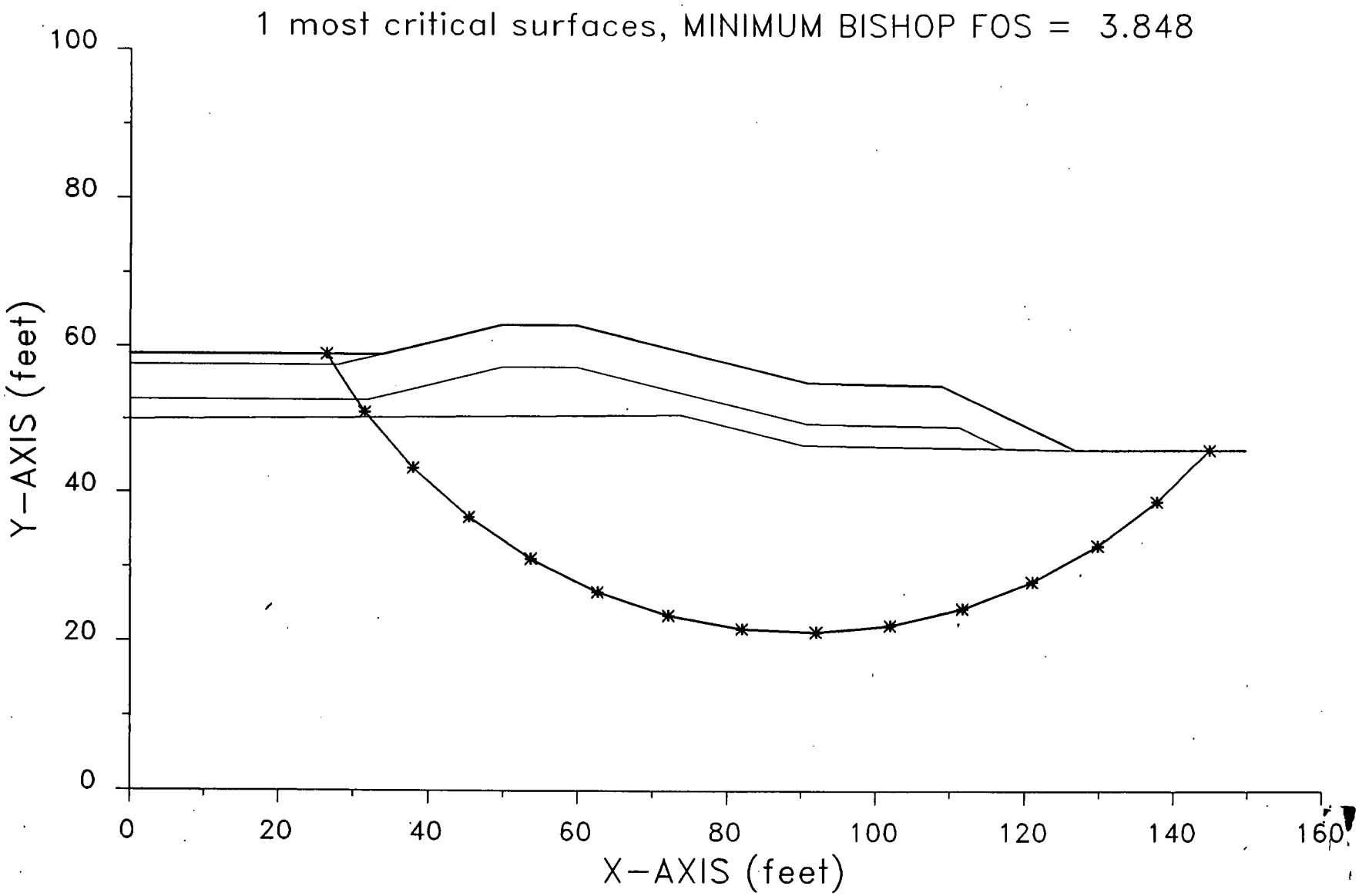
Sq. 20.02.96

Intercell Berm Stability (with runoff water)



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*       Slope Stability Analysis        *
*             using the                 *
*           Method of Slices            *
*                                       *
*        Copyright (C) 1992 - 94        *
*   Interactive Software Designs, Inc.  *
*       Moscow, ID 83843, U.S.A.        *
*                                       *
*         All Rights Reserved           *
*                                       *
*  Ver. 5.100                95 - 1305  *
*****************************************
```

Problem Description : Liner system

SEGMENT BOUNDARY COORDINATES
---

7 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	59.0	34.0	59.0	4
2	34.0	59.0	50.0	63.0	1
3	50.0	63.0	60.0	63.0	1
4	60.0	63.0	91.0	55.2	1
5	91.0	55.2	109.0	54.8	1
6	109.0	54.8	127.0	45.9	1
7	127.0	45.9	150.0	45.9	3

12 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	57.5	28.0	57.5	1
2	28.0	57.5	34.0	59.0	1
3	.0	52.7	32.0	52.7	1
4	32.0	52.7	50.0	57.2	2
5	50.0	57.2	60.0	57.2	2
6	60.0	57.2	91.0	49.5	2
7	91.0	49.5	111.4	49.1	2
8	111.4	49.1	117.4	46.1	2
9	.0	50.0	74.0	50.7	3
10	74.0	50.7	90.4	46.6	3
11	90.4	46.6	117.4	46.1	3
12	117.4	46.1	127.0	45.9	3

ISOTROPIC Soil Parameters
---

4 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	0
2	130.0	130.0	1200.0	.00	.000	.0	0
3	135.0	135.0	1200.0	.00	.000	.0	0
4	62.4	62.4	.0	.00	.000	.0	0

A critical failure surface searching method, using a random technique for generating CIRCULAR surfaces has been specified.

750 trial surfaces will be generated and analyzed.

30 Surfaces initiate from each of 25 points equally spaced along the ground surface between x = 110.0 ft
and x = 145.0 ft

Each surface terminates between x = .0 ft
and x = 28.0 ft

Unless further limitations were imposed, the minimum elevation at which a surface extends is y = .0 ft

10.0 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 := -5.0 degrees

```
*************************************************************
**   Factor of safety calculation for surface #   713    **
**    failed to converge within FIFTY iterations          **
**                                                        **
**   The last calculated value of the FOS was   21.600    **
**   This will be ignored for final summary of results    **
*************************************************************
```

Circular surface (FOS =500.000) is defined by: xcenter = 67.24
ycenter = 293.38 Init. Pt. = 111.46 Seg. Length = 10.00

```
*************************************************************
**   Factor of safety calculation for surface #   716    **
**    failed to converge within FIFTY iterations          **
**                                                        **
**   The last calculated value of the FOS was   21.174    **
```

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```
**    This will be ignored for final summary of results    **
*************************************************************

Circular surface (FOS =500.000) is defined by: xcenter =     67.23
ycenter =    283.84   Init. Pt. =    111.46   Seg. Length =  10.00
-------------------------------------------------------------------

*************************************************************
**     Factor of safety calculation for surface #   724    **
**     failed to converge within FIFTY iterations           **
**                                                          **
**    The last calculated value of the FOS was   21.567     **
**    This will be ignored for final summary of results     **
*************************************************************

Circular surface (FOS =500.000) is defined by: xcenter =     61.69
ycenter =    198.16   Init. Pt. =    110.00   Seg. Length =  10.00
-------------------------------------------------------------------

*************************************************************
**     Factor of safety calculation for surface #   729    **
**     failed to converge within FIFTY iterations           **
**                                                          **
**    The last calculated value of the FOS was   24.924     **
**    This will be ignored for final summary of results     **
*************************************************************

Circular surface (FOS =500.000) is defined by: xcenter =     66.75
ycenter =    328.71   Init. Pt. =    110.00   Seg. Length =  10.00
-------------------------------------------------------------------

*************************************************************
**     Factor of safety calculation for surface #   730    **
**     failed to converge within FIFTY iterations           **
**                                                          **
**    The last calculated value of the FOS was   20.701     **
**    This will be ignored for final summary of results     **
*************************************************************

Circular surface (FOS =500.000) is defined by: xcenter =     61.80
ycenter =    184.39   Init. Pt. =    110.00   Seg. Length =  10.00
-------------------------------------------------------------------

*************************************************************
**     Factor of safety calculation for surface #   739    **
**     failed to converge within FIFTY iterations           **
**                                                          **
**    The last calculated value of the FOS was   24.031     **
**    This will be ignored for final summary of results     **
*************************************************************

Circular surface (FOS =500.000) is defined by: xcenter =     72.61
ycenter =    423.47   Init. Pt. =    110.00   Seg. Length =  10.00
-------------------------------------------------------------------
```

000456

Factors of safety have been calculated by the :

* * * * * SIMPLIFIED BISHOP METHOD * * * * *

The most critical circular failure surface
is specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	145.00	45.90
2	137.88	38.88
3	129.86	32.90
4	121.10	28.07
5	111.77	24.49
6	102.03	22.22
7	92.07	21.30
8	82.08	21.75
9	72.25	23.56
10	62.75	26.70
11	53.78	31.11
12	45.49	36.70
13	38.04	43.37
14	31.58	51.00
15	26.50	59.00

**** Simplified BISHOP FOS = 3.848 ****

```
*********************************************************************
**                                                                 **
**  Out of the    750 surfaces generated and analyzed by XSTABL,   **
**        6 surfaces were found to have MISLEADING FOS values.     **
**                                                                 **
*********************************************************************
```

The following is a summary of the TEN most critical surfaces

Problem Description : Liner system

	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.	3.848	90.35	94.23	72.96	145.00	26.50	1.148E+07
2.	3.917	89.76	96.95	75.21	145.00	24.85	1.188E+07
3.	3.933	88.99	93.34	71.20	142.08	26.81	1.092E+07
4.	3.950	89.11	94.88	72.15	142.08	26.71	1.101E+07
5.	3.972	88.48	94.86	73.69	143.54	24.14	1.166E+07
6.	4.019	88.38	97.69	75.67	143.54	23.36	1.192E+07
7.	4.026	87.47	91.71	69.08	139.17	26.79	1.033E+07
8.	4.031	90.60	102.21	76.30	142.08	27.75	1.131E+07
9.	4.040	87.50	94.23	71.82	140.63	25.12	1.095E+07
10.	4.041	88.66	99.87	75.94	142.08	24.84	1.152E+07

* * * END OF FILE * * *

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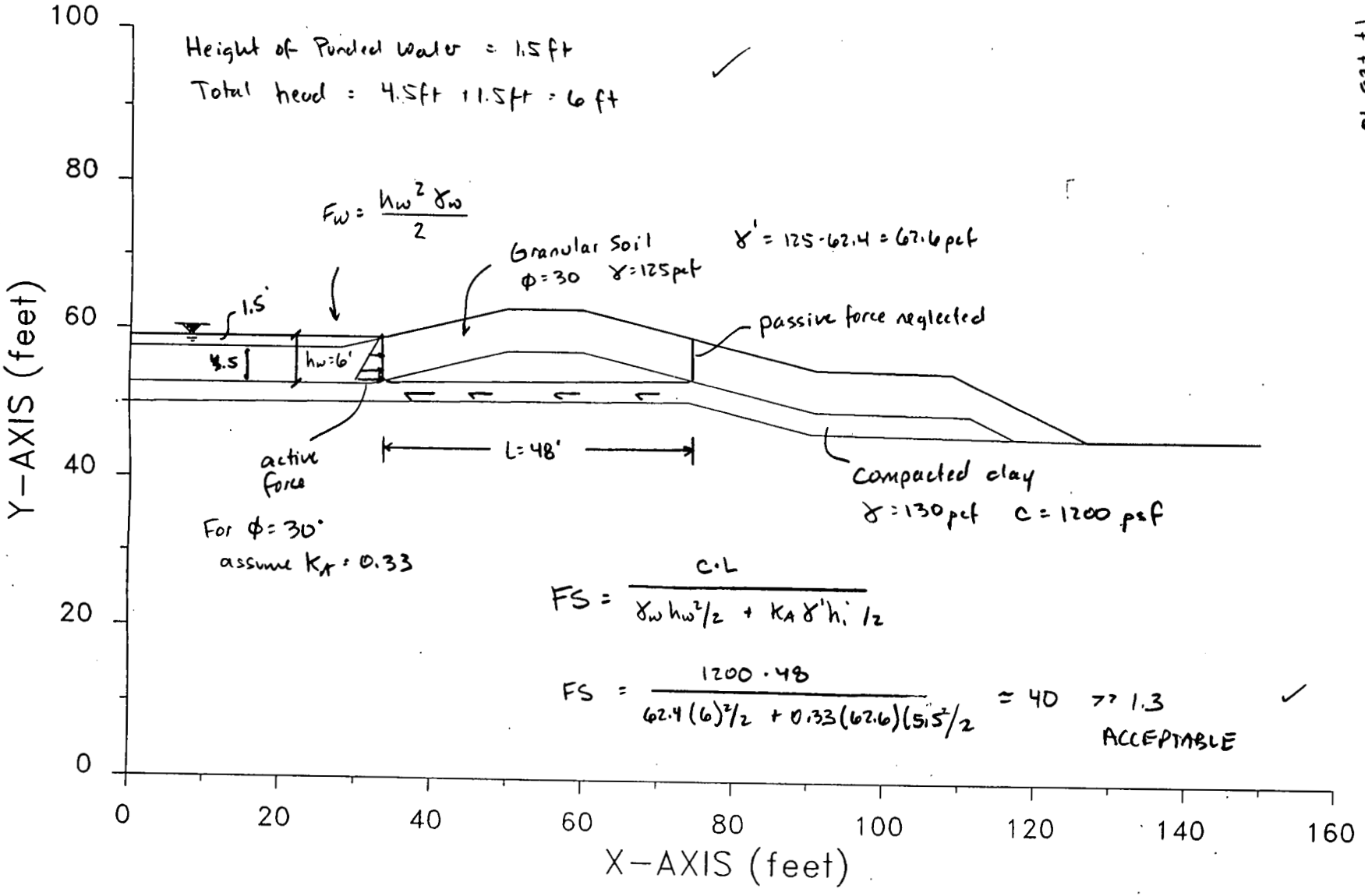
Sa. 10.02.96

LATERAL STABILITY CALCULATION

M. Gleason
17 Feb 96

Height of Ponded Water = 1.5 ft

Total head = 4.5 ft + 1.5 ft = 6 ft



$$FS = \frac{c \cdot L}{\gamma_w h_w^2/2 + K_A \gamma' h_i^2/2}$$

$$FS = \frac{1200 \cdot 48}{62.4(6)^2/2 + 0.33(62.6)(5.5^2/2} \approx 40 \gg 1.3$$

ACCEPTABLE

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SB. 20.02.96

000157

3.5 Final Cover System

COMPUTATION COVER SHEET

SUBJECT OF CALCULATION: FINAL COVER SYSTEM

Computations By: (Cognizant Engineer)
Signature: Mark H. Gleason — Date: 17 Feb 96
Printed Name and Title: MARK H. GLEASON, Assistant Project Engineer

Assumptions and Procedures Checked by: (Checker)
Signature: Saad Qureshi — Date: 20 FEB '96
Printed Name and Title: SAAD QURESHI, PROJECT ENGINEER

Computations Checked by:
Signature: Saad Qureshi — Date: 20 Feb '96
Printed Name and Title: SAAD QURESHI, PROJECT ENGINEER

Computations Backchecked by: (Cognizant Engineer)
Signature: Mark H. Gleason — Date: 20 Feb 96
Printed Name and Title: MARK H. GLEASON, Assistant Project Engineer

Approved by: (PDP)
Signature: Mark H. Gleason — Date: 20 Feb 96
Printed Name and Title: MARK H. GLEASON, Assistant Project Engineer

Approved by: (DTL and TETL)
Signature: Rudolph Bonaparte — Date: 22 FEB 96
Printed Name and Title: Rudolph Bonaparte, Principal (DTL)

Record of Revision (Number and initial all revisions)

NO.	REASON	DATE	BY	CHECKED	APPROVAL
C	Intermediate Design				
D	IDP-EPA Submittal	3 Apr 96			

Signature: _____
Number: _____
Registration Stamp (if applicable)

GE3900-09.7/F9530022.CD

Written by: M. Gleason Date: 96/2/17 Reviewed by: SQ Date: 20/Feb/96

Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 9.7

COVER SYSTEM STABILITY

EXECUTIVE SUMMARY

Purpose

The purpose of this calculation package is to evaluate the minimum static slope stability factor of safety of the final cover system for the On-Site Disposal Facility (OSDF) and to compare the calculated value with the minimum accepted value.

Procedure

Provided in this package are the analyses of final cover system static slope stability for potential slip surfaces that pass along interfaces within the final cover system. The conditions considered are: (i) final cover system for short-term stability at 6H:1V inclination; (ii) final cover system for long-term stability at 6H:1V and 5H:1V slope inclinations.

The minimum acceptable factors of safety based on the UMTRA Technical Approach Document (DOE, 1989) are: (i) long-term stability of final cover system, FS $\geq$ 1.5; and (ii) short-term stability of final cover system, FS $\geq$ 1.3. The stability analyses are performed using established geotechnical procedures for calculating veneer stability.

Results for Final Cover System Stability

Case	Factor of Safety	
· 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

Based on the calculations presented in this document, the static slope stability for both short-term and long-term conditions for the final cover system must meet the minimum acceptable value established in DOE (1989). A final cover system with a 5H:1V slope does not meet this minimum acceptable factor of safety requirement.

FINAL COVER SYSTEM

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3.	Analysis	2/11

Written by: M. Gleason Date: 96/2/17 Reviewed by: SQ. Date: 20/Feb/96

Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 9.7

RB (DTL) 18 FEB96

COVER SYSTEM STABILITY

CALCULATION PACKAGE

Purpose: The purpose of this document is to provide the engineering calculations to evaluate the static slope stability factor of safety for the OSDF final cover system (Figure 1). The calculations provide an analysis of the stability of the final cover system for potential slip surfaces that pass along the critical interfaces that exist within the system.

Procedure: The calculation procedure for the final cover system stability analysis is described in 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 slope stability of the final cover system is calculated using the methods described in Giroud, et al. 1995a and 1995b.

Final Cover System

The final cover system will be constructed over the entire OSDF. The maximum slope inclination for the final cover system is 6H:1V. For the analysis, a maximum continuous slope height is assumed to be 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 establish that a 5H:1V slope does not satisfy minimum stability requirements).

Analysis:

Use the following equation adapted from Giroud et al. 1995a and 1995b:

$$FS = \frac{\gamma_t (t - t_w) + \gamma_b t_w}{\gamma_t (t - t_w) + \gamma_{sat} t_w} \frac{\tan\delta}{\tan\beta} + \frac{a/\sin\beta}{\gamma_t (t - t_w) + \gamma_{sat} t_w}$$

$$+ \frac{\gamma_t (t - t_w^*) + \gamma_b t_w}{\gamma_t (t - t_w) + \gamma_{sat} t_w} \frac{t}{h} \frac{\sin\phi}{2 \sin\beta \cos\beta \cos(\beta + \phi)}$$

$$+ \frac{c\, t/h}{\gamma_t (t - t_w) + \gamma_{sat} t_w} \frac{\cos\phi}{\sin\beta \cos(\beta + \phi)} \frac{T/h}{\gamma_t (t - t_w) + \gamma_{sat} t_w}$$

Written by: M. Gleason Date: 96 / 2 /17 Reviewed by: SG. Date: 20 /Feb/ 96

Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 9.7

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COVER SYSTEM STABILITY

where:

FS = Factor of Safety
γ_t = total unit weight of soil (pcf)
γ_{sat} = saturated unit weight of soil (pcf)
γ_b = buoyant 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:

$$FS = \frac{\gamma_t (t - t_w) + \gamma_b t_w}{\gamma_t (t - t_w + \gamma_{sat} t_w} \frac{\tan \delta}{\tan \beta}$$

$$+ \frac{\gamma_t (t - t_w^*) + \gamma_b t_w}{\gamma_t (t - t_w) + \gamma_{sat} t_w} \frac{t}{h} \frac{\sin \phi}{2 \sin\beta \cos\beta \cos(\beta + \phi)}$$

Data for Analysis:

Presented below are the components and the interfaces present in the final cover system, as indicated in Figure 1. Assumptions are made regarding the shear strengths of these materials and interfaces to evaluate which material or interface is most critical in terms of shear strength for the slope stability analysis. A more detailed discussion regarding selection of these material properties is provided in the Data Verification Section of the other calculations.

Written by: M. Gleason Date: 96/2/17 Reviewed by: SQ. Date: 20/Feb/96

Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 9.7

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COVER SYSTEM STABILITY

Interface/Material	Properties	Reference
Contouring layer (compacted fill)	Assume ML/SM Material γ_t = 130pcf ϕ_{min} = 30°	Reference 2
Compacted clay cap	γ_t = 130pcf compacted ϕ = 23-29° c = 100-400psf For analysis use ϕ = 25° c = 0	Reference 3 Table 4-9
GCL internal shear strength and/or GCL/HDPE geomembrane interface shear strength		Reference 5
long-term: Hydrated bentonite, no effect on GCL reinforcement	ϕ dependent on σ_n For cover system σ_n = 950psf ϕ_{peak} = 15° $\phi_{large\ displacement}$ = 13° Fig 3	
short-term: Hydrated reinforced GCL or non-hydrated geomembrane-protected GCL (i.e., Gundseal)	Reinforced GCL $\phi_p = 2\phi_p$ unreinforced - at low σ_n ϕ_p = 30° Dry GCL ϕ_p = 25° dry $\tan\delta/\tan\phi$ = 0.8 δ = 20°	
Geotextile/textured HDPE geomembrane interface	Assume lowest δ_p = 25° under low normal stress	Reference 4
Granular soil - drainage gravel, biointrusion barrier, granular filter, vegetative soil layer, topsoil	Assume γ_t = 125pcf Assume ϕ_{min} = 30°	Reference 4
Geotextile/granular soil interface	$\tan\delta/\tan\phi$ = 0.8 δ_{min} = 25° for ϕ = 30°	Reference 4
Geotextile/compacted clay interface	For ϕ_{clay} = 25° $\tan\delta/\tan\phi$ = 0.8 δ = 20°	Reference 4

Written by: M. Gleason Date: 96/2/17 Reviewed by: SQ. Date: 20/Feb/96

Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 9.7

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COVER SYSTEM STABILITY

From the analysis presented in the previous section, the interfaces presented below are considered to be critical for this slope stability analysis.

- The critical interface for short-term final cover system stability is either:
  - interface shear strength of dry GCL/HDPE geomembrane interface (assuming Gundseal type product used) without hydraulic head (head acts on geomembrane, not GCL); or
  - interface shear strength of geotextile/HDPE geomembrane interface with 0.5 ft of hydraulic head.
- The critical interface shear strength for the final cover system stability for long-term conditions is the shear strength of the hydrated bentonite component of the GCL. For long-term conditions, the bentonite component of the GCL (either reinforced or unreinforced) is assumed to be hydrated and any reinforcement is not effective. In addition, for long-term conditions, assume that the HDPE geomembrane is not intact, and a maximum hydraulic head of 0.5 ft acts on the GCL.

Based on analyses performed by GeoSyntec in the Cover System Performance Calculation Package, assume that the maximum hydraulic head in the final cover system is 0.5 ft.

Minimum Acceptable Factors of Safety Based on UMTRA Technical Approach Document (DOE, 1989) Ref. 6

For Final Cover System

Long-Term Stability	FS $\geq$ 1.5
Short-Term Stability	FS $\geq$ 1.3

Written by: M. Gleason Date: 96/2/17 Reviewed by: SQ. Date: 20/Feb/96

Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 9.7

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COVER SYSTEM STABILITY

Parameters for Design

Final Cover System

$\gamma_t = \gamma_{sat} = 125$ pcf

$\gamma_b = 62.6$ pcf

$\phi = 30°$

$t = 6.8$

$t_w = 0.5$ ft (Assumed)

$t_w^* = 3.4$ ft (Assumed)

$\beta = 9.5°$ (6H:1V) [or 11.3° (5H:1V)]

$h = 60$ ft max

δ = Variable with case

Final Cover System Stability

Short-Term Stability

Case A Dry GCL/HDPE geomembrane interface $\delta = 20°$
For this case, tw = 0, tw* = 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 Reinforced GCL/HDPE geomembrane interface with $\delta = 25°$, tw = 0.5 ft, tw* = 3.4 ft

$$FS = \frac{125(6.8-0.5) + 62.6(0.5)}{125(6.8-0.5) + 125(0.5)} \frac{\tan 25}{\tan 9.5}$$

Written by: M. Gleason Date: 96/2/17 Reviewed by: SQ. Date: 20/Feb/96

Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 9.7

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COVER SYSTEM STABILITY

$$+ \frac{125(6.8-3.4) + 62.6(3.4)}{125(6.8-0.5) + 125(0.5)} \frac{6.8}{60} \frac{\sin 30}{2\sin 9.5 \cos 9.5 \cos(39.5)}$$

FS = 2.68 + 0.07 = 2.7 acceptable

Final cover system is stable in short term.

Written by: M. Gleason Date: 96/2/17 Reviewed by: SQ. Date: 20/Feb/96

Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 9.7

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COVER SYSTEM STABILITY

Long-Term Stability - Hydrated GCL

6H:1V Slope

tw = 0.5 tw* = 3.4 δ = 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 δ = 13°

FS = 1.33 + 0.07 = 1.4 acceptable

5H:1V Slope

tw = 0.5 tw* = 3.4 δ = 15° peak β = 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: 96/2/17 Reviewed by: SQ. Date: 20/Feb/'96

Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 9.7

RB (DTL) 18 FEB 96

COVER SYSTEM STABILITY

REFERENCES

1. FERMCO, *On-Site Disposal Facility Statement of Work*, June ~~1005~~ 1995 MHB.

2. Holtz, R.P., 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 Unite 2, Project Order 132, July 1995 by Parsons, Fairfield Executive Center, 6120 South Gilmore Road, Fairfield, Ohio 45014.

4. Data established from:

   - 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, po. 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. Bonaparte, R., Othman, M.A., Rad, N.R., Swan, R.H., Vander Linde, D.L., "Evaluation of Various Aspects of GCL Performance," *Proceedings, Geosynthetic Clay Liner Workshop,* U.S. Environmental Protection Agency, Ohio, August, 1995, in press.

6. U.S. Department of Energy, *"Uranium Mini Tailings Remediation Control Act, Remedial Action Design"*, Technical Approach Document, Revision II, December 1989.

7. Giroud, J.P., Williams, N.D., Pelte, T., and Beech, J.F., "Stability of Geosynthetic - Soil Layered Systems on Slopes," Industrial Fabrics Association International, *Geosynthetics International*, Vol. 2, No. 6, St. Paul, MN, pp. 1115-1148.

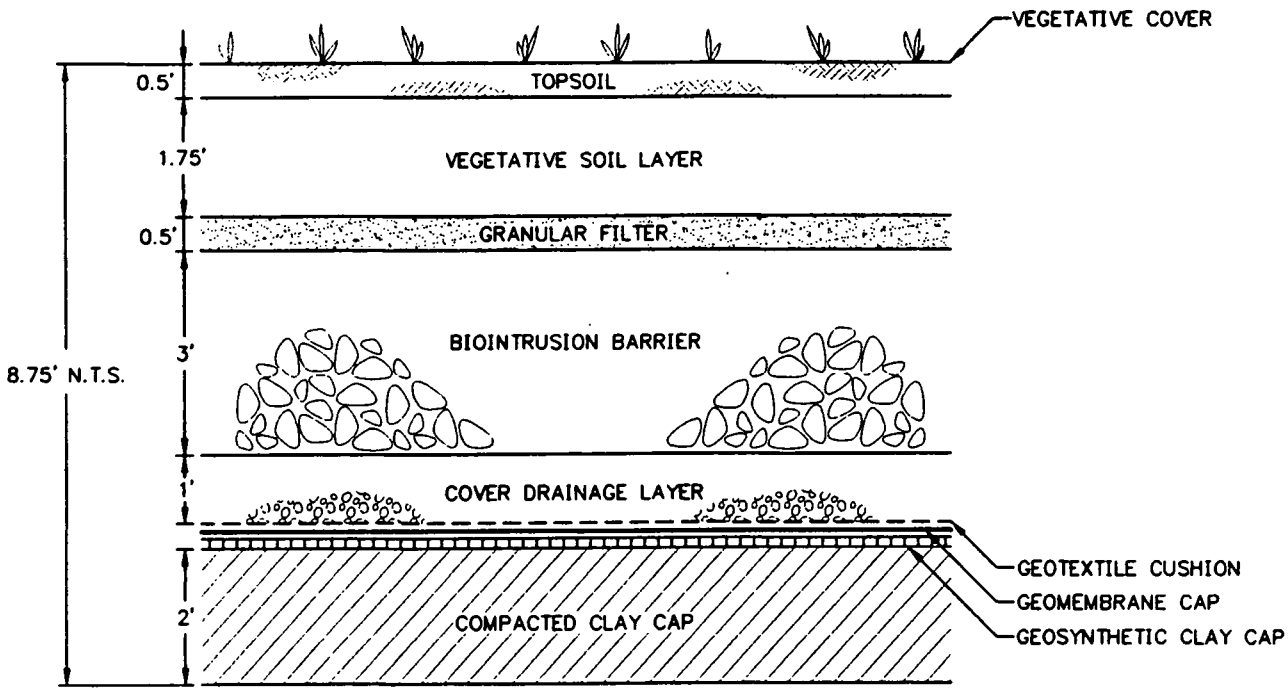
8. Giroud, J.P., Bachus, R.C., and Bonaparte, R., "Influence of Water Flow on the Stability of Geosynthetic - Soil Layered Systems on Slopes," Industrial Fabrics Association International, *Geosynthetics International,* Vol. 2, No. 6, St. Paul, MN, pp. 1149-1180.

Written By: M. GLEASON Date: 96/2/17 Reviewed by: SQ. Date: 20 Feb '96

Client: FERMILO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.7

RB DR 18 FEB 96

FIGURE 1



FINAL COVER SYSTEM

M. Gleason 17 Feb 96

RB(DTL) 18 FEB 96

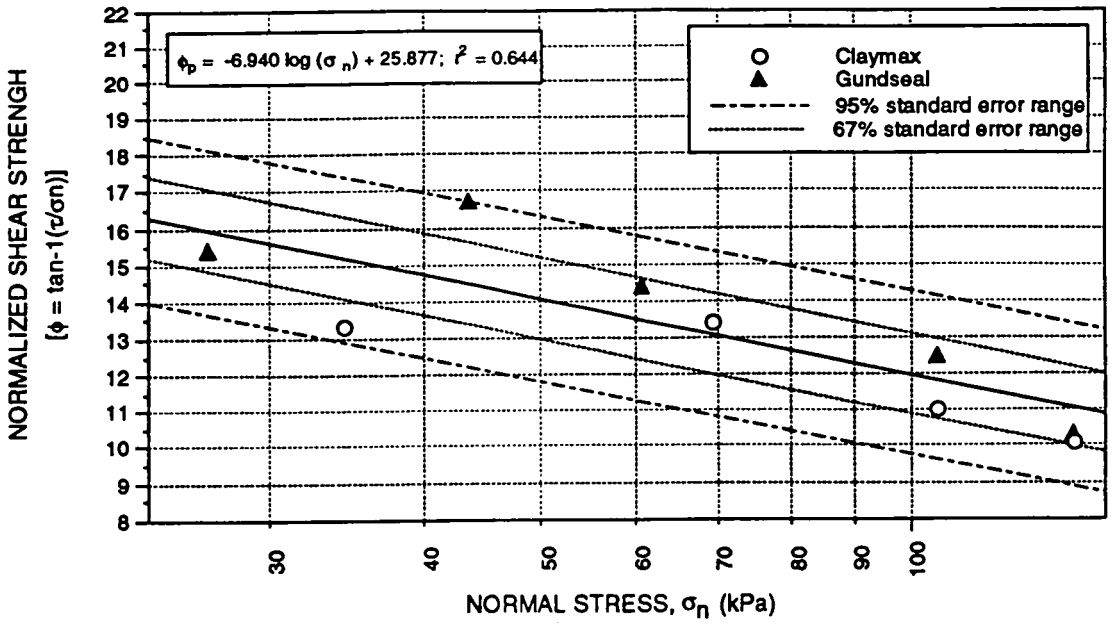


Figure 4. Log-linear regression analysis for peak CD conditions.

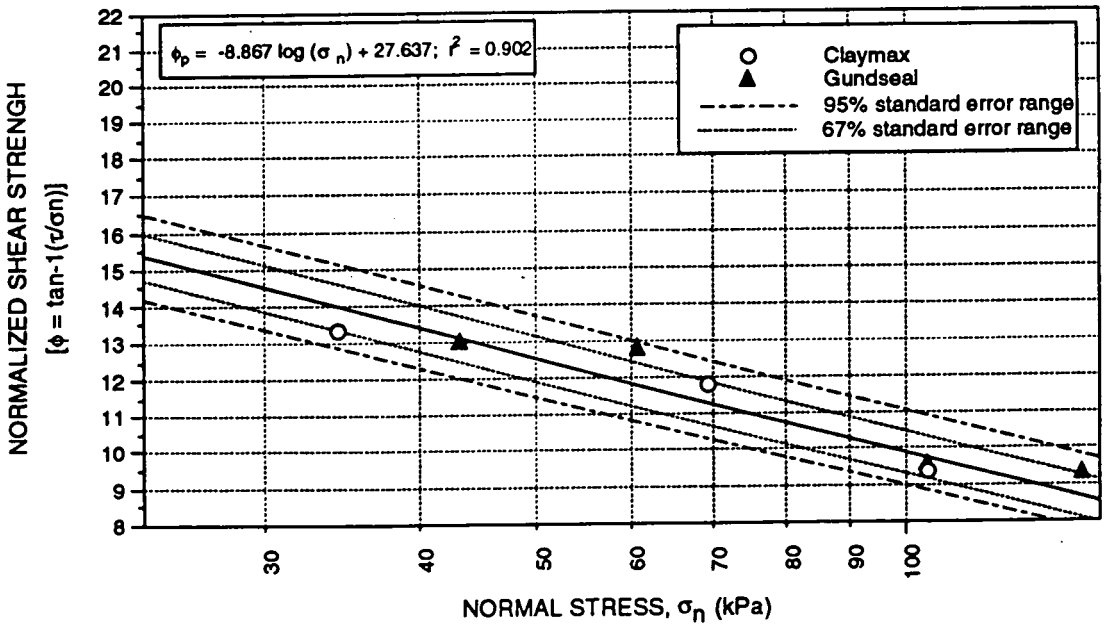


Figure 5. Log-linear regression analysis for large-displacement CD conditions. From Bonaparte et al (1996).

3.6 Access Corridor

COMPUTATION COVER SHEET

SUBJECT OF CALCULATION: ACCESS CORRIDOR

Computations By: (Cognizant Engineer)
Signature: [signature] Date: 2/16/96
Printed Name and Title: R. David Espinoza, Assistant Project Engineer

Assumptions and Procedures Checked by: (Checker)
Signature: [signature] Date: 20 Feb '96
Printed Name and Title: SAAD QURESHI, PROJECT ENGINEER

Computations Checked by:
Signature: [signature] Date: 20 Feb '96
Printed Name and Title: SAAD QURESHI, PROJECT ENGINEER

Computations Backchecked by: (Cognizant Engineer)
Signature: [signature] Date: 2/20/96
Printed Name and Title: R. David Espinoza, Assistant Project Engineer

Approved by: (PDP)
Signature: Mark H. Gleason Date: 20 Feb 96
Printed Name and Title: MARK H. GLEASON, Assistant Project Engineer

Approved by: (DTL and TETL)
Signature: Rudolph Bonaparte Date: 22 FEB 96
Printed Name and Title: Rudolph Bonaparte, Principal (DTL)

Record of Revision (Number and initial all revisions)

NO.	REASON	DATE	BY	CHECKED	APPROVAL
C	Intermediate Design				
D	IDP - EPA Submittal	3 Apr 96	[illegible]		

Signature: _____
Number: _____
Registration Stamp (if applicable)

GE3900-09.4/F9530025.CD

Written by: D. Espinoza Date: 96 / 02 / 08 Reviewed by: SQ. Date: 20 / Feb / 96

Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 09.4

ACCESS CORRIDOR STABILITY

EXECUTIVE SUMMARY

Purpose:

These calculations are performed to evaluate the minimum static slope stability factor of safety for the access corridor. The analysis is performed for short-term and long-term conditions.

Procedure:

Stability is evaluated by calculating the minimum factor of safety of access corridor slope using the 2-dimensional limit equilibrium analysis chart solutions presented by Duncan et. al (1987).

Data Verification:

The following information is developed for this calculation package: (i) the cross section used for the analysis ~~are~~ is obtained from the Construction Drawings and is interpreted to represent the location with the largest volume of fill; (ii) an estimate of the potential traffic load on the top of the access corridor; (iii) appropriate shear strength of the corridor material (i.e. compacted brown till) and underlying foundation material (i.e. in-situ brown till) based on the data verification section presented in the Foundation Stability calculation package; and (iv) the effect of the perched ground-water table on the stability analysis.

The computed minimum factor of safety is compared to the target value of factor of safety given in the Design Criteria Package (i.e. 1.3 for short-term conditions and 1.5 for long-term conditions). The slope stability of the access corridor is considered to be adequate if the calculated minimum factor of safety is equal to or greater than the target value.

Conclusions:

The calculated minimum factor of safety for short-term conditions is 4.1. The calculated factor of safety for long-term conditions is 2.8. Each of these values exceed the target value of 1.3.

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The factor of safety for the access corridor is considered to be acceptable based on the variability of the foundation stratigraphy, and the considered effect of the perched groundwater table.

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ACCESS CORRIDOR

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Written by: D. Espinoza Date: 96 / 02 / 08 Reviewed by: SQ. Date: 20 / Feb / 96

Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 09.4
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Access Corridor Stability

Purpose:

These calculations are performed to evaluate the minimum static slope stability factor of safety for the access corridor. The analysis is performed for short-term and long-term conditions.

Procedure:

The slope stability of the access corridor slope is evaluated by calculating the minimum factor of safety using the 2-dimensional limit equilibrium analysis chart solutions presented by Duncan et. al (1987).

Data Verification:

The access corridor is located on the perimeter of the OSDF and supports a roadway. The access corridor is designed to be stable at the end of construction and to remain stable thereafter. Stability of the access corridor is assessed by considering potential slip surfaces that pass through the access corridor material. A factor of safety for slope stability is calculated for the critical potential slip surface. The design is acceptable if the factor of safety exceeds the designated target value. Both short-term (end of construction) and long-term conditions are considered. The target value of factor of safety given in the Design Criteria Package is 1.3 for short-term conditions and 1.5 for long-term conditions. The main issues to be considered in the analysis are:

- Geometry of the access corridor;
- Physical properties of the access corridor and foundation materials; and
- pore pressures within the access corridor.

Geometry:

The geometry of the access corridor was obtained from the Construction Drawings. The slopes of the embankment are a maximum 6H:1V. The maximum height of the access corridor is 10 ft. A surcharge, applied by maintenance vehicles is assumed to be 250 psf. These factors are identified in Figure 1.

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Material Parameters:

The shear strength and unit weight of access corridor material and foundation soils are considered for both short-term (end of construction) and long-term conditions. The material properties are assumed based on the information presented by (Parsons, 1995), and as interpreted in the foundation stability calculation package (GeoSyntec Doc. No. F9530020.CDO).

The access corridor fill material is assumed to be recompacted brown till (i.e., compacted clay). Based on the analysis and interpretations provided in the foundation stability calculation package (GeoSyntec Doc. No. F9530020.CDO), the appropriate shear strength parameters for the compacted clay are as follows:

End of construction: $\phi=0$ and $c=1200$ psf (total stress conditions)
Long-term: $\phi=25^{\circ}$ and $c=0$ psf (effective stress conditions)

From the same document, an appropriate value of total unit weight is $\gamma=135$ pcf.

Based on the analysis and interpretation referenced above, the foundation material is a natural brown till that will underlie the access corridor to a depth of approximately 15 ft. The natural brown till is underlain by a stronger gray till. For the purpose of this analysis, the foundation is conservatively assumed to consist of all brown till. The shear strengths of the natural brown till are assumed to be the same as for the compacted clay. The unit weight of brown till is assumed to be 135 pcf.

Pore Pressures:

For short-term conditions the classical assumption that pore pressure effects are accounted for in selected values of undrained shear strength is 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 access corridor materials. The top of the perched ground water table is assumed to be consistent with the original ground surface. This assumption is supported by site information, as summarized in "Hydrostatic Forces" calculation package (GeoSyntec Document No. F9530014.CDO).

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Procedures:

The following procedures are followed for the calculation of the access corridor stability:

1. The most critical case for access corridor stability involves the highest and steepest access corridor slope. This statement implicitly assumes that both foundation and access corridor materials are relatively uniform throughout the OSDF. The critical cross section is selected based on the Construction Drawings. All slopes are inclined at 6H:1V. Hence, steepness is not a factor in the selection of the critical location. The maximum slope height is H=10 ft.

2. Surcharge and pore pressure distributions for access corridor are selected. A surcharge (q) equal to 250 psf is assumed (Figure 1). This load corresponds to the minimum surcharge recommended by AASHTO to represent traffic loading for retaining wall design (AASHTO, 1992). This assumption is appropriate for this calculation because only traffic associated with maintenance is expected on the access corridor.
   For short-term conditions, the classical assumption that pore pressure effects are accounted for in selected values of undrained shear strength is appropriate. 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 access corridor materials. The top of the perched ground water table is assumed to be consistent with the original ground surface.

3. For calculation of the critical factor of safety for short- and long-term conditions the methodology and chart solutions provided by Duncan et. al . (1987) are used. This reference provides solutions for a range of conditions which encompass the conditions of concern herein.

   The geometry, stratigraphy, and material properties presented in the data verification section of this calculation are used.

<u>End of Construction:</u>

The methodology followed in the calculation of the factor of safety for $\phi=0$ soils is described by Duncan et al. (1987). The factor of safety is computed as:

$$F_s = \left(\frac{cN_c}{P_d}\right)$$

$$\text{with} \quad P_d = \frac{\gamma\ H + q - \gamma_w\ H_w}{\mu_q\ \mu_w\ \mu_t}$$

where N_c =5.53 is obtained from Figure 2, using slope inclination, β, =9.46 (6H:1V), depth, d =∞, soil cohesion, c=1200 psf, slope height, H =10 ft, submerged slope height, H_w=0, the traffic surcharge, q=250, the soil unit weight, γ=135 pcf, the water unit weight, γ_w=62.4 pcf. The surcharge reduction factor, μ_q=1, is obtained from Figure 3a. Seepage and tension cracks are assumed to have no effect on the stability of the access corridor. The submergence reduction factor, μ_w, and the tension crack reduction factor, μ_t, obtained from Figure 3b, are equal to unity. For the values shown, P_d and the factor of safety is:

$$P_d = \frac{(135)\ (10) + 250 - 62.4(0)}{(1)(1)(1)} = 1600$$

$$F_s = \left(\frac{(1200)(5.53)}{1600}\right) = 4.1$$

Long-Term Analysis

The methodology followed in the calculation of the factor of safety for ϕ>0 soils is described by Duncan et al. (1987). For the case of c=0, the factor of safety is computed by:

$$F_s = \left(\frac{P_e}{P_d}\right)\left(\frac{\tan\phi}{\tan\beta}\right)$$

where P_d is the same as the end of construction case and P_e is given by

$$P_e = \frac{\gamma\ H + q - \gamma_w\ H'_w}{\mu_q\ \mu'_w}$$

H=10 ft, γ = 135pcf, q = 250pcf, and the height of water within the slope, H'_w = 0. As for the undrained case, the seepage correction factor, μ'_w=1 and μ_q=1, thus P_e = 1600psf = P_d.

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Thus, the factor of safety is given by:

$$F_s = \left(\frac{\tan 25}{1/6}\right) = 2.8$$

Summary:

The target critical factors of safety for the access corridor are 1.3 for end of construction (i.e., short-term) and 1.5 for long-term conditions.

The calculated critical factors of safety must be equal to or greater than target values to establish adequate stability. The calculated factor of safety are:

End of construction:	Fs = 4.1 > 1.3 (acceptable)	(undrained conditions)
Long term	Fs = 2.8 > 1.5 (acceptable)	(drained conditions)

The stability is adequate for both cases.

References:

AASHTO, "*Standard Specifications for Highway Bridges,*" 15th edition, Art 3.203, 1992.

Duncan J.M., Buchignani, A.L. and De Wet, M., "*An Engineering Manual for Slope Stability Studies,*" Department of Civil Engineering, Virginia Polytech and State University, 1987.

Parsons, "*Disposal Facility Pre-Design Geotechnical Investigations,*" Soil Investigation Data Report, Operable Unit 2, Project Order 32, 1995.

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Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.4

ACCESS CORRIDOR STABILITY

Short-Term Conditions $\phi = 0$ analysis

$$FS = \frac{N_o C}{P_d} \qquad P_d = \frac{\gamma H + q - \gamma_w H_w}{\mu_g \mu_w \mu_t}$$

H = slope height	=	10 ft	
C = cohesion	=	1200 psf	
γ = unit weight	=	135 pcf	
q = surcharge	=	0 psf	
H_w = submerged slope height	=	0 ft	
γ_w = unit weight of water	=	62.4 pcf	
μ_g = surcharge reduction factor	=	1.0	Fig 3
μ_w = submergance reduction factor	=	1.0	Fig 3
μ_t = tension crack	=	1.0	(no tension crack)

$$\beta = \tan^{-1}(1/6) = 9.46° \rightarrow N_o = 5.53$$

$$P_d = (135(10) + 250 - 0(62.4))/1 = 1{,}600 \text{ psf}$$

$$FS = \frac{(5.53)(1{,}200 \text{ psf})}{1{,}600 \text{ psf}} = 4.1$$

FS > 1.3 SLOPE IS ACCEPTABLE

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ASSESS CORRIDOR STABILITY

LONG TERM CONDITIONS

USE Methodology from Ref 2.

$$FS = \frac{P_e}{P_d} \frac{\tan\phi}{\tan\beta}$$

where P_d = 1600 psf (from short term conditions)

$$P_e = \frac{\gamma H + q - \gamma_w H_w'}{\mu_g \ \mu_w'}$$

$H = 10$ ft $\quad \gamma = 135$ pcf $\quad q = 250$ psf

$H_w' = 0 \quad \mu_w' = 1 \quad \mu_q = 1.0$

$$P_e = \frac{135(10) + 250 - 0}{1} = 1{,}600 \text{ psf}$$

$\tan\beta = 1/6 \qquad \phi = 25$

$$FS = \frac{1{,}600}{1{,}600}\left(\frac{\tan 25}{1/6}\right) = 2.8$$

$FS > 1.5$ - slope is acceptable.

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Client: FERMCO Project: OSDF Project/Proposal No.: Task No.:

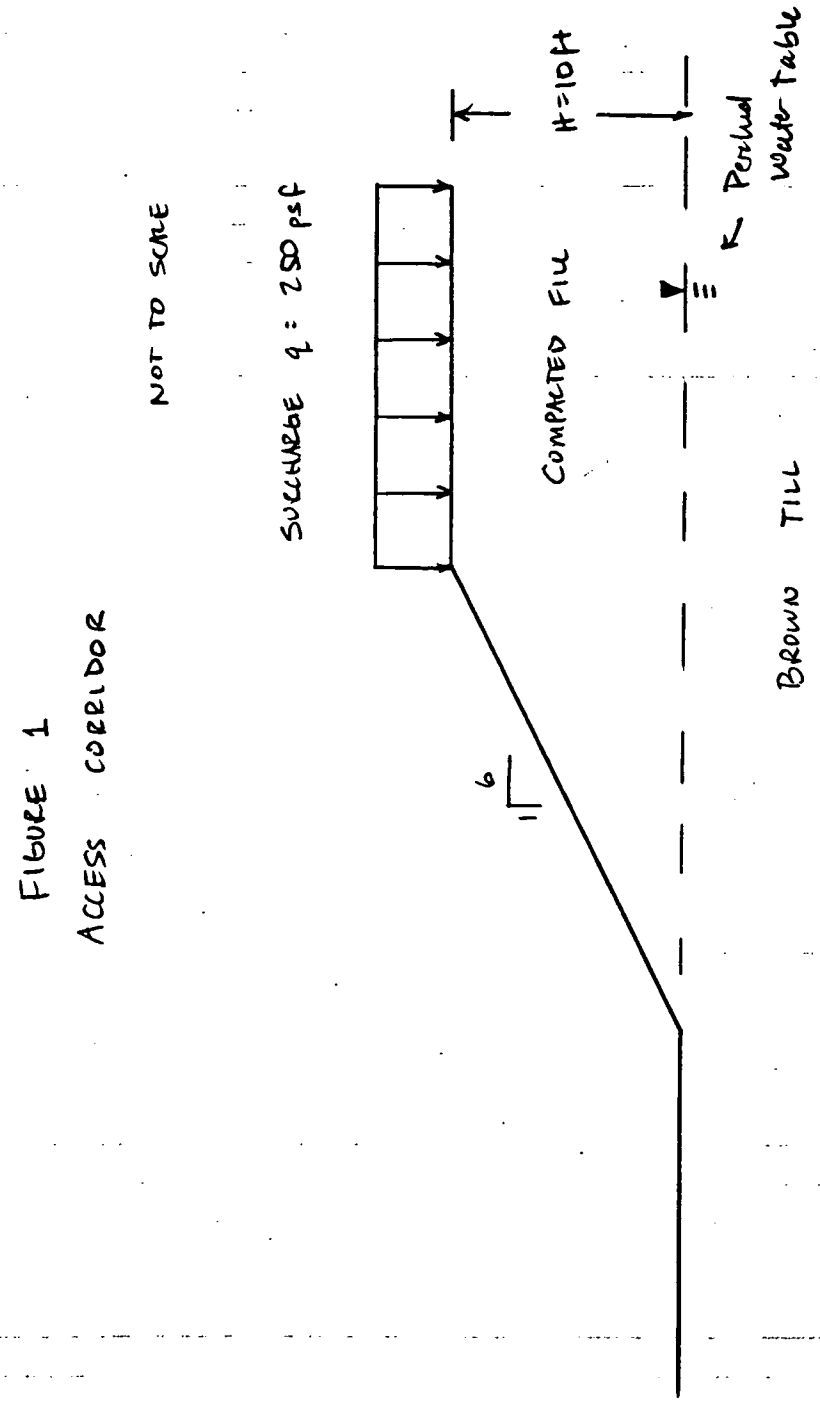

FIGURE 1
ACCESS CORRIDOR

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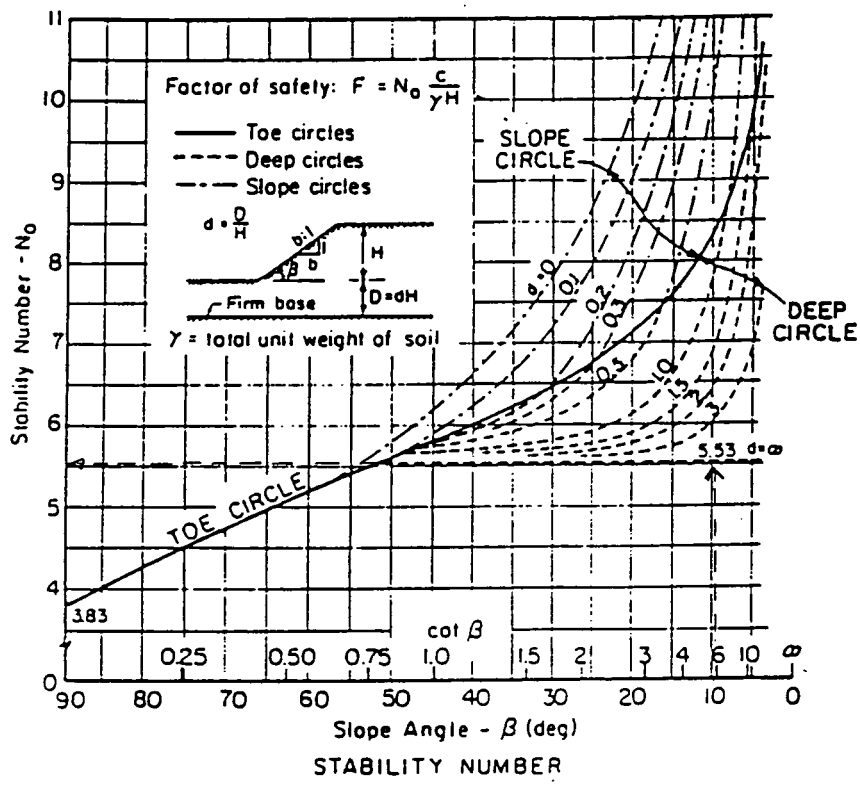
FIGURE 2



STABILITY NUMBER

For $d = \infty$
$N_o = 5.53$

SOURCE : REFERENCE 2 (FIGURE 6)

3.7 Borrow Area Cut Slopes

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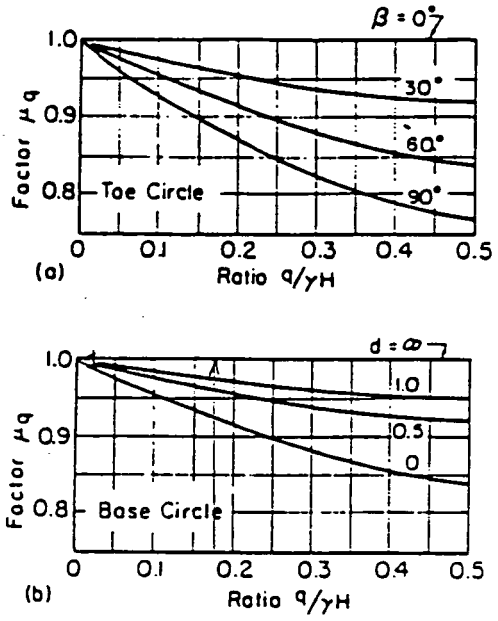
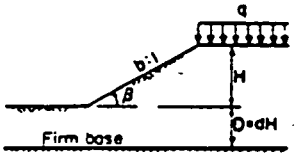
FIGURE 3

REDUCTION FACTORS FOR SURCHARGE

3a.

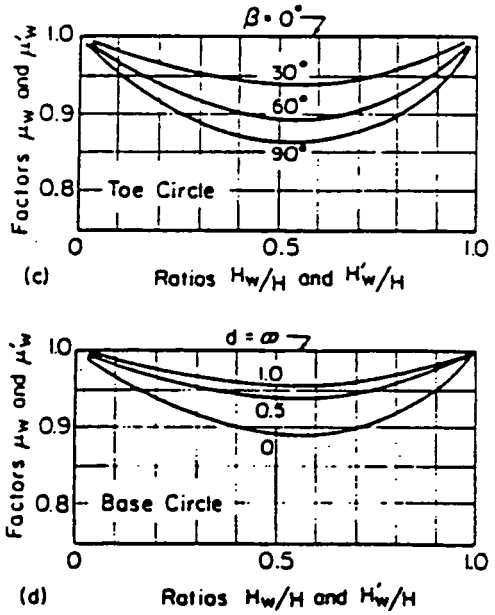


Key Sketch

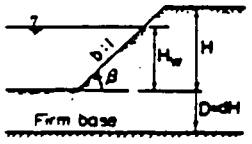


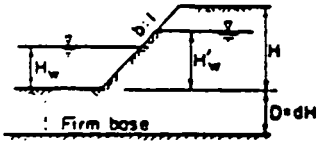
3b.

REDUCTION FACTORS FOR SUBMERGENCE (μ_w) AND SEEPAGE (μ'_w)



Key Sketches





SOURCE: REFERENCE 2 (FIGURE 7)

COMPUTATION COVER SHEET

SUBJECT OF CALCULATION: BORROW AREA CUT SLOPES

Computations By: (Cognizant Engineer)
Signature: [signature] Date: 02/16/96
Printed Name and Title: R. David Espinoza, Assistant Project Engineer

Assumptions and Procedures Checked by: (Checker)
Signature: [signature] Date: 20 Feb '96
Printed Name and Title: SAAD QUESHI, PROJECT ENGINEER

Computations Checked by:
Signature: [signature] Date: 20 Feb '96
Printed Name and Title: SAAD QURESHI, PROJECT ENGINEER

Computations Backchecked by: (Cognizant Engineer)
Signature: [signature] Date: 2/20/96
Printed Name and Title: R. David Espinoza, Assistant Project Engineer

Approved by: (PDP)
Signature: Mark H. Gleason Date: 20 Feb 96
Printed Name and Title: MARK H. GLEASON, Assistant Project Engineer

Approved by: (DTL and TETL)
Signature: Rudolph Bonaparte Date: 22 Feb 96
Printed Name and Title: Rudolph Bonaparte, Principal (DTL)

Record of Revision (Number and initial all revisions)

NO.	REASON	DATE	BY	CHECKED	APPROVAL
D	IDP - EPA Submittal	3 Apr 96			

Signature: _____
Number: _____
Registration Stamp (if applicable)

GE3900-09.4/F9630087.CD

BORROW AREA CUT SLOPES

EXECUTIVE SUMMARY

Purpose:

These calculations are performed to evaluate the minimum static slope stability factor of safety for the excavated slopes of the borrow area. The calculations are performed for both short-term and long term conditions.

Procedure:

The slope stability of the borrow area cut slopes is evaluated by calculating the minimum factor of safety using the 2-dimensional limit equilibrium analysis chart solution presented by Duncan et. al (1987).

Data Verification:

The following information is developed for this calculation package: (i) the cross section used for the analysis is obtained from the Construction Drawings and is interpreted to represent the location with the largest cut; (ii) no traffic surcharge is assumed for the crest of the borrow area cut slope; (iii) a conservative estimate of the shear strength of the borrow area cut material (i.e. in-situ brown till) is based on the data verification section of the Foundation Stability calculation package; and (iv) the effect of the perched ground-water on the stability analysis is considered.

The computed minimum factor of safety is compared to the target value of factor of safety given in the Design Criteria Package (i.e., 1.3 for short-term and 1.5 for long term conditions). The stability of the borrow area cut slopes is considered to be adequate if the calculated minimum factor of safety is equal to or greater than the target value.

Conclusions:

The calculated minimum borrow area cut slope stability factor of safety for short-term conditions is 2.5. The calculated minimum borrow area cut slope stability factor of safety for long-term conditions is 1.5. These values exceed the target values of 1.3 and 1.5 for short- and long-term conditions, respectively.

These calculated factors of safety are conservative because the parameters selected for the analysis have taken into consideration the inherent variability in material properties and foundation stratigraphy, as well as the effect of a perched ground-water table. Therefore, the short-term and long-term stability of the borrow area cut slopes is adequate.

BORROW AREA CUT SLOPES

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Borrow Area Cut Slopes

Purpose:

The purpose of these calculations is to evaluate the minimum static slope stability factor of safety for the excavated slopes of the borrow area. The calculations are performed for both short-term and long term conditions.

Procedure:

The slope stability of the borrow area cut slopes is evaluated by calculating the minimum factor of safety using the 2-dimensional limit equilibrium analysis chart solution presented by Duncan et. al (1987).

Data Verification:

The cut slopes of the borrow area are designed to be stable during excavation of the borrow material and are designed to remain stable thereafter. Stability of the borrow area cut slopes is assessed by considering potential slip surfaces that pass through the remaining material an into the open borrow area excavation. A factor of safety for slope stability is calculated for the critical potential slip surface. The design is considered to be acceptable if the factor of safety exceeds the designated target value. Both short-term (end of excavation) and long-term conditions are considered. The target value for factor of safety given in the Design Criteria Package is 1.3 for short-term conditions and is 1.5 for long-term conditions. The primary issues to be considered in the analysis are:

- Geometry of the critical cross section of the borrow cut area;
- Physical properties of excavated materials in the borrow area; and
- pore pressures within borrow area cut slope.

Geometry:

The geometry of the cut slopes in the borrow area was obtained from the Construction Drawings. The slopes of the borrow area excavation have a maximum inclination of 6H:1V (horizontal to vertical). The maximum excavation is not greater than 20 ft. These factors are identified in Figure 1.

Material Parameters:

The shear strength and the unit weight of the borrow area material are considered for both short-term (end-of-excavation) and long-term conditions. The soils to be excavated in the borrow area consist of brown till. The material properties of the brown till are assumed based on the information presented by (Parsons, 1995), and as interpreted in the foundation stability calculation package (GeoSyntec Document Number F9530020.CDO). Based on the analysis and interpretation provided in the

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foundation stability calculation package, the shear strength parameters of the brown till are as follows:

End of excavation:	ϕ=0 and c=1200 psf (undrained, total stress conditions)
Long-term:	ϕ=25° and c= 0 psf (drained, effective stress conditions)

From the same document, the unit weight of the brown till is γ=135 pcf.

Based on the analysis and interpretation represented above, the excavated material is a brown till that is underlain by a gray till. The gray till is assumed to have a higher shear strength than the brown till. For the purposes of this analysis, the excavated soil and foundation material are assumed to consist of brown till. This assumption corresponds to a conservative analysis.

Pore Pressure:

The effect of the perched ground-water table in the borrow area is considered. For the most severe case, the perched ground-water table is assumed to be consistent with the ground surface. For short-term conditions the classical assumption that pore pressure effects are accounted for in selected values of undrained shear strength are employed. For long-term conditions, it is assumed that perched and aquifer ground-water levels will remain at the ground surface, hence pore pressure will be present in the remaining brown till material.

Analysis:

The following procedures are followed to calculate the slope stability of the borrow area cut slopes:

1. The most critical case for borrow area slope stability involves the deepest and steepest excavated slope. All excavated slopes are inclined at 6H:1V. Hence, steepness is not a factor in the selection of the critical location. The maximum expected slope height is H=20 ft.

2. Vehicle surcharge and pore pressure distributions for the excavated slopes are selected. It is assumed that there will be no vehicle surcharge. The perched ground-water table is assumed to be consistent with the ground surface.

   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 at the ground surface, hence pore pressure will be present in the slope materials.

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3. For calculation of critical factor of safety for short- and long-term conditions the methodology and chart solutions provided by Duncan et al. (1987) are used. This reference provides solutions for a range of conditions which encompass the expected conditions in the borrow area.

The geometry, stratigraphy, and material properties presented in the data verification section of this calculation are used.

End of Construction:

The methodology followed in the calculation of the factor of safety for ϕ=0 soils is described by Duncan et al. (1987). The factor of safety is computed as:

$$F_s = \left(\frac{cN_c}{P_d}\right)$$

$$\text{with} \quad P_d = \frac{\gamma\ H + q - \gamma_w\ H_w}{\mu_q\ \mu_w\ \mu_t}$$

where N_c=5.53 is obtained from Figure 2 using a slope inclination, β=9.46 (6H:1V), a depth, d=∞, a soil cohesion, c=1200 psf, a slope height, H=20 ft, a height of the submerged slope, H_w=0, a surcharge, q=0, a soil unit weight, γ=135 pcf, and a water unit weight, γ_w=62.4pcf. The surcharge reduction factor, μ_q, is obtained from Figure 3a, the submergence reduction factor, μ_w, is obtained from Figure 3b, and the tension crack reduction factor, μ_t, is equal to unity (i.e., no tension crack is allowed). The surcharge and submergence reduction factors are also equal to unity. For these values, P_d, and the factor of safety (FS) are:

$$P_d = \frac{(135)\ (20) + 0 - 62.4(0)}{(1)(1)(1)} = 2700 \text{ psf}$$

$$F_s = \left(\frac{(1200)(5.53)}{2700}\right) = 2.5$$

Long-term Conditions:

The methodology followed in the calculation of the factor of safety for ϕ>0 soils is described by Duncan et al. (1987). For the case of c=0, the factor of safety is computed by:

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$$F_s = \left(\frac{P_e}{P_d}\right)\left(\frac{\tan\phi}{\tan\beta}\right)$$

where P_d is the same as the end of construction case and P_e is given by

$$P_e = \frac{\gamma\ H + q - \gamma_w\ H'_w}{\mu_q\ \mu'_w}$$

H=10 ft., γ = 135 pcf., q =0 pcf., and the height of water in the slope, H'_w= 20. From Figure 3, for H'_w /H = 1, μ_w=1.0 and the surcharge reduction factor, μ_q=1.0. Thus

$$P_d = \frac{(135)20 + 0 - 62.4(20)}{(1)(1)} = 1452 \text{ psf}$$

The factor of safety is given by:

$$F_s = \left(\frac{1452}{2700}\right)\left(\frac{\tan 25}{1/6}\right) = 1.50$$

Summary:

The target critical factors of for slope stability of the borrow area cut slopes are 1.3 for end of excavation conditions (i.e., short-term, undrained total stress analysis) and 1.5 for long-term conditions (i.e., drained, effective stress analysis).

The calculated critical factors of safety must be equal to or greater than the target values to establish adequate stability. The calculated factor of safety are:

End of excavation conditions: Fs = 2.46 ≥ 1.3 (acceptable)
Long-term conditions Fs = 1.50 ≥ 1.5 (acceptable)

The stability is adequate for both cases.

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References

Duncan J.M., Buchignani, A.L. and De Wet, M., *"An Engineering Manual for Slope Stability Studies,"* Department of Civil Engineering, Virginia Polytech and State University, 1987.

Parsons, *"Disposal Facility Pre-Design Geotechnical Investigations,"* Soil Investigation Data Report, Operable Unit 2, Project Order 32, 1995.

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Client: FEEMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.4

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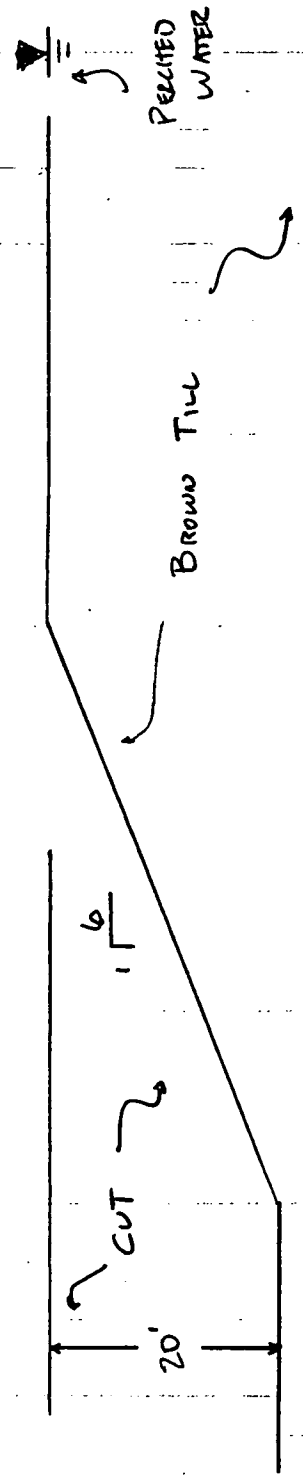
FIGURE 1

BORROW AREA CUT SLOPES

NOT TO SCALE



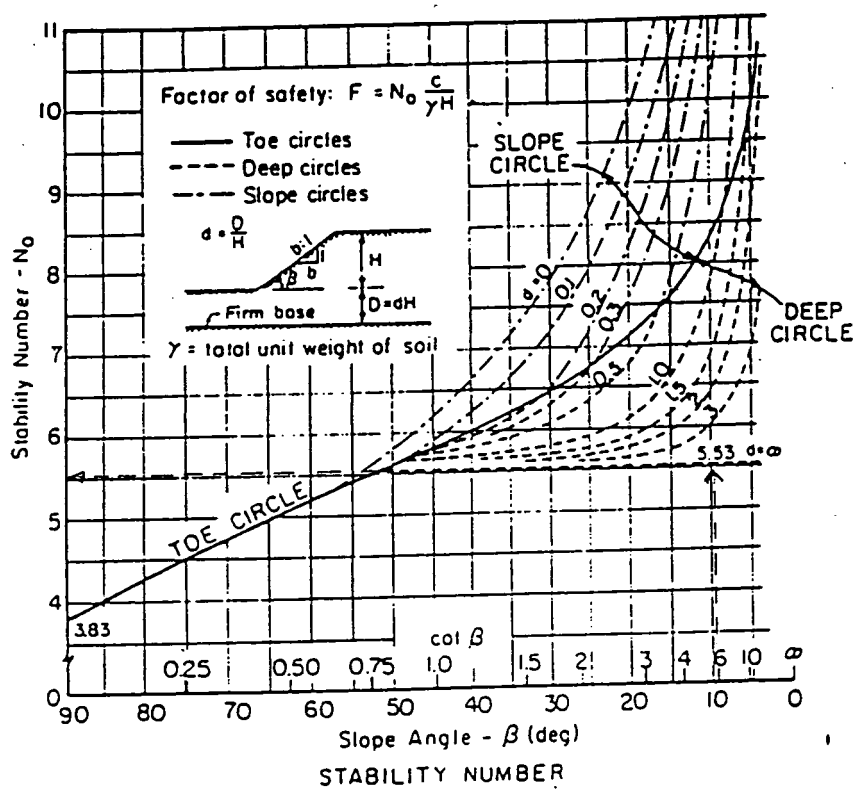
GRAY TILL STRATA NOT CONSIDERED FOR DESIGN, WHICH IS CONSERVATIVE.

Written by: M. GLEASON Date: 96 / 2 / 8 (YY MM DD) Reviewed by: SR. Date: 96 / 02 / 20 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.4

RB (DTL) 16 FEB 96

FIGURE 2



For $d = \infty$, $N_0 = 5.53$

SOURCE: Duncan et al., 1987 (Fig 6)

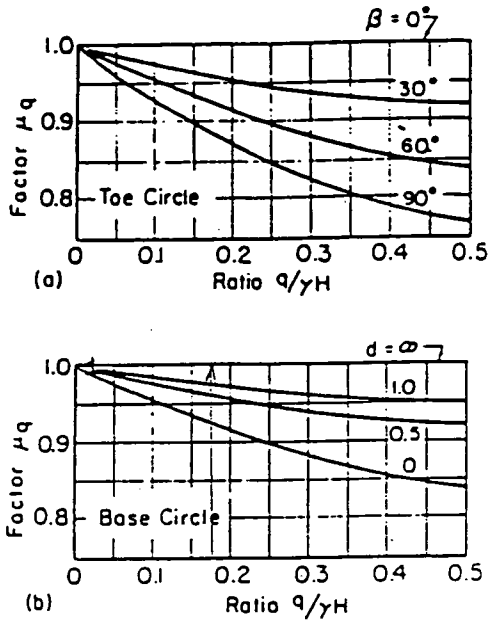
Written by: M. GLEASON Date: 96/2/8 (YY MM DD) Reviewed by: SQ. Date: 96/02/20 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.4

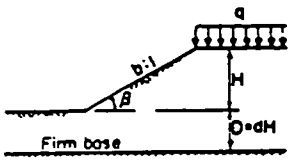
RB (DTL) 16 FEB 96

FIGURE 3

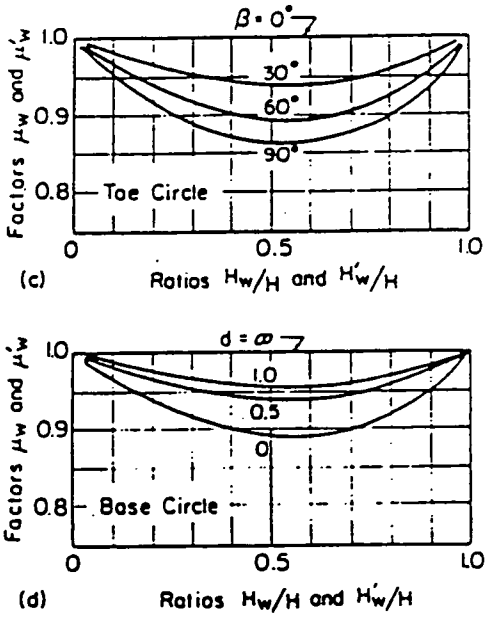
REDUCTION FACTORS FOR SURCHARGE



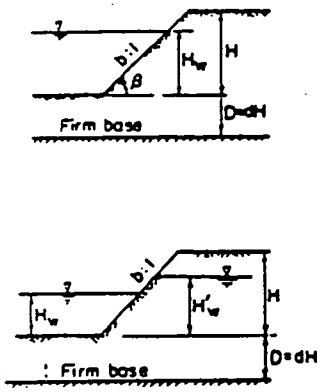
Key Sketch



REDUCTION FACTORS FOR SUBMERGENCE (μ_w) AND SEEPAGE (μ'_w)



Key Sketches



SOURCE: DUNCAN et al., 1987 (Fig 7)

4. GEOTECHNICAL - SEISMIC SLOPE STABILITY

4.1 Hazard Assessment
4.2 Site Response Analysis
4.3 Performance Analysis

4.1 Hazard Assessment

COMPUTATION COVER SHEET

SUBJECT OF CALCULATION: SEISMIC HAZARD ASSESSMENT

Computations By: (Cognizant Engineer)
Signature: Neven Matasović — 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
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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: 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				
Ø	30-percent submittal	10-18-95	N.M.	MHG	RB
B	Preliminary Design - EPA Submitted	14 Dec 95	[illegible]	—	—
C	60 PERCENT SUBMITTAL	19 Feb 96	N.M.	MHG	RB
D	Intermediate Design - EPA Submitted	3 Apr 96	[illegible]	—	—

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.

Written by: _____ Date: _____ Reviewed by: _____ Date: _____

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.10

SEISMIC HAZARD ASSESSMENT

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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).

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

Algermissen, S.T., Perkins, D.M., Tenhaus, P.C., Hanson, S.L. and Bender, B.L. (1990), "Probabilistic Earthquake Acceleration and Velocity Maps for the United States and Puerto Rico," Department of Interior, *U.S. Geological Survey Miscellaneous Filed Studies Map MF-2120.*

ATC-35 (1994), *"Seminar on New Developments in Earthquake Ground Motion Estimation and Implications for Engineering Design Practice,"* Los Angeles, California

Atkinson, G.M. and Boore, D.M. (1990), "Recent Trends in Ground Motion and Spectral Response Relations for North America," *Earthquake Spectra*, Vol. 6, No. 1, pp. 15-35.

Boore, D.M., and Atkinson, G.M. (1987), "Stochastic Prediction of Ground Motion and Spectral Response Parameters at Hard-Rock Sites in Eastern North America", *Bulletin of the Seismological Society of America*, Vol. 77, pp. 440-467.

EPA (1993), "Technical Manual: Solid Waste Disposal Facility Criteria," United States Environmental Protection Agency, EPA 530-R93-017, Washington, District of Columbia

EPA (1995), "RCRA Subtitle D (258) Seismic Design Guidance for Municipal Solid Waste Landfill Facilities," United States Environmental Protection Agency, EPA 600-R95-051, Washington, District of Columbia

Friberg, P.A., and K.H. Jacob (1990), "NCEER Strong-Motion Data Base: A User Manual for the GeoBase Release," *NCEER Technical Report*, NCEER-90-005.

Heaton, T.H., Tajima, F. and Mori, A.W. (1986), "Estimating Ground Motions Using Recorded Accelerograms," *Surveys in Geophysics*, No. 8, pp. 25-83.

Jennings, P.C., Housner, G.W. and Tsai, N.C. (1968), "Simulated Earthquake Motions," Research Report, Earthquake Engineering Research Laboratory, California Institute of Technology, Pasadena, California.

Johnston, A.C. and Nava, S.J. (1994), "Seismic Hazard Assessment in the Central United States," Proc. *ATC-35 Seminar on New Developments in Earthquake Ground Motion Estimation and Implications for Engineering Design Practice*, Los Angeles, California, pp. 2-1 - 2-12.

Nuttli, O.W. and Herrman, R.B. (1981), "Excitation of Attenuation of Strong Ground Motion," *Abstract*: 21st General Assembly, IASPEI-AISPIT, London, Canada.

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Client: FERMCO

Date: 17.Oct. 1995
Project: OSDF

Reviewed by: MHG
Project No.: GE3900

Date: 20 Oct 95
Task No.: 9.10
RB 24 Oct 95

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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000517

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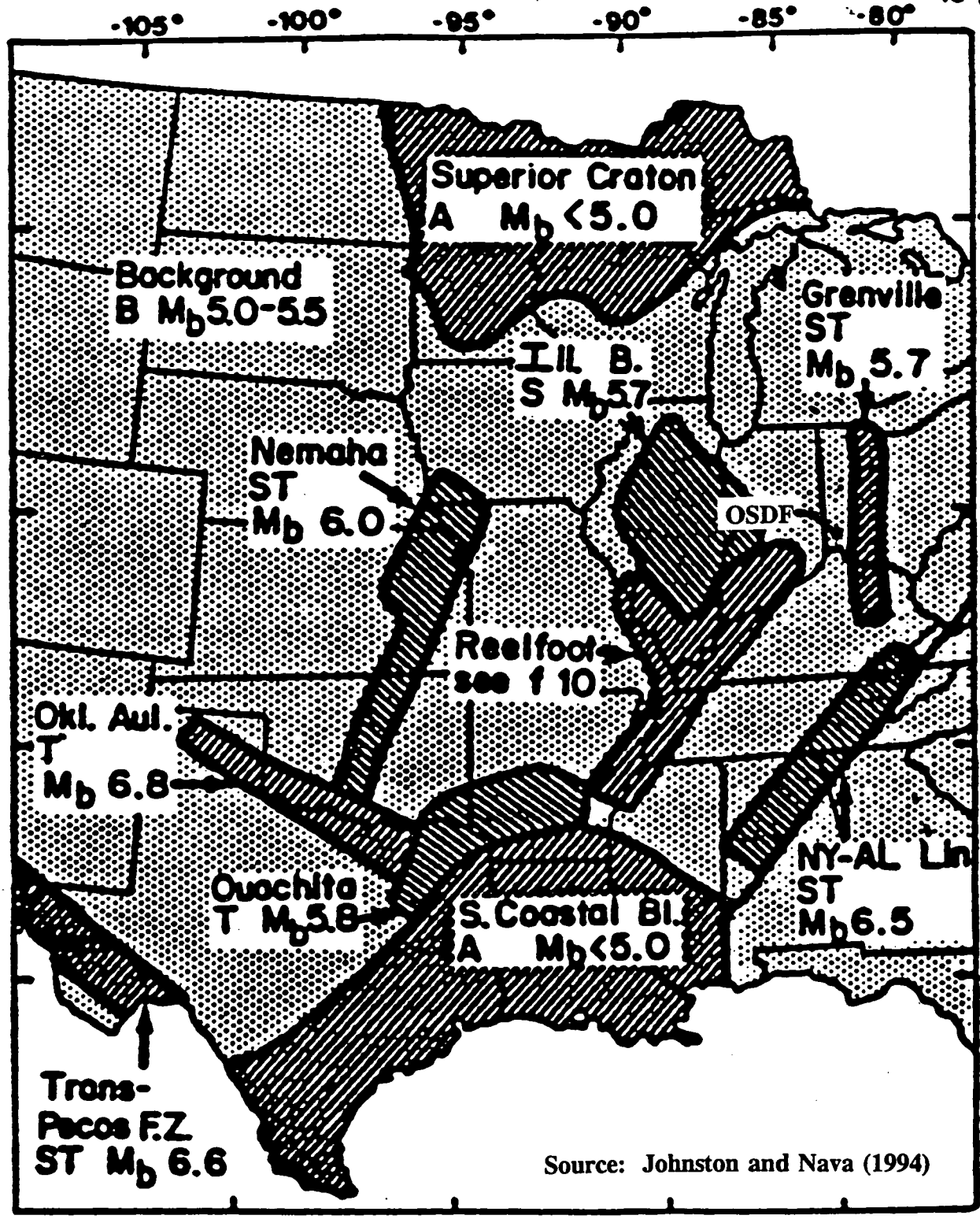

FIGURE 1

N.M. 10-17-95

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.

MHB 20 Oct 95

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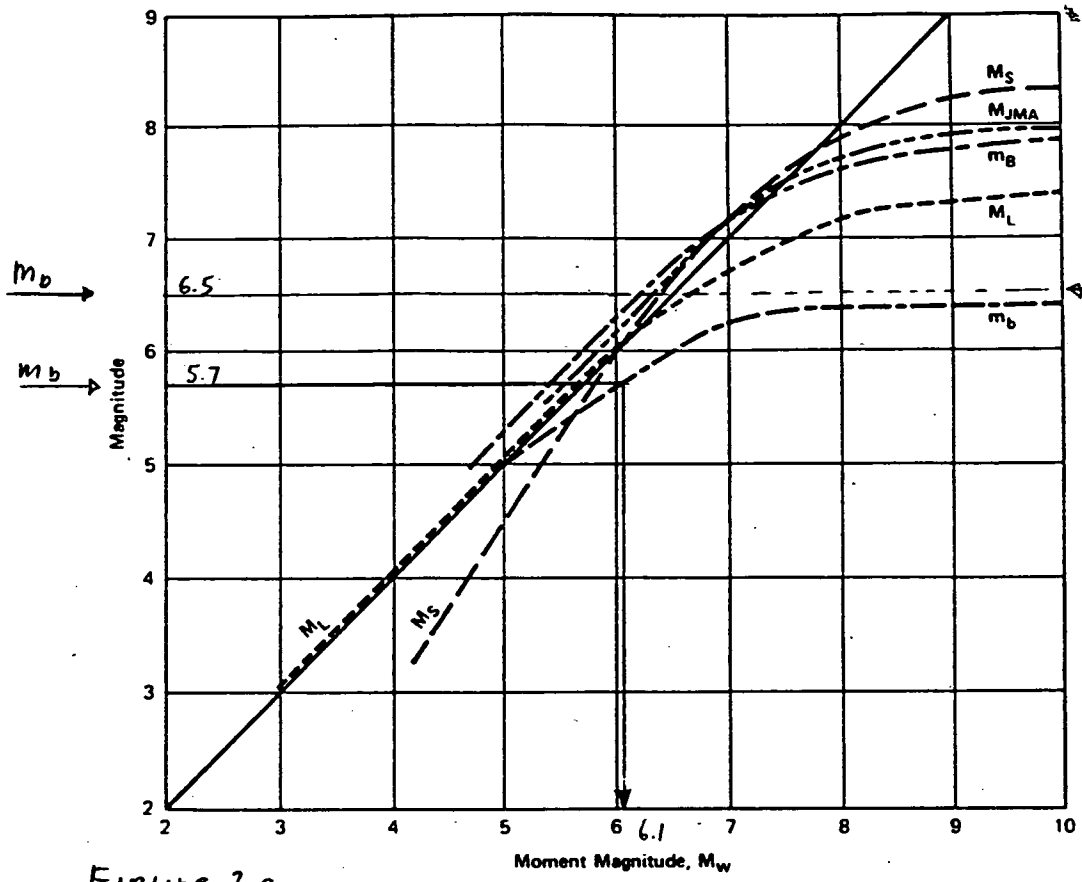
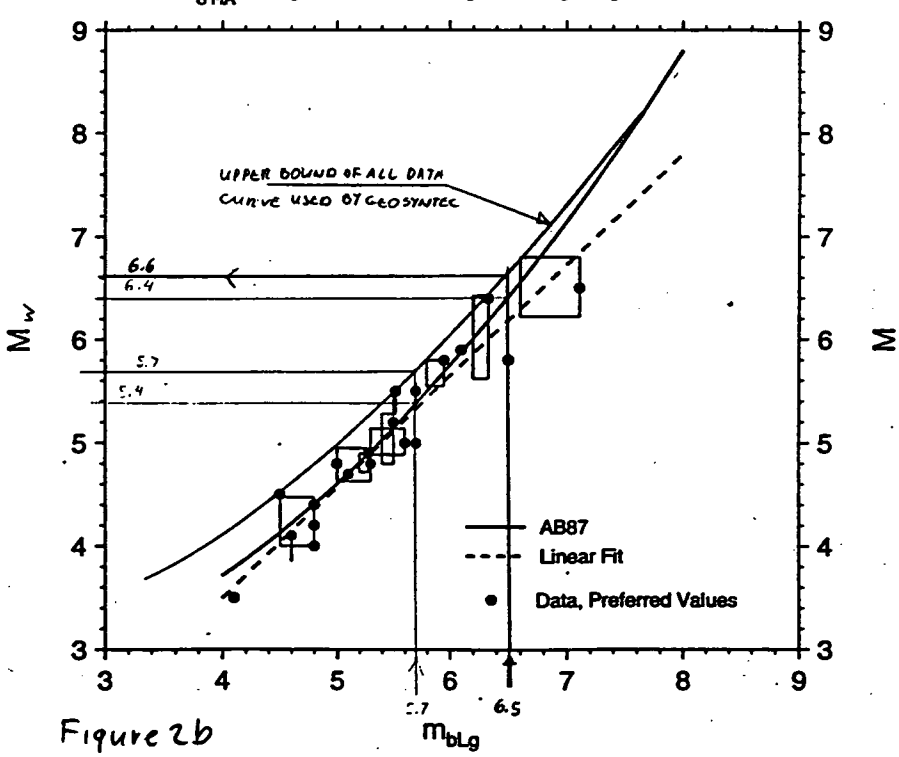


NOTE: SATURATION @ $m_D \approx 6.4$ USE MODIFIED BOORE AND ATKINSON CHART IN FIGURE 2b

N.M. 10-17-95

Figure 2a

Fig. 12 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, 1986)



N.M. 10-17-95.

Figure 2b

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.

MHB 20 Oct 95

RB 24 Oct 95

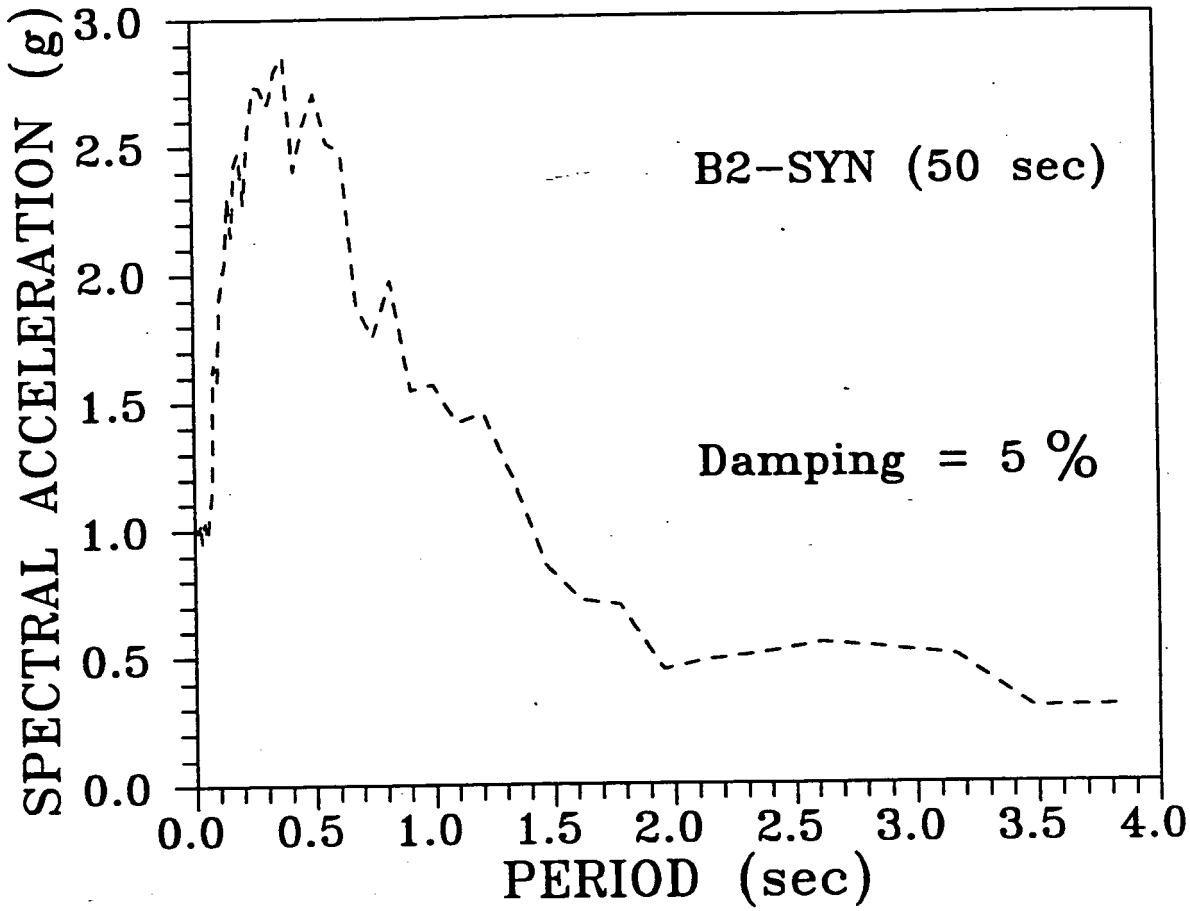


Figure 3 - Response Spectrum of B2-SYN Synthetic Accelerogram N.M. 10-17-95

4.2 Site Response Analysis

COMPUTATION COVER SHEET

SUBJECT OF CALCULATION: SEISMIC SITE RESPONSE ANALYSIS

Computations By: (Cognizant Engineer)
Signature: Neven Matasović — 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]	—	—
C	60 PERCENT SUBMITTAL (all updated)	2-16-96	N.M.	MHG	RB 20 Feb 96
D	Intermediate Design - EPA Submitted	3 Apr 96	[illegible]	—	—

GEOSYNTEC CONSULTANTS

Written by: Neven Matasović Date: 17 Oct. 1995 Reviewed by: 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.

Written by: _____ Date: _____ Reviewed by: _____ Date: _____

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 9.10

SEISMIC SITE RESPONSE ANALYSIS

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	Appendix: Shake 91 Output	17/22

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.

Parsons, "Remedial Investigation Report for Operable Unit 2," *Fernald Environmental Management Project*, Fernald, Ohio, January 1995.

Parsons, "Disposal Facility Pre-Design Geotechnical Investigation, Soil Investigation Data Report Summary Document," Operable Unit 2, *Fernald Environmental Management Project*, Fernald, Ohio, July 1995.

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.

U.S. Department of Energy (DOE), *"Pre-Design Investigation and Site Selection Report for the On-Site Disposal Facility"*, Fernald Environmental Project, DOE Fernald Area Office, Fernald, OH, July 1995.

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 $\approx$ 15	769	Seed and Idriss (1970)
4	10	Impacted Materials (mostly soil fill)	125	S_u = 1,000 psf; PI $\approx$ 15	769	Seed and Idriss (1970)
5	10	Impacted Materials (mostly soil fill)	125	S_u = 1,000 psf; PI $\approx$ 15	769	Seed and Idriss (1970)
6	10	Impacted Materials (mostly soil fill)	125	S_u = 1,000 psf; PI $\approx$ 15	769	Seed and Idriss (1970)
7	10	Impacted Materials (mostly soil fill)	125	S_u = 1,000 psf; PI $\approx$ 15	769	Seed and Idriss (1970)
8	3	Clay Liner (recompacted brown till)	130	S_u = 1,200 psf; PI $\approx$ 15	~~843~~ 826	Seed and Idriss (1970)
9 & 10	5 + 5	Natural Soil (brown till)	135	S_u = 1,200 psf; PI $\approx$ 15	811	Seed and Idriss (1970)
11 & 12	10 + 35	Natural Soil (gray till)	145	S_u = 1,900 psf; PI $\approx$ 15	984	Seed and Idriss (1970)
13	172	Granular Soil (dense sand)	135	N = 40; PI $\approx$ 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.

Written by: Neven Matasovic Date: 95/10/17 Reviewed by: MHG Date: 95/10/20

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

constant of gravity (32.174 ft/sec²)

$$V_s = \sqrt{\frac{G_m \, g}{\gamma}} \text{ (in ft/sec)} \quad \text{(Eq. 3)}$$

$$= \sqrt{\frac{564.2\,(32.174)}{0.125}} = 381.1 \text{ ft/sec}$$

Written by: Neven Matasović 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

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

  B26 - Error not relevant for analysis - MHG.

  $G_m = 2300 \cdot 1200 = 2760$ ksf; $V_s = \cancel{843}$ ft/sec

- 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: Naven Matorović Date: 95 / 10 / 17 (YY MM DD) Reviewed by: MHG Date: 95 / 10 / 20 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 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

$$V_s = \sqrt{\frac{3004 \cdot (32.174)}{0.135}} = 846\ ft/sec$$

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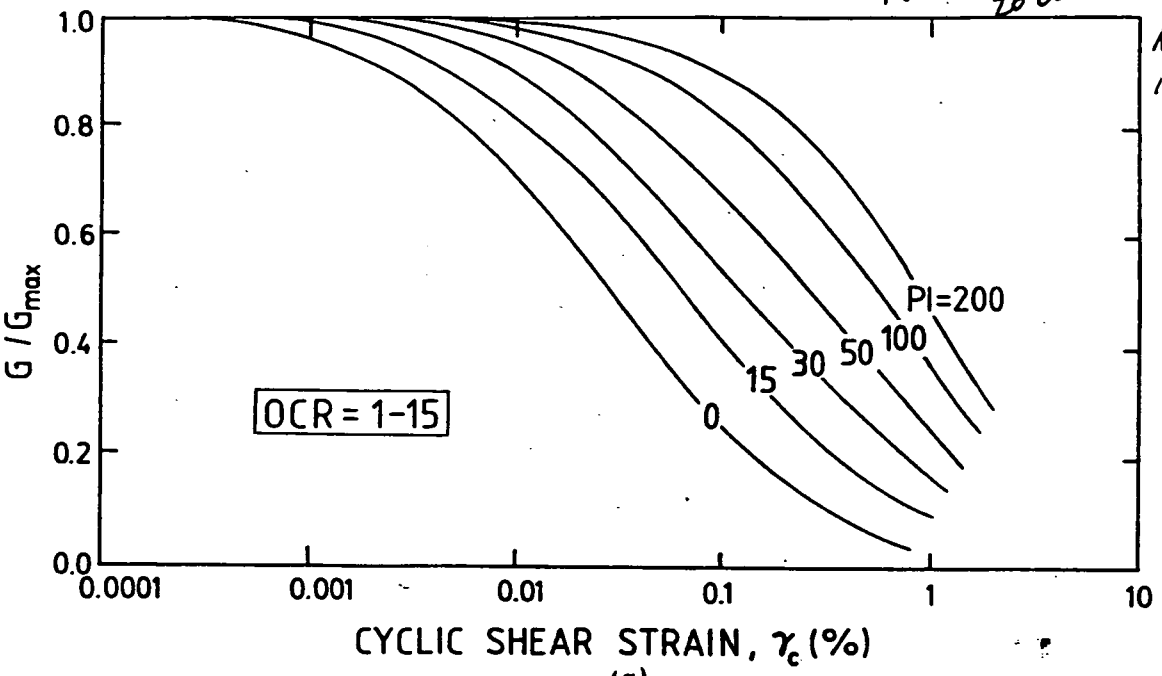
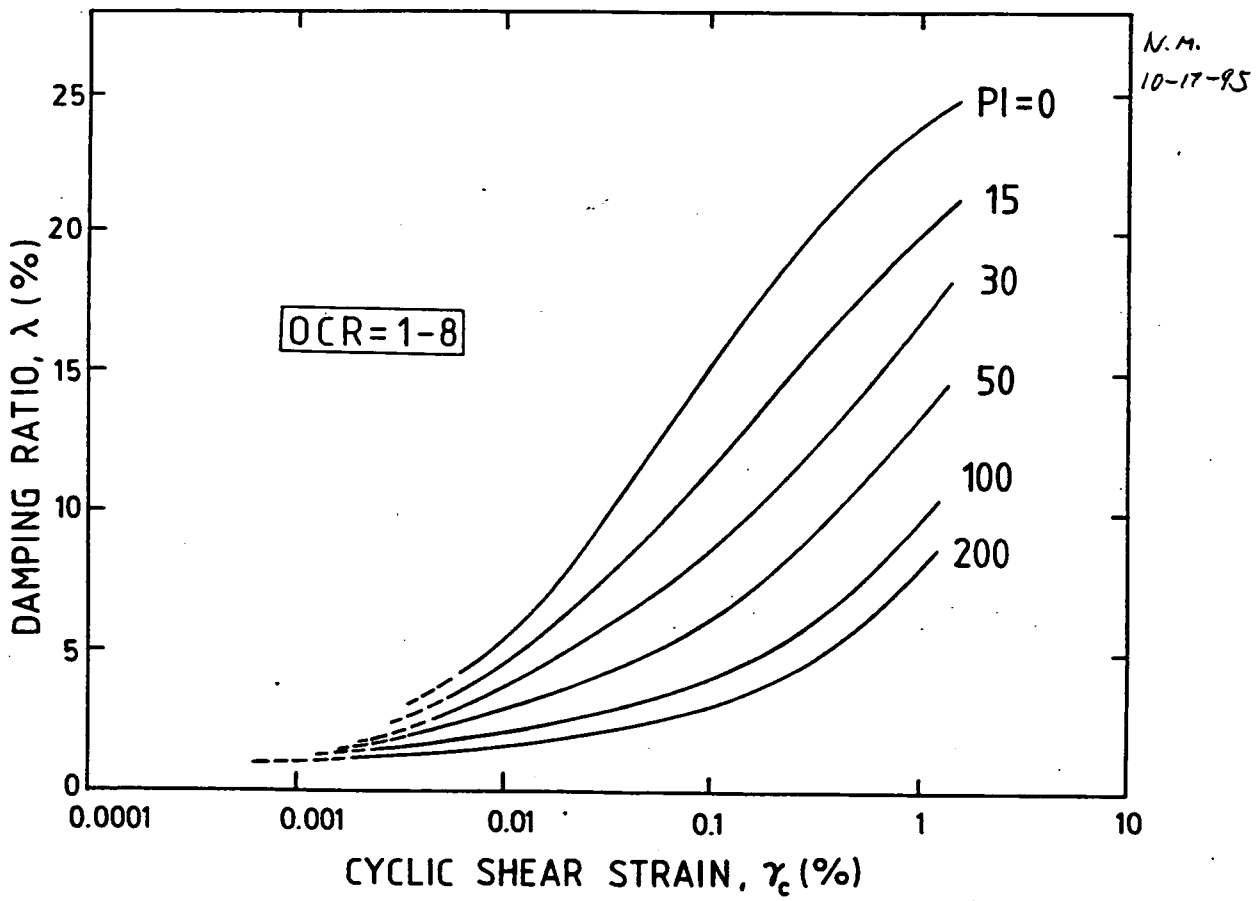
RB 24 Oct 95
MHH 20 oct 95



(a)



(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

NMM 20 Oct 95

18

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253

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.

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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	.558
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	.566

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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
P R O F I L E - CASE 3 - The Most Crit. Prof.

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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

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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	3058.8	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	1749.0	.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	3119.0	.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

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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

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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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20 Oct 95

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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).

See Section 1.2 of the Design Parameter Summary.

4.3 Performance Analysis

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. STEINHAUSSON, PROJECT ENGINEER

Computations Checked by:
Signature: Eric S. Steinhausson — Date: 16 Oct '95
Printed Name and Title: ERIC S. STEINHAUSSON, 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	FC	—	—
C	60% Submittal	20 Feb 96	MHG	SSS	RB
D	IDP - EPA Submittal; new pgs 1 and 5/69	3 Apr 96	FC	—	—

Written by: M. GLEASON Date: 96/3/29 Reviewed by: [illegible] Date: 96/03/29

Client: FERMCO 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 in (3 mm). This calculated deformation is less than the maximum permissible seismic deformation of 6 in (0.15 m) based on the recommendations in Seed and Bonaparte (1992) and Anderson and Kavazanjian (1995). Therefore, the seismic performance of the OSDF during the design seismic event is acceptable.

SEISMIC PERFORMANCE EVALUATION

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	• Deformation Analysis Files	36/69
	Appendix A: XSTABL - Version 5	A1/21
	Appendix B: YSLIP_C	B1/4

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 Impacted Material Stability;
- OSDF Access Corridor 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).

Written by: M. Gleason Date: 96/2/7 Reviewed by: [illegible] Date: 96/02/20

Client: Fernio Project: OSDF Proj./Propōsal No.: GE 3900 Task No.: 9.11

RB (DTR) 16 FEB 96

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. The maximum permanent seismic deformation for all analysis conditions should be no larger than 6 in. (0.15 m) based on recommendations in Seed and Bonaparte (1992) and Anderson and Kavazanjian (1995).

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Written by: M. Gleason Date: 96/2/7 Reviewed by: [illegible] Date: 96/02/20

Client: Fernco Project: OSDF Proj./Proposal No.: GE 3900 Task No.: 9.11

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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 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.

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 yield 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 in (3 mm) for each case. This calculated deformation is less than the maximum permissible seismic deformation of 6 in. (0.15 m) based on the recommendations 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.

Written by: M. GLEASON Date: 95/10/20 Reviewed by: HS Date: 95/10/20

Client: FERMCO Project: OSDF Proj./Proposal No.: GE 3900 Task No.: 9.11

RB (DTL) 16 FEB 96

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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: 96/2/7 Reviewed by: HS Date: 96/02/20

Client: Fernco Project: OSDF Proj./Proposal No.: GE 3900 Task No.: 9.11

RB (DTL) 16 FEB 96

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 • long term	125	friction angle = 25°	Foundation Stability
Compacted Clay • long term	130	friction angle = 25°	Foundation Stability
Brown Till • long term	135	friction angle = 25°	Foundation Stability
Gray Till • long term	145	friction angle = 30°	Foundation Stability
Great Miami Aquifer Soils	135	friction angle = 35°	Foundation Stability

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Written by: M. GLEASON Date: 96/2/7 Reviewed by: [illegible] Date: 96/02/20

Client: FERMCO Project: OSDF Proj./Proposal No.: GE 3900 Task No.: 9.11

RB (DTL) 16 FEB 96

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 = 7,700 psf friction angle = 17° @ σ_n = 5,600 psf friction angle = 23° @ σ_n = 2,000 psf friction angle = 30° @ σ_n = 400 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 = 7,700 psf friction angle = 8° @ σ_n = 6,200 psf friction angle = 10° @ σ_n = 3,500 psf friction angle = 12° @ σ_n = 2,000 psf	Interim/Final Waste Slope Stability

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Written by: M. Gleason Date: 96/2/7 Reviewed by: [illegible] Date: 96/02/20

Client: Fernco Project: OSDF Proj./Proposal No.: GE 3900 Task No.: 9.11

RB (DTL) 16 FEB 96

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 0.28	0.11 0.11	0.9 - Deformation Analysis Required 2.5 - No Seismic Deformation
OSDF Liner System and Impacted Materials • Interim Configuration • Final Configuration	0.19 0.10	0.11 0.11	1.7 - No Seismic Deformation 0.9 - 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	0.28	0.11	2.5 - 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.

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 (DTL) 16 FEB 96

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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

M. Gleason
95/10/20

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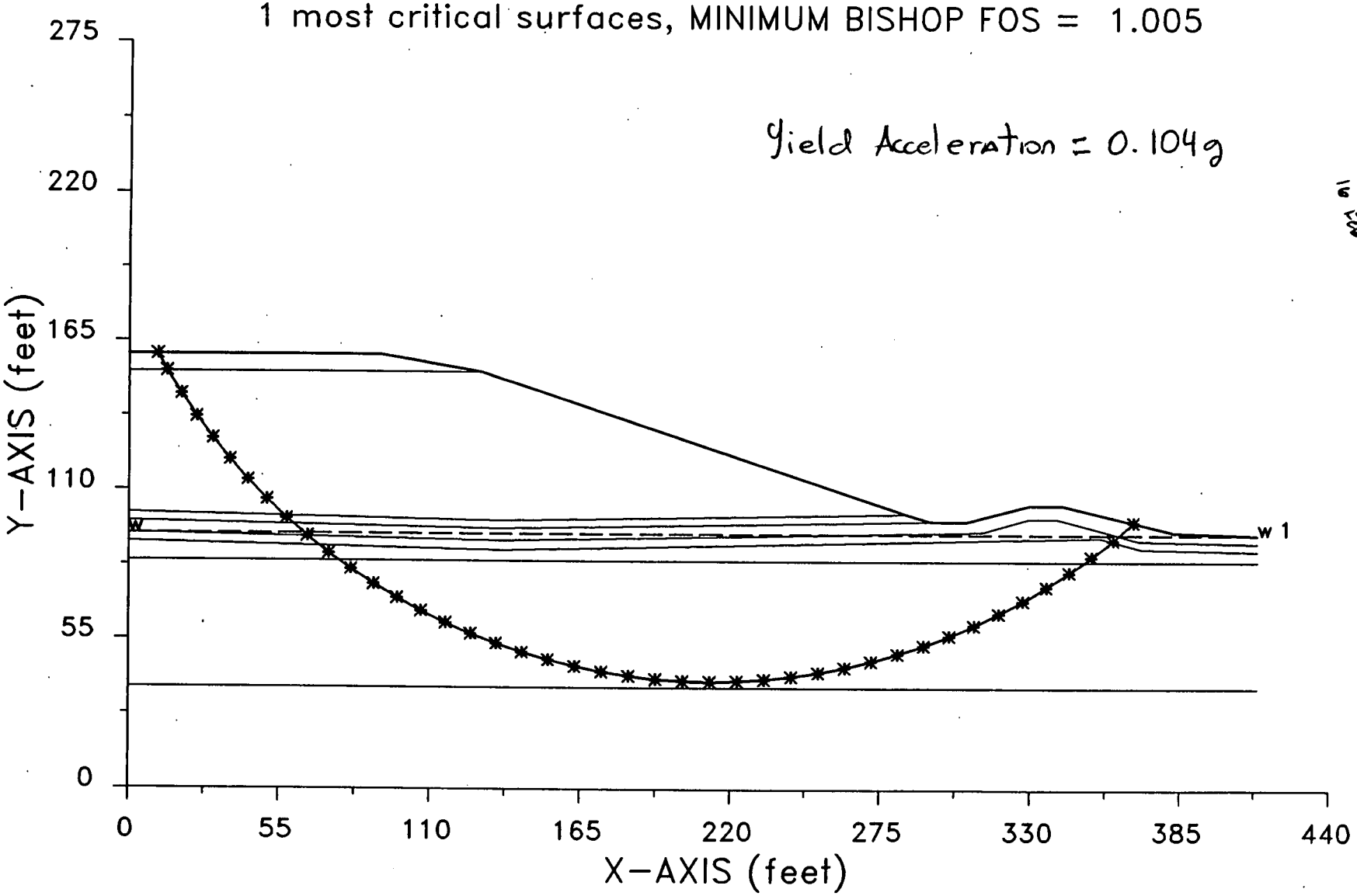
XSTABL OUTPUT FILES

OSDF Interim Configuration–Seismic Yield
1 most critical surfaces, MINIMUM BISHOP FOS = 1.005

Yield Acceleration = 0.104g



N. Glasson
16 Feb 96

XSTABL File: CASE8APP 2-16-96 15:02

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*              X S T A B L              *
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*        Slope Stability Analysis       *
*              using the                *
*           Method of Slices            *
*                                       *
*        Copyright (C) 1992 - 94        *
*   Interactive Software Designs, Inc.  *
*        Moscow, ID 83843, U.S.A.       *
*                                       *
*          All Rights Reserved          *
*                                       *
* Ver. 5.100                95 - 1305   *
*****************************************
```

Problem Description : OSDF Interim Configuration-Seismic Y

SEGMENT BOUNDARY COORDINATES
---

10 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	92.0	160.0	2
2	92.0	160.0	129.0	153.6	2
3	129.0	153.6	150.0	146.6	2
4	150.0	146.6	285.0	101.6	1
5	285.0	101.6	294.0	99.0	2
6	294.0	99.0	307.0	99.0	2
7	307.0	99.0	330.0	105.0	2
8	330.0	105.0	342.0	105.0	2
9	342.0	105.0	383.0	95.0	2
10	383.0	95.0	414.0	94.0	2

17 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	153.6	129.0	153.6	1
2	.0	101.6	136.5	98.9	1
3	136.5	98.9	285.0	101.6	1
4	.0	98.6	136.5	95.9	2
5	136.5	95.9	294.0	99.0	2
6	.0	94.2	136.5	91.5	3
7	136.5	91.5	313.0	95.0	3
8	313.0	95.0	330.0	100.0	3
9	330.0	100.0	340.0	100.0	3
10	340.0	100.0	370.0	92.0	3
11	370.0	92.0	414.0	91.0	3
12	.0	91.0	136.5	88.0	4
13	136.5	88.0	356.0	93.0	4
14	356.0	93.0	371.0	89.0	4
15	371.0	89.0	414.0	88.0	4
16	.0	84.0	414.0	84.0	5
17	.0	37.0	414.0	37.0	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	1
5	145.0	145.0	1900.0	.00	.000	.0	0
6	135.0	135.0	.0	35.00	.000	.0	0

1 Water surface(s) have been specified

Unit weight of water = 62.40 (pcf)

Water Surface No. 1 specified by 2 coordinate points

M. Jackson 16 Feb 96

```
**********************************
        PHREATIC SURFACE,
**********************************
```

Point No.	x-water (ft)	y-water (ft)
1	.00	94.00
2	414.00	94.00

A horizontal earthquake loading coefficient
of .104 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.

1000 trial surfaces will be generated and analyzed.

25 Surfaces initiate from each of 40 points equally spaced
along the ground surface between x = 220.0 ft
and x = 385.0 ft

Each surface terminates between x = 10.0 ft
and x = 100.0 ft

Unless further limitations were imposed, the minimum elevation

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at which a surface extends is y = .0 ft

10.0 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 43 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	368.08	98.64
2	360.50	92.12
3	352.65	85.92
4	344.53	80.08
5	336.17	74.59
6	327.58	69.47
7	318.78	64.72
8	309.78	60.36
9	300.60	56.40
10	291.26	52.83
11	281.77	49.67
12	272.16	46.93
13	262.43	44.60
14	252.61	42.70
15	242.72	41.22
16	232.78	40.17
17	222.80	39.55
18	212.80	39.37
19	202.80	39.62
20	192.83	40.30
21	182.89	41.41
22	173.01	42.95
23	163.20	44.92
24	153.49	47.31
25	143.89	50.12
26	134.43	53.33
27	125.11	56.96
28	115.95	60.99
29	106.98	65.41
30	98.21	70.21
31	89.66	75.38
32	81.33	80.93
33	73.26	86.82
34	65.44	93.07
35	57.91	99.64
36	50.66	106.53
37	43.72	113.73
38	37.10	121.23
39	30.81	129.00
40	24.86	137.04
41	19.27	145.33
42	14.03	153.85
43	10.62	160.00

**** Simplified BISHOP FOS = 1.005 ****

M. Blesso 16 Feb 96

The following is a summary of the TEN most critical surfaces

Problem Description : OSDF Interim Configuration-Seismic Y

	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.	1.005	213.54	270.46	231.09	368.08	10.62	1.678E+08
2.	1.005	211.32	259.01	220.57	363.85	14.26	1.578E+08
3.	1.006	204.36	250.29	211.84	355.38	12.78	1.491E+08
4.	1.010	180.33	226.32	182.84	313.08	9.99	1.144E+08
5.	1.012	178.35	223.46	180.00	308.85	9.97	1.116E+08
6.	1.013	181.24	227.22	182.80	313.08	11.31	1.136E+08
7.	1.013	204.62	257.19	216.55	355.38	11.17	1.520E+08
8.	1.013	185.55	231.75	187.41	321.54	12.47	1.186E+08
9.	1.014	224.14	293.36	252.31	380.77	10.01	1.886E+08
10.	1.014	208.20	262.47	221.57	359.62	11.77	1.568E+08

* * * END OF FILE * * *

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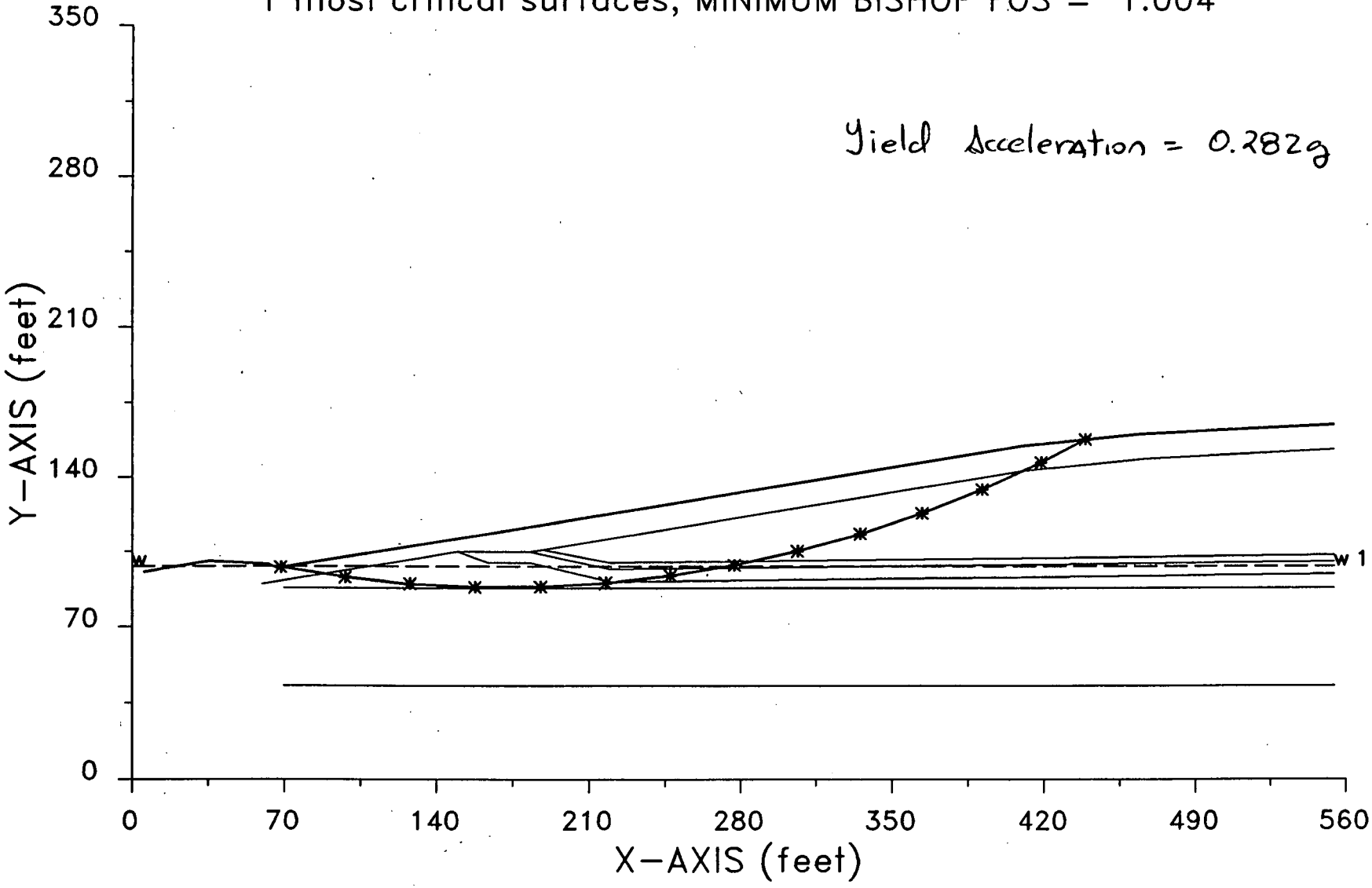
OSDF Final Configuration—Seismic Yield

1 most critical surfaces, MINIMUM BISHOP FOS = 1.004



M. Blake 16 Feb 96

BSS 2/16/96

15/14

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XSTABL File: CASE9PP 2-16-96 10:03

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*        Slope Stability Analysis       *
*              using the                *
*           Method of Slices            *
*                                       *
*        Copyright (C) 1992 - 94        *
*   Interactive Software Designs, Inc.  *
*        Moscow, ID 83843, U.S.A.       *
*                                       *
*         All Rights Reserved           *
*                                       *
*  Ver. 5.100                95 - 1305  *
*****************************************
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Problem Description : OSDF Final Configuration-Seismic Yie

SEGMENT BOUNDARY COORDINATES
---

6 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	5.5	95.6	35.5	100.6	2
2	35.5	100.6	62.5	99.3	2
3	62.5	99.3	67.0	97.5	2
4	67.0	97.5	410.0	154.7	2
5	410.0	154.7	465.0	160.2	2
6	465.0	160.2	555.0	164.7	2

17 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	60.0	90.0	120.0	100.0	4
2	120.0	100.0	150.0	105.0	4
3	150.0	105.0	183.0	105.0	3
4	183.0	105.0	189.0	106.0	2
5	189.0	106.0	410.0	142.8	1
6	410.0	142.8	467.0	148.5	1
7	467.0	148.5	555.0	152.9	1
8	189.0	106.0	220.0	100.0	2
9	220.0	100.0	555.0	103.5	2
10	183.0	105.0	220.0	97.0	3
11	220.0	97.0	555.0	100.5	3
12	150.0	105.0	164.0	100.0	4
13	164.0	100.0	183.0	100.0	4
14	183.0	100.0	220.0	91.0	4
15	220.0	91.0	555.0	94.5	4
16	70.0	88.0	555.0	88.0	5
17	70.0	43.0	555.0	43.0	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	1
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	130.0	.0	30.00	.000	.0	0

1 Water surface(s) have been specified

Unit weight of water = 62.40 (pcf)

Water Surface No. 1 specified by 2 coordinate points

****
PHREATIC SURFACE,
****

Point No.	x-water (ft)	y-water (ft)
1	.00	98.00
2	555.00	98.00

A horizontal earthquake loading coefficient of .282 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.

1000 trial surfaces will be generated and analyzed.

20 Surfaces initiate from each of 50 points equally spaced along the ground surface between x = 60.0 ft
and x = 200.0 ft

Each surface terminates between x = 360.0 ft
and x = 440.0 ft

Unless further limitations were imposed, the minimum elevation at which a surface extends is y = .0 ft

N. Blasson 16 Feb 96

SSS 96/02/10 16/09

253

000565

30.0 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 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	68.57	97.76
2	98.20	93.08
3	128.04	89.99
4	158.01	88.51
5	188.01	88.65
6	217.96	90.40
7	247.77	93.76
8	277.36	98.71
9	306.63	105.25
10	335.52	113.36
11	363.92	123.00
12	391.77	134.17
13	418.98	146.81
14	439.33	157.63

**** Simplified BISHOP FOS = 1.004 ****

The following is a summary of the TEN most critical surfaces

Problem Description : OSDF Final Configuration-Seismic Yie

	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	170.47	645.99	557.62	68.57	439.33	2.556E+08
2.	1.010	178.56	558.19	470.07	77.14	421.50	2.016E+08
3.	1.012	154.28	539.56	449.03	71.43	375.13	1.373E+08
4.	1.015	181.06	545.29	456.93	80.00	419.37	1.938E+08
5.	1.019	158.00	718.43	627.07	68.57	437.96	2.576E+08
6.	1.025	161.75	536.18	445.10	77.14	382.88	1.416E+08
7.	1.027	181.39	548.30	458.86	82.86	418.15	1.889E+08
8.	1.028	186.93	536.14	447.12	85.71	421.67	1.908E+08
9.	1.031	155.43	719.90	627.31	71.43	431.68	2.401E+08
10.	1.035	158.58	701.80	608.95	74.29	429.72	2.306E+08

* * * END OF FILE * * *

M. Bleuse 16 Feb 96

TSS 96/080 17/69

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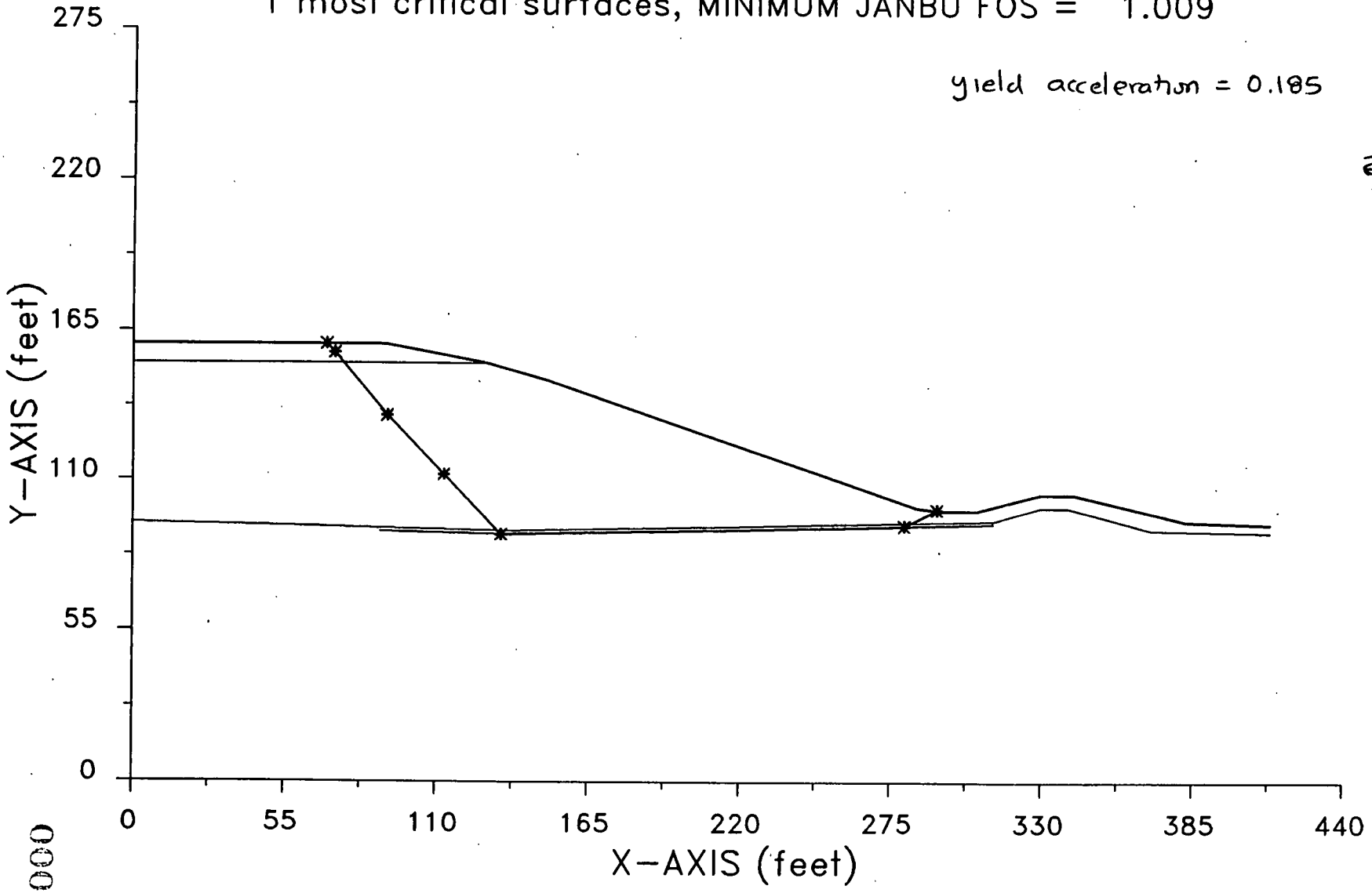
000366

OSDF Interim Configuration–Hyd. Peak

1 most critical surfaces, MINIMUM JANBU FOS = 1.009

yield acceleration = 0.185



M. Wilcox
16 Feb 96

RSS Applic
18/69

253

XSTABL File: CASE10 1-23-96 16:19

```
*****************************************
*              X S T A B L              *
*                                       *
*        Slope Stability Analysis       *
*              using the                *
*           Method of Slices            *
*                                       *
*        Copyright (C) 1992 - 94        *
*   Interactive Software Designs, Inc.  *
*       Moscow, ID 83843, U.S.A.        *
*                                       *
*         All Rights Reserved           *
*                                       *
*  Ver. 5.100                95 - 1305  *
*****************************************
```

Problem Description : OSDF Final - Hydrated Peak (Seismic)

SEGMENT BOUNDARY COORDINATES
---

10 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	92.0	160.0	2
2	92.0	160.0	129.0	153.0	2
3	129.0	153.0	150.0	147.0	1
4	150.0	147.0	285.0	100.0	1
5	285.0	100.0	294.0	99.0	1
6	294.0	99.0	307.0	99.0	2
7	307.0	99.0	330.0	105.0	2
8	330.0	105.0	342.0	105.0	2
9	342.0	105.0	383.0	95.0	2
10	383.0	95.0	414.0	94.0	2

9 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	129.0	153.0	1
2	.0	94.1	136.5	91.4	3
3	136.5	91.4	224.8	93.2	4
4	224.8	93.2	285.0	94.4	5
5	285.0	94.4	313.0	95.0	6
6	313.0	95.0	330.0	100.0	6
7	330.0	100.0	340.0	100.0	6
8	340.0	100.0	370.0	92.0	6
9	370.0	92.0	414.0	91.0	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	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	25.00	.000	.0	0

A horizontal earthquake loading coefficient of .185 has been assigned

A vertical earthquake loading coefficient of .000 has been assigned

M. Clarke 16 Feb 96

A critical failure surface searching method, using a random technique for generating sliding BLOCK surfaces, has been specified.

800 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 30.0 ft

Box no.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Width (ft)
1	136.5	90.0	313.0	94.0	.0
2	90.0	91.0	136.0	90.0	.0

```
*************************************************************************
   -- WARNING -- WARNING -- WARNING -- WARNING -- (# 48)
*************************************************************************
Negative effective stresses were calculated at the base of a slice.
This warning is usually reported for cases where slices have low self
weight and a relatively high "c" shear strength parameter.  In such
cases, this effect can only be eliminated by reducing the "c" value.
*************************************************************************
```

USER SELECTED option to maintain strength greater than zero

```
*************************************************************
**     Factor of safety calculation for surface #   223   **
**     failed to converge within FIFTY iterations          **
**                                                         **
**    The last calculated value of the FOS was   -8.604    **
**    This will be ignored for final summary of results    **
*************************************************************
```

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000368

The trial failure surface in question is
defined by the following 8 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	196.18	130.92
2	188.24	124.07
3	161.70	110.07
4	139.35	90.06
5	115.08	90.45
6	110.48	120.10
7	101.96	148.86
8	91.77	160.00

```
*************************************************************
**     Factor of safety calculation for surface #   433    **
**     failed to converge within FIFTY iterations          **
**                                                         **
**    The last calculated value of the FOS was   -3.373    **
**    This will be ignored for final summary of results    **
*************************************************************
```

The trial failure surface in question is
defined by the following 8 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	198.78	130.02
2	198.03	129.46
3	174.88	110.38
4	152.54	90.36
5	107.89	90.61
6	102.91	120.20
7	101.90	150.18
8	99.04	158.67

Factors of safety have been calculated by the :

* * * * * SIMPLIFIED JANBU METHOD * * * * *

The 10 most critical of all the failure surfaces examined
are displayed below - the most critical first

Failure surface No. 1 specified by 7 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	292.35	99.18
2	280.41	93.26
3	133.72	90.05
4	113.18	111.92
5	92.56	133.71
6	73.42	156.81
7	70.50	160.00

** Corrected JANBU FOS = 1.009 ** (Fo factor =1.076)

Failure surface No. 2 specified by 7 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	293.45	99.06
2	277.61	93.20
3	133.67	90.05
4	114.53	113.15
5	93.74	134.78
6	73.62	157.04
7	71.74	160.00

** Corrected JANBU FOS = 1.013 ** (Fo factor =1.076)

Failure surface No. 3 specified by 7 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	294.47	99.00
2	282.19	93.30
3	130.82	90.11
4	111.50	113.07
5	93.07	136.74
6	73.12	159.14
7	72.31	160.00

** Corrected JANBU FOS = 1.015 ** (Fo factor =1.077)

Failure surface No. 4 specified by 7 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	291.69	99.26
2	281.29	93.28
3	123.79	90.27
4	103.15	112.04
5	84.01	135.14
6	64.35	157.80
7	62.20	160.00

** Corrected JANBU FOS = 1.016 ** (Fo factor =1.076)

Failure surface No. 5 specified by 7 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	304.34	99.00
2	298.82	93.68
3	128.23	90.17
4	107.81	112.15
5	87.71	134.41
6	71.08	159.39
7	70.47	160.00

** Corrected JANBU FOS = 1.016 ** (Fo factor =1.076)

Failure surface No. 6 specified by 6 coordinate points

M. Gleason 16 Feb 96

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Point No.	x-surf (ft)	y-surf (ft)
1	296.74	99.00
2	289.66	93.47
3	135.53	90.01
4	114.47	111.38
5	93.77	133.09
6	82.33	160.00

** Corrected JANBU FOS = 1.019 ** (Fo factor =1.079)

Failure surface No. 7 specified by 7 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	289.00	99.56
2	282.76	93.31
3	126.81	90.20
4	105.82	111.63
5	85.07	133.30
6	63.92	154.58
7	60.59	160.00

** Corrected JANBU FOS = 1.020 ** (Fo factor =1.075)

Failure surface No. 8 specified by 7 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	312.59	100.46
2	302.90	93.77
3	119.94	90.35
4	99.28	112.10
5	80.09	135.16
6	58.90	156.39
7	55.41	160.00

** Corrected JANBU FOS = 1.020 ** (Fo factor =1.072)

Failure surface No. 9 specified by 8 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	298.88	99.00
2	293.65	94.64
3	263.70	92.88
4	113.99	90.48
5	94.17	113.00
6	73.68	134.92
7	54.45	157.94
8	53.70	160.00

** Corrected JANBU FOS = 1.021 ** (Fo factor =1.074)

Failure surface No.10 specified by 7 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	300.85	99.00
2	295.42	93.60
3	130.03	90.13
4	112.71	114.63
5	91.66	136.00
6	71.07	157.82
7	70.48	160.00

** Corrected JANBU FOS = 1.024 ** (Fo factor =1.076)

```
*****************************************************************
**                                                             **
** Out of the    800 surfaces generated and analyzed by XSTABL, **
**        2 surfaces were found to have MISLEADING FOS values. **
**                                                             **
*****************************************************************
```

The following is a summary of the TEN most critical surfaces

Problem Description : OSDF Final - Hydrated Peak (Seismic)

	Modified JANBU FOS	Correction Factor	Initial x-coord (ft)	Terminal x-coord (ft)	Available Strength (lb)
1.	1.009	1.076	292.35	70.50	3.482E+05
2.	1.013	1.076	293.45	71.74	3.436E+05
3.	1.015	1.077	294.47	72.31	3.435E+05
4.	1.016	1.076	291.69	62.20	3.675E+05
5.	1.016	1.076	304.34	70.47	3.588E+05
6.	1.019	1.079	296.74	82.33	3.402E+05
7.	1.020	1.075	289.00	60.59	3.708E+05
8.	1.020	1.072	312.59	55.41	3.828E+05
9.	1.021	1.074	298.88	53.70	3.898E+05
10.	1.024	1.076	300.85	70.48	3.473E+05

* * * END OF FILE * * *

M. Wilson 12 Feb 96

253

NSS 8/20/90

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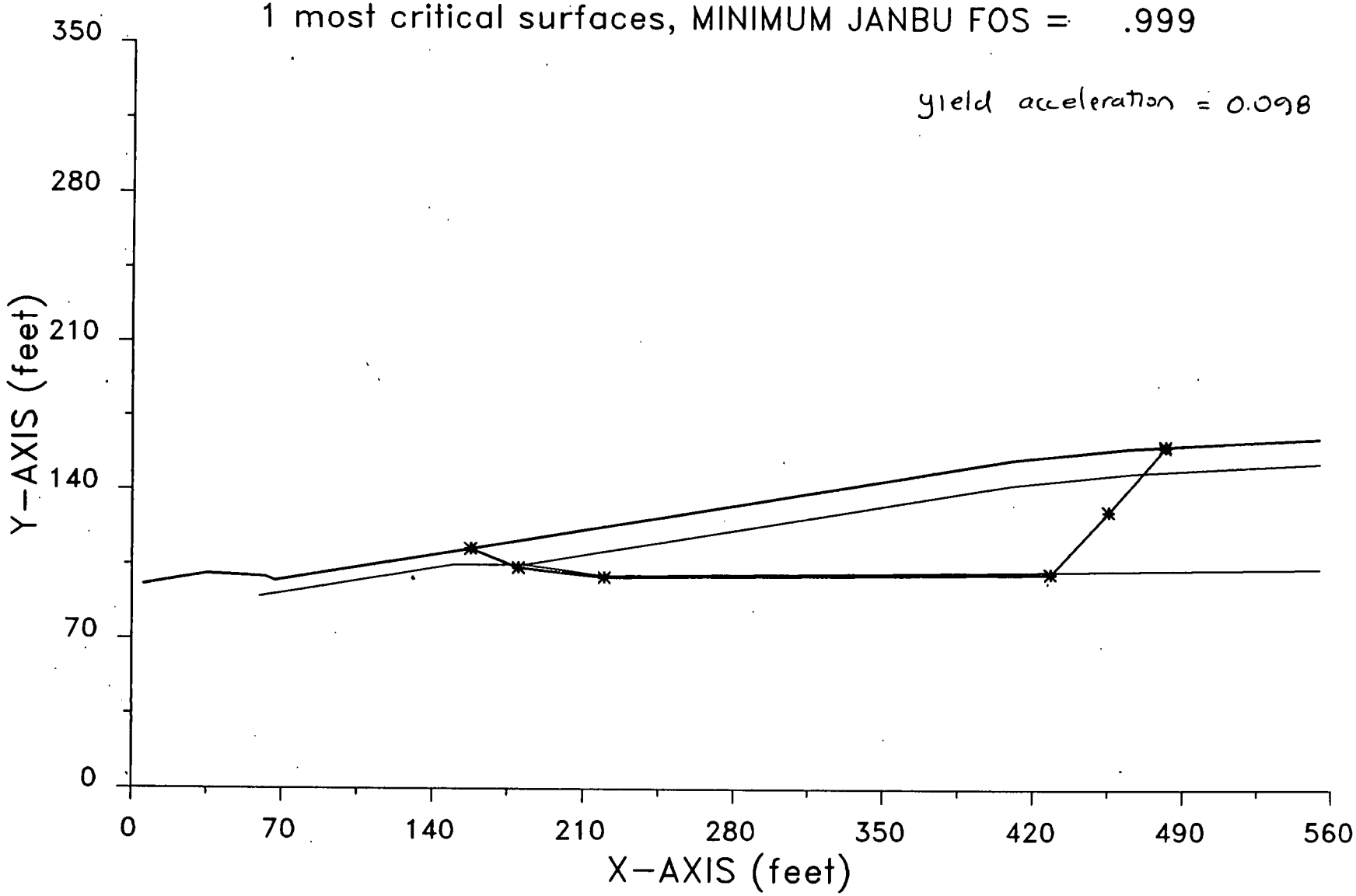
E11 2-02-96 9:27

OSDF Final Configuration–Hyd Peak

1 most critical surfaces, MINIMUM JANBU FOS = .999

yield acceleration = 0.098



M. Gleason
12 Feb 96

SS 96/010

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000571

XSTABL File: CASE11 2-02-96 9:27

```
*****************************************
*              X S T A B L              *
*                                       *
*        Slope Stability Analysis       *
*              using the                *
*           Method of Slices            *
*                                       *
*        Copyright (C) 1992 - 94        *
*   Interactive Software Designs, Inc.  *
*       Moscow, ID 83843, U.S.A.        *
*                                       *
*         All Rights Reserved           *
*                                       *
*  Ver. 5.100                95 - 1305  *
*****************************************
```

Problem Description : OSDF Final Configuration-Hyd Peak

SEGMENT BOUNDARY COORDINATES
---

6 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	5.5	95.6	35.5	100.6	2
2	35.5	100.6	62.5	99.3	2
3	62.5	99.3	67.0	97.5	2
4	67.0	97.5	410.0	154.7	2
5	410.0	154.7	465.0	160.2	2
6	465.0	160.2	555.0	164.7	2

11 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	60.0	90.0	120.0	100.0	2
2	120.0	100.0	150.0	105.0	2
3	150.0	105.0	183.0	105.0	2
4	183.0	105.0	189.0	106.0	1
5	189.0	106.0	410.0	142.8	1
6	410.0	142.8	467.0	148.5	1
7	467.0	148.5	555.0	152.9	1
8	183.0	105.0	220.0	100.0	6
9	220.0	100.0	300.0	100.8	5
10	300.0	100.8	410.0	102.0	4
11	410.0	102.0	555.0	103.5	3

ISOTROPIC Soil Parameters
---

6 Soil unit(s) specified

Soil Unit No.	Unit Weight Moist (pcf)	Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Water Constant (psf)	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	12.00	.000	.0	0

A horizontal earthquake loading coefficient of .098 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.

800 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 40.0 ft

Box no.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Width (ft)
1	220.0	99.0	220.0	99.3	.0
2	280.0	99.6	430.0	101.2	.0

```
*************************************************************
**     Factor of safety calculation for surface #   426    **
**     failed to converge within FIFTY iterations           **
**                                                          **
**    The last calculated value of the FOS was   -6.602     **
**    This will be ignored for final summary of results     **
*************************************************************
```

The trial failure surface in question is defined by the following 4 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	198.26	119.39
2	220.00	99.21
3	290.80	99.72
4	291.47	134.93

Factors of safety have been calculated by the :

* * * * * SIMPLIFIED JANBU METHOD * * * * *

M. Glasser 16 Feb 96

RS 2/6/96 23/19

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The 10 most critical of all the failure surfaces examined are displayed below - the most critical first

Failure surface No. 1 specified by 7 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	157.97	112.67
2	180.25	103.72
3	220.00	99.25
4	428.25	101.18
5	455.60	130.37
6	481.96	160.45
7	482.22	161.06

** Corrected JANBU FOS = .999 ** (Fo factor =1.038)

Failure surface No. 2 specified by 7 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	152.41	111.74
2	180.17	102.88
3	220.00	99.23
4	415.90	101.05
5	444.00	129.52
6	471.99	158.09
7	472.31	160.57

** Corrected JANBU FOS = 1.007 ** (Fo factor =1.038)

Failure surface No. 3 specified by 7 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	165.68	113.96
2	180.58	105.81
3	220.00	99.03
4	425.38	101.15
5	453.50	129.60
6	481.67	157.99
7	484.80	161.19

** Corrected JANBU FOS = 1.013 ** (Fo factor =1.038)

Failure surface No. 4 specified by 6 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	169.31	114.56
2	180.38	104.57
3	220.00	99.04
4	408.24	100.97
5	435.73	130.03
6	462.24	159.92

** Corrected JANBU FOS = 1.023 ** (Fo factor =1.040)

Failure surface No. 5 specified by 6 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	165.36	113.90
2	180.56	105.97
3	220.00	99.28
4	420.05	101.09
5	445.55	131.91
6	465.74	160.24

** Corrected JANBU FOS = 1.024 ** (Fo factor =1.040)

Failure surface No. 6 specified by 6 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	162.12	113.36
2	180.19	102.89
3	220.00	99.00
4	400.01	100.88
5	426.22	131.10
6	438.10	157.51

** Corrected JANBU FOS = 1.026 ** (Fo factor =1.042)

Failure surface No. 7 specified by 6 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	163.49	113.59
2	180.09	101.91
3	220.00	99.27
4	423.11	101.13
5	446.18	133.81
6	467.90	160.35

** Corrected JANBU FOS = 1.029 ** (Fo factor =1.040)

Failure surface No. 8 specified by 6 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	163.45	113.58
2	180.22	103.32
3	220.00	99.13
4	405.90	100.94
5	425.69	135.71
6	437.43	157.44

** Corrected JANBU FOS = 1.036 ** (Fo factor =1.042)

Failure surface No. 9 specified by 6 coordinate points

Point	x-surf	y-surf

M. Gleason 1/6 Feb 96

MSS Rfcalc 24/68

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No.	(ft)	(ft)
1	156.68	112.46
2	180.01	99.90
3	220.00	99.04
4	412.55	101.01
5	438.52	131.45
6	450.80	158.78

** Corrected JANBU FOS = 1.042 ** (Fo factor =1.040)

Failure surface No.10 specified by 6 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	165.33	113.90
2	180.42	104.90
3	220.00	99.11
4	370.52	100.57
5	393.10	133.59
6	409.09	154.55

** Corrected JANBU FOS = 1.042 ** (Fo factor =1.043)

```
*****************************************************************
**                                                             **
**  Out of the    800 surfaces generated and analyzed by XSTABL,  **
**        1 surfaces were found to have MISLEADING FOS values.   **
**                                                             **
*****************************************************************
```

The following is a summary of the TEN most critical surfaces

Problem Description : OSDF Final Configuration-Hyd Peak

	Modified JANBU FOS	Correction Factor	Initial x-coord (ft)	Terminal x-coord (ft)	Available Strength (lb)
1.	.999	1.038	157.97	482.22	2.792E+05
2.	1.007	1.038	152.41	472.31	2.733E+05
3.	1.013	1.038	165.68	484.80	2.818E+05
4.	1.023	1.040	169.31	462.24	2.556E+05
5.	1.024	1.040	165.36	465.74	2.624E+05
6.	1.026	1.042	162.12	438.10	2.364E+05
7.	1.029	1.040	163.49	467.90	2.632E+05
8.	1.036	1.042	163.45	437.43	2.269E+05
9.	1.042	1.040	156.68	450.80	2.596E+05
10.	1.042	1.043	165.33	409.09	1.910E+05

* * * END OF FILE * * *

000574

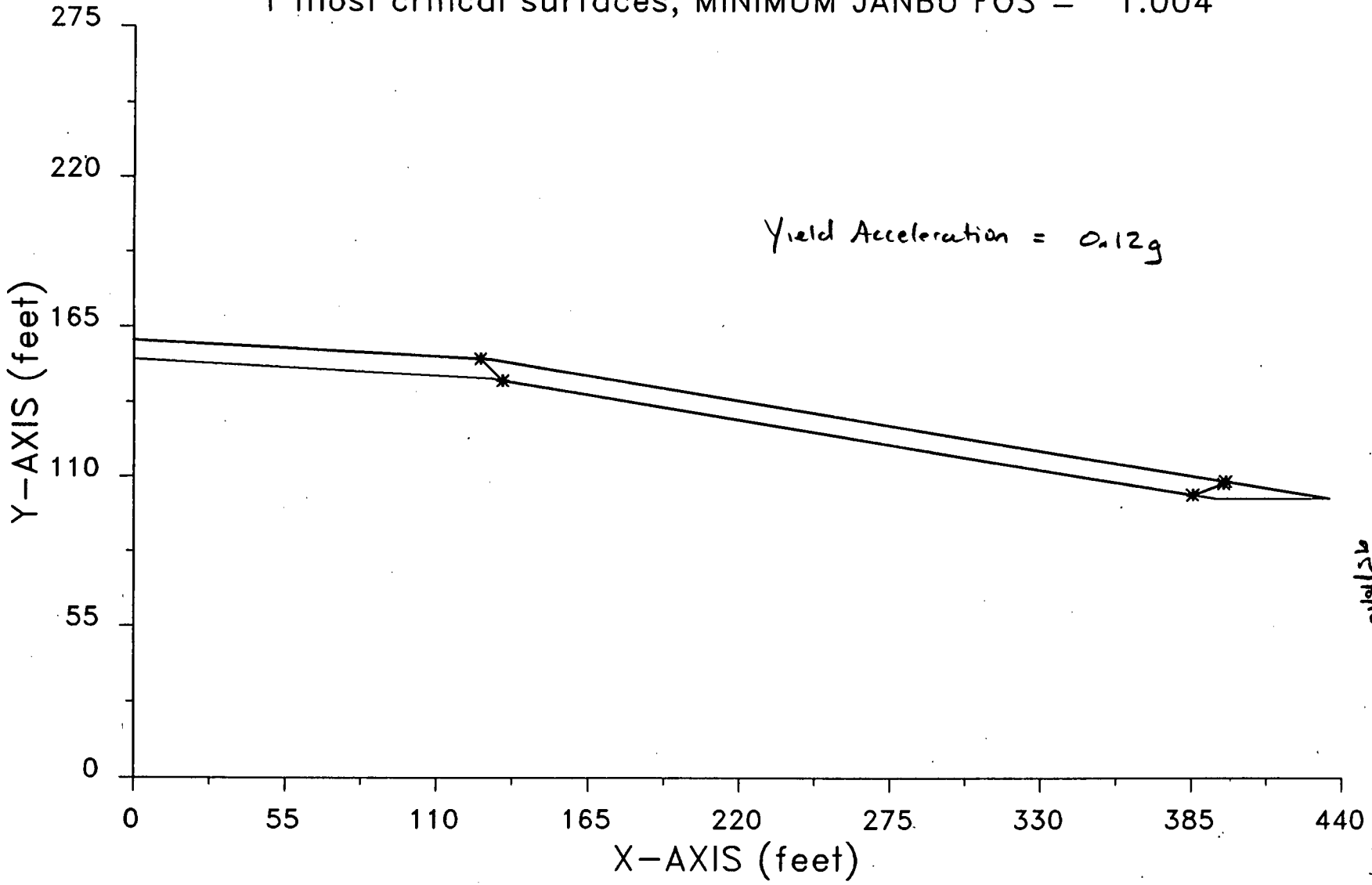
M. Blevins
14 Feb 96

SSS Rafalko 2/6/9

253

FINAL COVER VENER STABILTY – STATIC

1 most critical surfaces, MINIMUM JANBU FOS = 1.004



M. Gleason 9/10/96

253

9/10/96

26/69

RSS 27/69
95/10/16

XSTABL File: FCOVY 10-16-95 15:05

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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.        *
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*                                       *
*  Ver. 5.100                95 á 1305  *
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M. Gleeson
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

95/10/16

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)

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

** 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

95/10/16 30/69

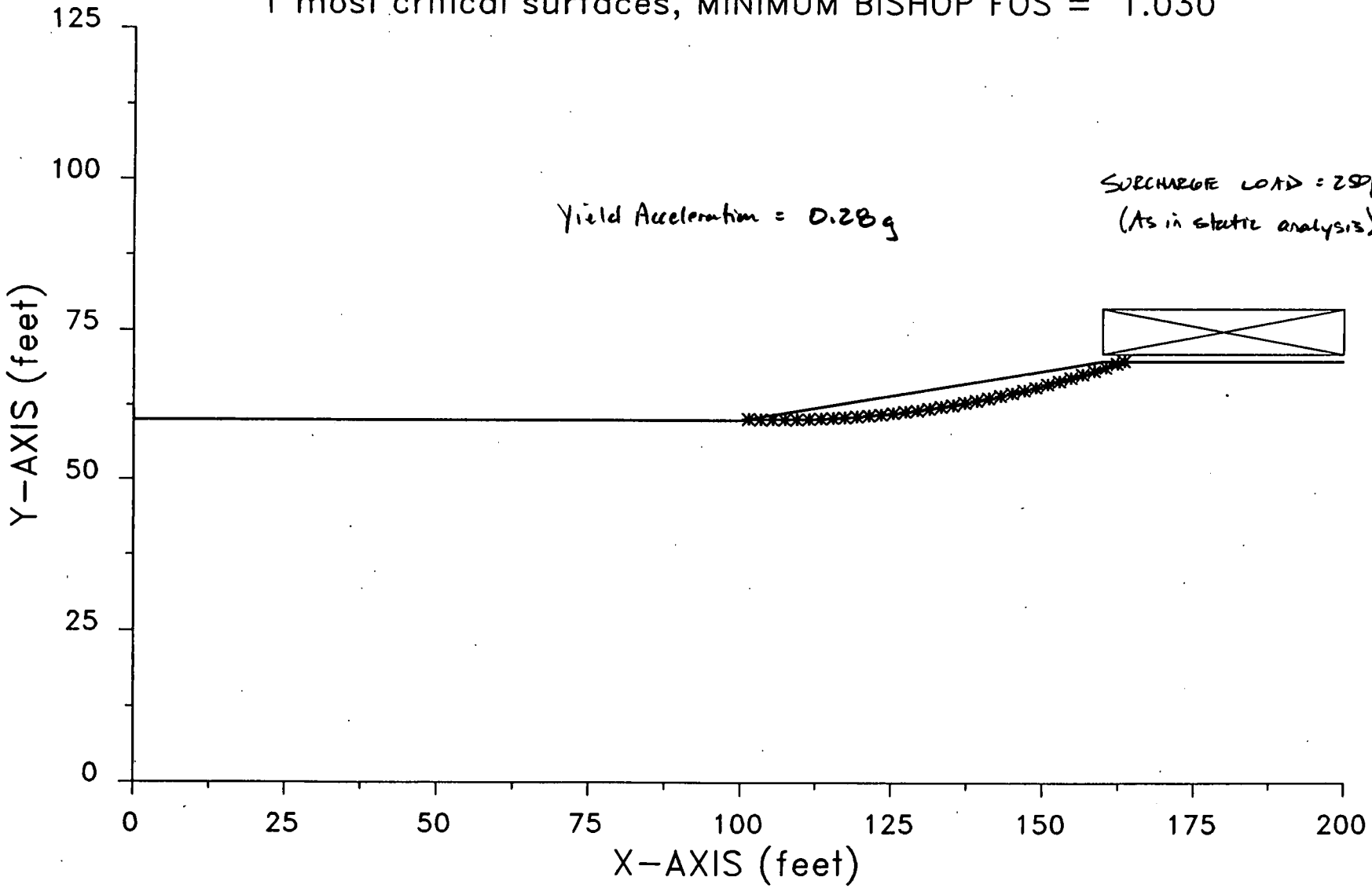
	Modified JANBU FOS	Correction Factor	Initial x-coord (ft)	Terminal x-coord (ft)	Available Strength (lb)
1.	1.004	1.007	397.94	126.39	6.359E+04
2.	1.007	1.008	400.81	139.31	6.113E+04
3.	1.011	1.008	406.05	135.64	6.379E+04
4.	1.011	1.008	389.21	127.96	6.148E+04
5.	1.013	1.008	376.35	132.21	5.712E+04
6.	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 * * *

M. Gleasm
95/10/16

ACCESS CORRIDOR – SEISMIC STABILITY

1 most critical surfaces, MINIMUM BISHOP FOS = 1.030



M. Gleason
20 Feb 96

253

ASS Reviewed 3/1/96

253

SSS 96/02/20

32/69

XSTABL File: BERM1Y 2-20-96 7:35 M. Gilcase 20 Feb 96

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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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*        Moscow, ID 83843, U.S.A.       *
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*          All Rights Reserved          *
*                                       *
*  Ver. 5.100                95 á 1305  *
*****************************************
```

Problem Description : ACCESS CORRIDOR - SEISMIC STABILITY

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	60.0	100.0	60.0	1
2	100.0	60.0	160.0	70.0	1
3	160.0	70.0	200.0	70.0	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 .280 has been assigned

A vertical earthquake loading coefficient
of .000 has been assigned

M. Blease 20 Feb 96

ASS 96/02/20

33/69

BOUNDARY LOADS

1 load(s) specified

Load No.	x-left (ft)	x-right (ft)	Intensity (psf)	Direction (deg)
1	160.0	200.0	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 = 160.0 ft
and x = 190.0 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 :

* * * * * SIMPLIFIED BISHOP METHOD * * * * *

M. Glasser 20 Feb 96

ASS 96/02/20

34/69

The most critical circular failure surface is specified by 33 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	101.43	60.24
2	103.43	60.19
3	105.43	60.17
4	107.43	60.17
5	109.43	60.20
6	111.43	60.24
7	113.43	60.31
8	115.42	60.41
9	117.42	60.53
10	119.42	60.67
11	121.41	60.83
12	123.40	61.02
13	125.39	61.23
14	127.37	61.46
15	129.36	61.72
16	131.34	62.00
17	133.32	62.30
18	135.29	62.63
19	137.26	62.98
20	139.22	63.35
21	141.18	63.75
22	143.14	64.16
23	145.09	64.60
24	147.04	65.07
25	148.98	65.55
26	150.91	66.06
27	152.84	66.59
28	154.76	67.15
29	156.68	67.72
30	158.58	68.32
31	160.49	68.94
32	162.38	69.58
33	163.56	70.00

**** Simplified BISHOP FOS = 1.030 ****

The following is a summary of the TEN most critical surfaces

Problem Description : ACCESS CORRIDOR - SEISMIC STABILITY

	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.	1.030	106.34	231.62	171.45	101.43	163.56	1.492E+06
2.	1.033	103.65	215.18	155.97	87.96	160.65	1.481E+06
3.	1.036	107.75	190.02	131.10	91.02	160.48	1.436E+06

4.	1.042	111.80	198.34	139.05	97.76	165.31	1.826E+06
5.	1.050	110.49	201.86	143.03	92.24	165.90	2.107E+06
6.	1.060	116.22	150.60	92.84	95.92	162.30	1.561E+06
7.	1.061	117.54	156.25	98.38	97.14	164.87	1.789E+06
8.	1.063	106.27	203.74	145.51	83.67	163.58	2.180E+06
9.	1.066	110.49	213.95	155.25	90.41	168.63	2.605E+06
10.	1.066	109.57	191.12	133.19	86.12	164.98	2.308E+06

* * * END OF FILE * * *

SSS 96/01/20 35/69

M. Glass
20 Feb 96

M. Gleason
95/10/20

253

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95-10-20

36/69

DEFORMATION ANALYSIS FILES

M. Gleason
95/10/20

SSS
95-10-20

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

M. Gleason
7 Feb 96

RSS 96/02/20

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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
5.170026	.000000	.000000	.000000
5.175000	.704807	.001753	.000001
5.175548	.533654	.000000	.000002
5.175548	.000000	.000000	.000002
5.200000	.000000	.000000	-.000235
9.329642	.000000	.000000	-.000235
9.350000	11.064249	.112620	.000066
9.375000	14.259717	.429170	.002667
9.400000	7.741723	.704188	.008378
9.425000	-6.544872	.719149	.015675
9.450000	-25.954069	.312912	.021152
9.458537	-33.261491	.000000	.021797
9.458537	.000000	.000000	.021797
50.975000	.000000	.000000	.021797

M. Gleason
95/10/20

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95-10-20

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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

YSLIP-IN.XLS

M. GLEASON 7 Feb 96 /SS 96/02/20 40/69

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

Case 2 Interim/Final Impacted Materials
(Failure Surface Along the Liner System)

Interface phi = 8 degrees 0.139626 radians

a-yield = 0.10 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	
2.2	0.038397	0.101576	
2.3	0.040143	0.099813	
2.25	0.03927	0.100695	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

YSLIP_C INPUT FILE - FOUNDATION CONDITION

M. Gleason 95/10/20


```
25. 19.8 10000. 10000. 0.
0. 1 1
2040 255 16320 0.025 1
 -0.000089-0.000010-0.000160 0.000177 0.000097-0.000068 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
 -0.001230-0.001490-0.001850-0.002330-0.002980-0.003510-0.004060-0.004440
 -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
 -0.004510-0.003580-0.002150-0.000800 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 0.000748 0.003120 0.005222 0.007601 0.008518 0.009060 0.010156
  0.011235 0.012369 0.013551 0.014537 0.015012 0.014833 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
 -0.020480-0.023640-0.025680-0.026210-0.025250-0.022680-0.019070-0.015530
 -0.013060-0.011860-0.011630-0.012020-0.012140-0.011140-0.009030-0.006080
 -0.002940-0.000330 0.000366-0.001640-0.006120-0.013100-0.020730-0.028280
 -0.034560-0.037950-0.037360-0.032150-0.021980-0.007180 0.010887 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 0.001129-0.014030-0.027290-0.034330
 -0.036560-0.035300-0.031700-0.026740-0.019310-0.011460-0.007210-0.006220
 -0.008370-0.013010-0.018740-0.023570-0.026770-0.028770-0.030520-0.032550
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 -0.041910-0.037790-0.032020-0.025520-0.019700-0.015510-0.012540-0.009150
 -0.003510 0.006214 0.021282 0.041341 0.063658 0.083625 0.096932 0.100529
  0.092603 0.073156 0.045043 0.014503-0.011610-0.029940-0.041170-0.046530
 -0.045710-0.038910-0.028730-0.019290-0.013240-0.010130-0.008710-0.008030
 -0.010990-0.014060-0.019100-0.022670-0.024660-0.023460-0.017670-0.008120
  0.002491 0.012433 0.021633 0.028973 0.031526 0.027401 0.016222-0.001600
 -0.023960-0.047700-0.069030-0.087290-0.097690-0.099420-0.090940-0.071820
 -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 0.031480 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 0.020815 0.032847 0.040363 0.040276 0.031581
  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
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M. Gleason
95/10/20

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YSLIP_C INPUT LINEZ CONDITION

43/69


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M. Gleason
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YSLIP-C INPUT FILE FINAL COVER

M. Gleason 95/10/20

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M. Gleason
95/10/20

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FERMCO - OSDF
GK3980-9.11
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 x 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 ✓

Time	Shear Stress		Accleration	(-)
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

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Time	Shear Stress		Accleration	(-)
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
3.2	-0.02097		-0.00294	0.00294
3.225	-0.00237		-0.00033	0.00033
3.25	0.00261	0.00037	-0.00037	
3.275	-0.01169		-0.00164	0.00164
3.3	-0.04360		-0.00612	0.00612
3.325	-0.09331		-0.01310	0.01310
3.35	-0.14772		-0.02073	0.02073
3.375	-0.20149		-0.02828	0.02828
3.4	-0.24622		-0.03456	0.03456
3.425	-0.27042		-0.03795	0.03795
3.45	-0.26620		-0.03736	0.03736
3.475	-0.22906		-0.03215	0.03215
3.5	-0.15662		-0.02198	0.02198
3.525	-0.05114		-0.00718	0.00718
3.55	0.07700	0.01081	-0.01081	
3.575	0.20479	0.02874	-0.02874	
3.6	0.30601	0.04295	-0.04295	
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

Time	Shear Stress		Accleration	(-)
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	-0.24120		-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	0.08362	-0.08362	
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	-0.13740		-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	-0.07832		-0.01099	0.01099
5.625	-0.10590		-0.01486	0.01486
5.65	-0.13606		-0.01910	0.01910
5.675	-0.16153		-0.02267	0.02267
5.7	-0.17571		-0.02466	0.02466
5.725	-0.16710		-0.02346	0.02346
5.75	-0.12589		-0.01767	0.01767

5.775	-0.05706	-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	0.20643 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
[illegible]	-0.17070	-0.02396	0.02396
[illegible]25	-0.33907	-0.04770	0.04770
[illegible]5	-0.49754	-0.06983	0.06983
[illegible].975	-0.62191	-0.08729	0.08729
6.1	-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	0.19896 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	-0.49063	-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	-0.18602	-0.02622	0.02622
6.875	-0.04483	-0.00629	0.00629
6.9	0.09035 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	0.20670 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	

[illegible]75	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	0.45603 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	0.07109 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 0.02082	-0.02082	
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	-0.19279	-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	-0.00620	-0.00088	0.00088
8.225	0.02077 0.00292	-0.00292	
8.25	0.02258 0.00317	-0.00317	
8.275	-0.00132	-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	-0.63521	-0.08917	0.08917
8.475	-0.66903	-0.09390	0.09390
[illegible]5	-0.64105	-0.09000	0.09000
[illegible]25	-0.58624	-0.08220	0.08220
[illegible]5	-0.47203	-0.06626	0.06626
[illegible]575	-0.33279	-0.04671	0.04671
8.6	-0.19886	-0.02788	0.02788
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	-0.03590	-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	0.05431 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	-0.25150	-0.03530	0.03530
9.2	-0.19125	-0.02684	0.02684
9.225	-0.05590	-0.00785	0.00785
9.25	0.12882 0.01797	-0.01797	
9.275	0.33384 0.04674	-0.04674	
9.3	0.53150 0.07461	-0.07461	
9.325	0.69292 0.09725	-0.09725	
9.35	0.79123 0.11105	-0.11105	
9.375	0.81494 0.11429	-0.11429	
9.4	0.76710 0.10767	-0.10767	
9.425	0.66392 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	0.07960 0.01118	-0.01118	
9.725	0.14052 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	0.39720 0.05576	-0.05576	
9.85	0.43738 0.06139	-0.06139	
9.875	0.46172 0.06480	-0.06480	
9.9	0.45280 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	-0.00633	-0.01212	0.01212
10.05	-0.23239	-0.03262	0.03262
10.075	-0.38970	-0.05471	0.05471
10.1	-0.53300	-0.07481	0.07481
10.125	-0.63804	-0.08955	0.08955
10.15	-0.69289	-0.09729	0.09729
10.175	-0.70823	-0.09828	0.09828
10.2	-0.66580	-0.09345	0.09345
10.225	-0.59875	-0.08403	0.08403
10.25	-0.50582	-0.07088	0.07088

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	-0.18607	-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	0.17382 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	-0.22627	-0.03177	0.03177
11.05	-0.09660	-0.01357	0.01357
11.075	0.05447 0.00765	-0.00765	
11.1	0.19284 0.02707	-0.02707	
11.125	0.29885 0.04183	-0.04183	
11.15	0.36314 0.05097	-0.05097	
11.175	0.39881 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	0.28027 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	0.18898 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	-0.03282	0.03282
11.625	-0.22830	-0.03204	0.03204
11.65	-0.17661	-0.02479	0.02479
11.[illegible]	-0.08742	-0.01227	0.01227
11.7	0.03523 0.00494	-0.00494	
11.725	0.17785 0.02496	-0.02496	
11.75	0.28925 0.04340	-0.04340	

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11.775	0.39544	0.05550	-0.05550	
11.8	0.42008	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
12.025	-0.54294		-0.07620	0.07620
12.05	-0.52027		-0.07302	0.07302
12.075	-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	-0.31789		-0.04459	0.04459
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	0.03088	-0.03088	
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	0.30604	0.04307	-0.04307	
13.025	0.22821	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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13.275	-0.39542		-0.05550	0.05550
13.3	-0.29010		-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	0.06243	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	0.26928	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	-0.22883		-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	0.15858	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	-0.32110		-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	0.19813	0.02668	-0.02668	
14.475	0.32310	0.04535	-0.04535	
14.5	0.43141	0.06055	-0.06055	
14.525	0.49855	0.06997	-0.06997	
14.55	0.51699	0.07256	-0.07256	
14.575	0.49989	0.07016	-0.07016	
14.6	0.46067	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	0.02823	0.00204	-0.00204	
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	-0.37268		-0.05244	0.05244
14.9	-0.34789		-0.04871	0.04871
14.925	-0.31197		-0.04379	0.04379
14.95	-0.27786		-0.03889	0.03889
14.975	-0.25639		-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	-0.08833		-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	0.02280	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	0.52340	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	0.16262	0.02296	-0.02296	
15.975	0.23691	0.03325	-0.03325	
16	0.32904	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	0.58604	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	0.38235	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	0.05014	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	0.05826	0.00819	-0.00819	
16.85	-0.05248		-0.00735	0.00735
16.875	-0.14650		-0.02056	0.02056
16.9	-0.21386		-0.03002	0.03002
16.925	-0.25198		-0.03535	0.03535
16.95	-0.24953		-0.03502	0.03502
16.975	-0.20881		-0.02810	0.02810
17	-0.09988		-0.01402	0.01402
17.025	0.02159	0.00443	-0.00443	
17.05	0.16015	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	0.04772	-0.04772	
17.175	0.24802	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	-0.34804		-0.04773	0.04773
17.3	-0.44742		-0.06288	0.06288
17.325	-0.52198		-0.07325	0.07325
17.35	-0.57717		-0.08101	0.08101
17.375	-0.61222		-0.08607	0.08607
17.4	-0.61824		-0.08565	0.08565
17.425	-0.55723		-0.07822	0.07822
17.45	-0.46869		-0.06578	0.06578
17.475	-0.36626		-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	-0.34621		-0.04861	0.04861
17.725	-0.44513		-0.06247	0.06247
17.75	-0.51555		-0.07236	0.07236

17.775	-0.55881	-0.07832	0.07832
17.8	-0.57016	-0.08082	0.08082
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
.025	-0.20834	-0.02924	0.02924
05	-0.23885	-0.03229	0.03229
..075	-0.24402	-0.03425	0.03425
18.1	-0.25030	-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	-0.08598	-0.01194	0.01194
18.5	-0.03884	-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	0.30894 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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275	0.45460 0.06380	-0.06380	
..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	0.00982 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	-0.06986	0.06986
20.425	-0.45683	-0.06412	0.06412
20.45	-0.48528	-0.05690	0.05690
20.475	-0.34988	-0.04911	0.04911
20.5	-0.29500	-0.04140	0.04140
525	-0.23901	-0.03355	0.03355
55	-0.18054	-0.02534	0.02534
.575	-0.11831	-0.01660	0.01660
20.6	-0.05122	-0.00719	0.00719
20.625	0.01778 0.00248	-0.00248	
20.65	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	0.21583 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	-0.27017	-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	0.05960 0.00836	-0.00836	
22.225	0.03399 0.00477	-0.00477	
22.25	0.03615 0.00507	-0.00507	

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	0.08986 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	-0.16040	-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	-0.08810	0.08810
23.275	-0.59501	-0.08262	0.08262
23.3	-0.53448	-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	0.19098 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	0.19882 0.02670	-0.02670	
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		-0.02889	0.02889
23.8	-0.10061		-0.01412	0.01412
23.825	-0.06985		-0.00843	0.00843
23.85	-0.02914		-0.00489	0.00489
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	0.51990	0.07284	-0.07284	
24.325	0.49079	0.06888	-0.06888	
24.35	0.44849	0.06295	-0.06295	
24.375	0.39548	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	-0.47080		-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	-0.26038		-0.03655	0.03655
25.45	-0.22933		-0.03219	0.03219
25.475	-0.21393		-0.03003	0.03003
25.5	-0.20899		-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	0.00425	0.01102	-0.01102	
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	0.33927	0.04762	-0.04762	
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	0.17211	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	
.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	0.27034	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	0.34886	0.04784	-0.04784	

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	0.23811	0.03238	-0.03238	
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	0.01906	0.00267	-0.00267	
27.175	0.02887	0.00405	-0.00405	
27.2	0.01894	0.00266	-0.00266	
27.225	-0.00582		-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	0.04854	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	-0.18034		-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	-0.14288		-0.02005	0.02005
27.85	-0.12118		-0.01701	0.01701
27.875	-0.09855		-0.01383	0.01383
27.9	-0.07670		-0.01077	0.01077
27.925	-0.05882		-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	-0.00250		-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	0.01590	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	-0.03483		-0.00488	0.00488
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	0.02385	0.00334	-0.00334	
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	0.08007	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	-0.07881		-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	0.00480	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	0.08448	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	-0.13628		-0.01914	0.01914
29.55	-0.14796		-0.02077	0.02077
29.575	-0.14478		-0.02032	0.02032
29.6	-0.12877		-0.01835	0.01835
29.625	-0.10980		-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	-0.11896		-0.01557	0.01557
29.975	-0.09486		-0.01320	0.01320
30	-0.05985		-0.00840	0.00840
30.025	-0.00872		-0.00122	0.00122
30.05	0.05166	0.00725	-0.00725	
30.075	0.11047	0.01550	-0.01550	
30.1	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	-0.03730		-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	-0.19790		-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	0.00861	-0.00861	
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	

31.275	0.12732	0.01787	-0.01787	
31.3	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	0.15085	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	-0.05348		-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	-0.08885		-0.01236	0.01236
32.5	-0.10015		-0.01406	0.01406
32.525	-0.11095		-0.01557	0.01557
32.55	-0.12241		-0.01718	0.01718
32.575	-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

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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	-0.09830		-0.01260	0.01260
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	-0.22750		-0.03193	0.03193
33.05	-0.24643		-0.03459	0.03459
33.075	-0.24740		-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	0.08549	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	0.15890	0.02230	-0.02230	
33.85	0.16100	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	0.10610	0.01490	-0.01490	
33.975	0.08150	0.01144	-0.01144	
34	0.05810	0.00815	-0.00815	
34.025	0.04610	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	0.05396	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

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	-0.06607		-0.00928	0.00928
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	0.00970	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	-0.10710		-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	0.01121	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	
36.1	0.04727	0.00663	-0.00663	
36.125	0.05516	0.00774	-0.00774	
36.15	0.06487	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	0.00190	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	-0.03990		-0.00560	0.00560
36.875	-0.05090		-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

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	0.02670	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	-0.08180		-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	-0.01240		-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	0.05070	0.00712	-0.00712	
39.275	0.05426	0.00762	-0.00762	
39.3	0.05301	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

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	0.00182	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	0.01558	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

41.775	0.00461	0.00065	-0.00065	
41.8	0.00907	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	-0.02253		-0.00322	0.00322
42.025	-0.01585		-0.00222	0.00222
42.05	-0.00494		-0.00069	0.00069
42.075	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	0.01109	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	0.04408	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

43.275	-0.02189		-0.00307	0.00307
43.3	-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	-0.03748		-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	-0.02729		-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	-0.05106		-0.00728	0.00728
44.475	-0.05218		-0.00732	0.00732
44.5	-0.05068		-0.00711	0.00711
44.525	-0.04826		-0.00677	0.00677
44.55	-0.04486		-0.00630	0.00630
44.575	-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	-0.02504		-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

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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	0.03287	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	0.02285	0.00389	-0.00389	
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	0.01798	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

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	-0.00528		-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	0.01088	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	0.02200	0.00320	-0.00320	
47.25	0.02969	0.00417	-0.00417	
47.275	0.03722	0.00524	-0.00524	
47.3	0.04409	0.00620	-0.00620	
47.325	0.05147	0.00722	-0.00722	
47.35	0.05686	0.00797	-0.00797	
47.375	0.05793	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	

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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	0.02406	0.00338	-0.00338
47.875	0.01794	0.00252	-0.00252
47.9	0.01180	0.00166	-0.00166
47.925	0.00631	0.00089	-0.00089
47.95	0.00277	0.00039	-0.00039
47.975	0.00060	0.00008	-0.00008
48	0.00138	0.00019	-0.00019
48.025	0.00380	0.00054	-0.00054
48.05	0.00685	0.00096	-0.00096
48.075	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

M. Gleason
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49.275	0.00355	0.00050	-0.00050
49.3	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	-0.01842	-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
50.5	-0.01735	-0.00244	0.00244
50.525	-0.02054	-0.00288	0.00288
50.55	-0.02306	-0.00324	0.00324
50.575	-0.02507	-0.00352	0.00352
50.6	-0.02681	-0.00376	0.00376
50.625	-0.02830	-0.00397	0.00397
50.65	-0.02937	-0.00412	0.00412
50.675	-0.02995	-0.00420	0.00420
50.7	-0.02998	-0.00422	0.00422
50.725	-0.02974	-0.00417	0.00417
50.75	-0.02886	-0.00405	0.00405

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	0.01286	0.00183	-0.00183
51.15	0.01099	0.00154	-0.00154
51.175	0.01211	0.00170	-0.00170

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MG 95/10/20

FERMCO - OSDF
GE3990-9.11
Layer 2 - Cover Acceleration
Synthetic - B2-SYN

MAX= 0.14264
MIN= -0.13884

Acceleration = $\frac{\text{Shear Stress}}{\text{Normal Stress } (\sigma_n)}$

σ_n = 3ft × 0.125 kcf
= 0.375 ksf

Normal stress calculated at top of layer in question

Time	Shear Stress	Acceleration	(-)
0	0.000043	0.00011	-0.00011
.025	0.000024	0.00006	-0.00006
.05	0.000042	0.00011	-0.00011
.075	0.000022	0.00006	-0.00006
0.1	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	0.00008	-0.00008
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
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

check

$$Acc = \frac{-0.000129}{0.375}$$

$$= -0.00034 \checkmark$$

1.275	-0.001394	-0.00372	0.00372
1.3	-0.000845	-0.00225	0.00225
1.325	-0.000323	-0.00086	0.00086
1.35	0.000008	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	0.002555	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
2.525	0.003094	0.00825	-0.00825
2.55	0.003877	0.01034	-0.01034
2.575	0.004814	0.01284	-0.01284
2.6	0.005485	0.01463	-0.01463
2.625	0.004944	0.01318	-0.01318
2.65	0.003485	0.00988	-0.00988
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

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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	-0.003106	-0.00828	0.00828
3.2	0.000802	0.00214	-0.00214
3.225	0.003247	0.00866	-0.00866
3.25	0.003804	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	0.02267	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	0.05072	-0.05072
4.05	0.013208	0.03522	-0.03522
4.075	0.00635	0.01693	-0.01693
4.1	-0.001901	-0.00528	0.00528
4.125	-0.010517	-0.02805	0.02805
4.15	-0.016292	-0.04371	0.04371
4.175	-0.020617	-0.05498	0.05498
4.2	-0.023835	-0.06143	0.06143
4.225	-0.01986	-0.05296	0.05296
4.25	-0.011775	-0.03140	0.03140

M-Gleason 95/10/20

SSS 95-10-20

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	-0.008472	-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	-0.015670	-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	-0.002472	-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	0.034801	0.09282	-0.09282
5.25	0.019959	0.05322	-0.05322
5.275	0.002578	0.00687	-0.00687
5.3	-0.015252	-0.04094	0.04094
5.325	-0.029426	-0.07850	0.07850
5.35	-0.03256	-0.08949	0.08949
5.375	-0.025847	-0.06893	0.06893
5.4	-0.014324	-0.03820	0.03820
5.425	-0.009987	-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	-0.000239	-0.00063	0.00063
5.6	-0.002832	-0.00889	0.00889
5.625	-0.005618	-0.01498	0.01498
5.65	-0.008427	-0.02247	0.02247
5.675	-0.010889	-0.02882	0.02882
5.7	-0.011625	-0.03100	0.03100
5.725	-0.010623	-0.02835	0.02835
5.75	-0.009235	-0.02463	0.02463

000605

5.775	-0.007622	-0.02833	0.02833
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	0.012086	0.03223	-0.03223
5.975	0.004675	0.01247	-0.01247
[illegible]	-0.006643	-0.01771	0.01771
[illegible]125	-0.017831	-0.04755	0.04755
[illegible]5	-0.030910	-0.08245	0.08245
[illegible]075	-0.043510	-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	0.040678	0.10847	-0.10847
6.325	0.044195	0.11785	-0.11785
6.35	0.042793	0.11411	-0.11411
6.375	0.039189	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	0.026260	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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[illegible]75	0.006646	0.01772	-0.01772
[illegible]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	0.012160	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	-0.009868	-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	0.003753	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	-0.049866	-0.12884	0.12884
8.5	-0.044547	-0.11879	0.11879
[illegible]25	-0.034748	-0.09266	0.09266
[illegible]5	-0.024191	-0.06451	0.06451
[illegible]575	-0.013632	-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	0.002262	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	0.00807 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	0.07460	-0.07460
9.875	0.022809	0.06082	-0.06082
9.9	0.018891	0.05038	-0.05038
9.925	0.021061	0.05616	-0.05616
9.95	0.022049	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	-0.006760	-0.01805	0.01805
10.325	-0.005045	-0.01345	0.01345
10.35	-0.004053	-0.01294	0.01294
10.375	-0.005560	-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	0.0050 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	-0.022288	-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	0.015072	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	0.022282	0.05947	-0.05947
11.475	0.020845	0.05559	-0.05559
11.5	0.008615	0.02297	-0.02297
11.525	-0.006127	-0.01637	0.01637
11.55	-0.015228	-0.04061	0.04061
11.575	-0.017589	-0.04669	0.04669
11.6	-0.017287	-0.04587	0.04587
11.625	-0.017256	-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	0.09056	-0.09056
11.85	0.022387	0.05970	-0.05970
11.875	0.007866	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	-0.032481	-0.08648	0.08648
12	-0.037053	-0.09881	0.09881
825	-0.03647	-0.09725	0.09725
85	-0.031539	-0.08410	0.08410
..875	-0.025737	-0.06863	0.06863
12.1	-0.020568	-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	-0.027286	-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	0.014489	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	0.029430	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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275	-0.026166	-0.06978	0.06978
..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	0.012892	0.03414	-0.03414
13.4	0.020425	0.05447	-0.05447
13.425	0.024285	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	-0.009236	-0.02490	0.02490
13.575	-0.000638	-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	-0.010388	-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	-0.007284	-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	0.025897	0.06882	-0.06882
14.5	0.027043	0.07211	-0.07211
525	0.028007	0.07469	-0.07469
55	0.029701	0.07942	-0.07942
..575	0.031611	0.08439	-0.08439
14.6	0.030112	0.08039	-0.08039
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

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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	0.05596
14.95	-0.018191	-0.04851	0.04851
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	-0.019488	-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	0.034839	0.09077	-0.09077
15.725	0.0403	0.10747	-0.10747
15.75	0.043414	0.11577	-0.11577
15.775	0.03876	0.10336	-0.10336
15.8	0.027573	0.07353	-0.07353
15.825	0.017481	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

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	0.019002	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	0.016509	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	-0.019909	-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	0.026080	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	-0.008020	-0.02141	0.02141
17.25	-0.015046	-0.04012	0.04012
17.275	-0.02148	-0.05728	0.05728
17.3	-0.029112	-0.07762	0.07762
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	0.00217	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	-0.039992		-0.10641	0.10641
17.8	-0.034646		-0.09239	0.09239
17.825	-0.027576		-0.07354	0.07354
17.85	-0.024104		-0.06420	0.06420
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	-0.005083		-0.01355	0.01355
.025	-0.005501		-0.01467	0.01467
05	-0.008563		-0.02283	0.02283
..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	-0.001218		-0.00325	0.00325
18.5	0.002885		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	0.010296		0.04879	-0.04879
18.625	0.026986		0.07196	-0.07196
18.65	0.032832		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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.275	0.028029		0.07477	-0.07477
..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	0.026037		0.07157	-0.07157
19.425	0.019112		0.05097	-0.05097
19.45	0.01087	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	-0.019138		-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	-0.011368		-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	-0.018079		-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	-0.020104		-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	-0.026039		-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
.525	-0.006099		-0.01626	0.01626
55	-0.006112		-0.01630	0.01630
.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	0.005532		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

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20.775	0.009181		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	-0.020908		-0.05575	0.05575
21.875	-0.018802		-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	-0.000835		-0.00089	0.00089

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	0.007188		0.01895	-0.01895
22.8	0.003126		0.00834	-0.00834
22.825	0.002136		0.00570	-0.00570
22.85	0.003534		0.00948	-0.00948
22.875	0.003887		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	-0.010568		-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	0.021829		0.05688	-0.05688
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	0.001886	0.00402	-0.00402
23.925	0.001439	0.00384	-0.00384
23.95	0.001079	0.00288	-0.00288
23.975	0.0080	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	0.029728	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

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	-0.00786	-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	0.019460	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	0.007950	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
26.65	0.012504	0.03334	-0.03334
26.675	0.013811	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	0.019888	0.05869	-0.05869
26.825	0.019813	0.05870	-0.05870
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	-0.00868	-0.02315	0.02315
27.325	-0.00946	-0.02523	0.02523
27.35	-0.009450	-0.02522	0.02522
27.375	-0.007668	-0.02045	0.02045
27.4	-0.004014	-0.01070	0.01070
27.425	0.000824	0.00086	-0.00086
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	-0.004220	-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	-0.000570	-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	0.000129	0.00037	-0.00037
28.225	-0.001942	-0.00518	0.00518
28.25	-0.00265	-0.00707	0.00707

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	-0.007242	-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	-0.008870	-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	-0.007570	-0.02021	0.02021
29.55	-0.008025	-0.02140	0.02140
29.575	-0.008956	-0.02388	0.02388
29.6	-0.00948	-0.02528	0.02528
29.625	-0.007887	-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

000609

29.775	0.003781	0.01088	-0.01088
29.8	0.002033	0.00542	-0.00542
29.825	-0.000568	-0.00151	0.00151
29.85	-0.002729	-0.00720	0.00720
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	0.006708	0.01010	-0.01010
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	-0.02418	0.02418
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	-0.008204	-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	0.000060	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

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	0.012828	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	0.004566	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	-0.005203	-0.01409	0.01409
32.25	-0.004731	-0.01262	0.01262
32.275	-0.002719	-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	-0.012768	-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	-0.003942	-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	0.006503	0.01735	-0.01735
33.775	0.007904	0.02108	-0.02108
33.8	0.008987	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	0.008060	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

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	-0.004440	-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	0.005322	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	0.002192	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	0.000812	0.00217	-0.00217
35.725	0.001214	0.00324	-0.00324
35.75	0.001457	0.00389	-0.00389

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35.775	0.001037	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	
36	0.002567	0.00685	-0.00685
36.025	0.001524	0.00406	-0.00406
36.05	0.001122	0.00299	-0.00299
36.075	0.001137	0.00303	-0.00303
36.1	0.00158 0.00421	-0.00421	
36.125	0.002641	0.00704	-0.00704
36.15	0.004025	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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37.275	-0.001256	-0.00335	0.00335
37.3	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	0.006608	0.01783	-0.01783
37.825	0.007395	0.01972	-0.01972
37.85	0.00786 0.02096	-0.02096	
37.875	0.007723	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	0.001723	0.00462	-0.00462
38.475	0.002259	0.00602	-0.00602
38.5	0.002442	0.00651	-0.00651
38.525	0.002146	0.00572	-0.00572
38.55	0.001297	0.00346	-0.00346
38.575	-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

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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	0.003813	0.00983	-0.00983
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	0.002588	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	0.001920	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

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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	-0.000372	-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	0.003381	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	0.00380	-0.00380
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	-0.002308	-0.00615	0.00615
42	-0.001878	-0.00501	0.00501
025	-0.001023	-0.00273	0.00273
05	-0.000074	-0.00020	0.00020
..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	0.006028	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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275	-0.001028	-0.00487	0.00487
.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
525	-0.002432	-0.00649	0.00649
55	-0.001576	-0.00420	0.00420
.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

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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	0.002070	0.00554	-0.00554
45.425	0.002088	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

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	0.000432	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	0.000018	0.00005	-0.00005
47.05	0.000056	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

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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	0.000391	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
50.5	-0.000948	-0.00253	0.00253
525	-0.001065	-0.00284	0.00284
55	-0.001262	-0.00337	0.00337
.575	-0.00144	-0.00384	0.00384
50.6	-0.001504	-0.00401	0.00401
50.625	-0.001562	-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	-0.001386	-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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000613

SHAKE91 SHEAR STRESS TIME HISTORY - OUTPUT FILE

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STRESS -- stress in level 2        * FINAL COVER SYSTEM  LAYER   2
 .000043  .000024  .000042  .000022  .000040  .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 -.001705
   6
-.001953 -.001903 -.001767 -.001394 -.000845 -.000323  .000080  .000203
   7
 .000107  .000060 -.000274 -.000980 -.001754 -.002243 -.002245 -.001989
   8
-.001674 -.001513 -.001140 -.000401  .000621  .001369  .001405  .000780
   9
-.000706 -.002959 -.005191 -.006270 -.005624 -.004007 -.002101 -.000486
  10
 .000334  .000613  .001435  .002603  .003425  .003836  .004504  .004603
  11
 .004053  .004137  .004797  .005575  .006479  .006972  .006700  .005304
  12
 .003555  .002734  .002700  .002528  .002616  .003094  .003877  .004014
  13
 .005405  .004944  .003405  .001110 -.002260 -.005314 -.006396 -.006697
  14
-.007339 -.008680 -.010735 -.012381 -.012101 -.010452 -.007720 -.004647
  15
-.001823 -.000539 -.001775 -.004601 -.006577 -.006613 -.005477 -.003106
  16
 .000802  .003247  .003804  .002197  .000714 -.002574 -.007129 -.012532
  17
-.015967 -.016577 -.016732 -.015467 -.010731 -.004092  .003433  .012526
  18
 .022842  .031215  .033129  .027232  .019939  .010171  .019987  .019275
  19
 .015720  .013610  .015453  .019692  .023670  .025590  .025364  .024221
  20
 .022680  .019022  .013208  .006350 -.001981 -.010517 -.016392 -.020617
  21
-.023035 -.019860 -.011775 -.006054 -.004912 -.005255 -.004697 -.001397
  22
 .001749  .000043 -.005326 -.011100 -.016470 -.018869 -.014915 -.008473
  23
-.006215 -.009626 -.015476 -.018055 -.015122 -.010770 -.010230 -.015605
  24
-.021400 -.021114 -.015678 -.008461 -.001156  .003326  .002618 -.002473
  25
-.006936 -.006052  .001174  .012494  .025889  .039851  .048634  .051629
  26
 .046504  .034801  .019959  .002570 -.015352 -.029436 -.033560 -.025047
  27
```



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 .014324 -.009007 -.009986 -.009921 -.005425 -.000292  .001560 -.000230
  28
-.003032 -.005610 -.008427 -.010009 -.011625 -.010623 -.009235 -.007622
  29
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M. Gleason 95/10/20

95-1020

000615

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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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   4
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.018485 .021359 .026171 .031468 .035700 .038015 .038350 .036955
239
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240
.001382 .003876 .006848 .012081 .015382 .017523 .016674 .012692
241
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-.037882 -.034510 -.029544 -.024037 -.018517 -.013644 -.010387 -.009590
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-.011499 -.015365 -.019832 -.023944 -.027293 -.029714 -.031197 -.031544
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-.030780 -.029538 -.028418 -.027836 -.027847 -.027976 -.027342 -.025172
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-.021299 -.016357 -.010955 -.006314 -.003707 -.001559 .000660 .000486
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-.000011 -.000076 .001081 .003546 .006740 .010347 .014862 .017000
247
.018283 .017712 .015611 .012827 .010544 .009508 .010096 .012039

248
.018060 .025143 .032780 .040030 .046379 .051320 .054363 .054926
249
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250
-.025595 -.029863 -.031663 -.031875 -.031581 -.031381 -.031184 -.030719
251
-.029627 -.027586 -.023938 -.018861 -.013195 -.008327 -.005227 -.004190
252
-.004812 -.006686 -.009762 -.013573 -.017351 -.020543 -.023862 -.025072
253
-.026012 -.028303 -.029366 -.029948 -.030077 -.029736 -.028862 -.027372
254
-.022221 -.019286 -.015823 -.011611 -.007338 -.002674 .001379 .005253
255
.006311 .012038 .010273 .013100 .009476 .013063 .010998 .012107
256

253
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M. Gleason
95/10/20

555
95-020

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.

See Section 1.2 of the Design Parameter Summary.

B1/4

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.

See Section 1.2 of the Design Parameter Summary.

5. GEOTECHNICAL - SETTLEMENT

5.1 Foundation Settlement
5.2 Localized Impacted Material Settlement
5.3 Overall Impacted Material Settlement

5.1 Foundation Settlement

COMPUTATION COVER SHEET

SUBJECT OF CALCULATION: FOUNDATION SETTLEMENT

Computations By: (Cognizant Engineer)
Signature: Mark H. Gleason — Date: 14 Feb 96
Printed Name and Title: MARK H. GLEASON, Assistant Project Engineer

Assumptions and Procedures Checked by: (Checker)
Signature: [illegible] — Date: 02/16/96
Printed Name and Title: R. David Espinosa, Assistant Project Engineer

Computations Checked by:
Signature: [illegible] — Date: 2/16/96
Printed Name and Title: R. David Espinosa, Assistant Project Engineer.

Computations Backchecked by: (Cognizant Engineer)
Signature: Mark H. Gleason — Date: 19 Feb 96
Printed Name and Title: MARK H. GLEASON, Assistant Project Engineer

Approved by: (PDP)
Signature: Mark H. Gleason — Date: 19 Feb 96
Printed Name and Title: MARK H. GLEASON, Assistant Project Engineer

Approved by: (DTL and TETL)
Signature: Rudolph Bonaparte — Date: 20 Feb 96
Printed Name and Title: Rudolph Bonaparte, Principal (DTL)

Record of Revision (Number and initial all revisions)

NO.	REASON	DATE	BY	CHECKED	APPROVAL
C	Intermediate Design	21 Feb 96			
D	IDP-EPA Submittal	3 Apr 96			

Signature: _____
Number: _____
Registration Stamp (if applicable)

Written by: M. Gleason Date: 96/2/14 Reviewed by: R.D.E Date: 96/2/16

Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 9.9

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 account for variation in the site stratigraphy and 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: 2.84 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

  Maximum change = 0.61% Post-settlement grade of leachate collection pipes will maintain positive flow. 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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Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 9.9

FOUNDATION SETTLEMENT

CALCULATION PACKAGE

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Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 9.9

RB(DTL) 15 FEB 96

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.

The analysis accounts for the variability in the foundation soils and the location of the ground water table. The effect of the perched water table was not considered to be significant for this analysis.

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 in 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;

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- load imposed by the landfill materials;
- geometry of the landfill; and
- location of the settlement point for calculation.

Analyses

A. Given the landfill geometry shown on 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 settlement at Points A, B, C, and D indicated on Figure 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, and C (Figure 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.

E1. Settlement of Cohesive Soils

Total Settlement $S_t = S_i + S_p + S_s$

where S_i = elastic settlement (immediate)
S_p = primary consolidation settlement (time and surcharge dependent)
S_s = secondary compression settlement (time dependent).

a. Elastic Settlement, S_i (or Δh_i for each layer)

$$\Delta h_i = (\Delta\sigma_v/M)\, H_o$$

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Client: FERMCO Project: OSDF Project/Proposal No.: 6E 3900 Task No.: 9.9

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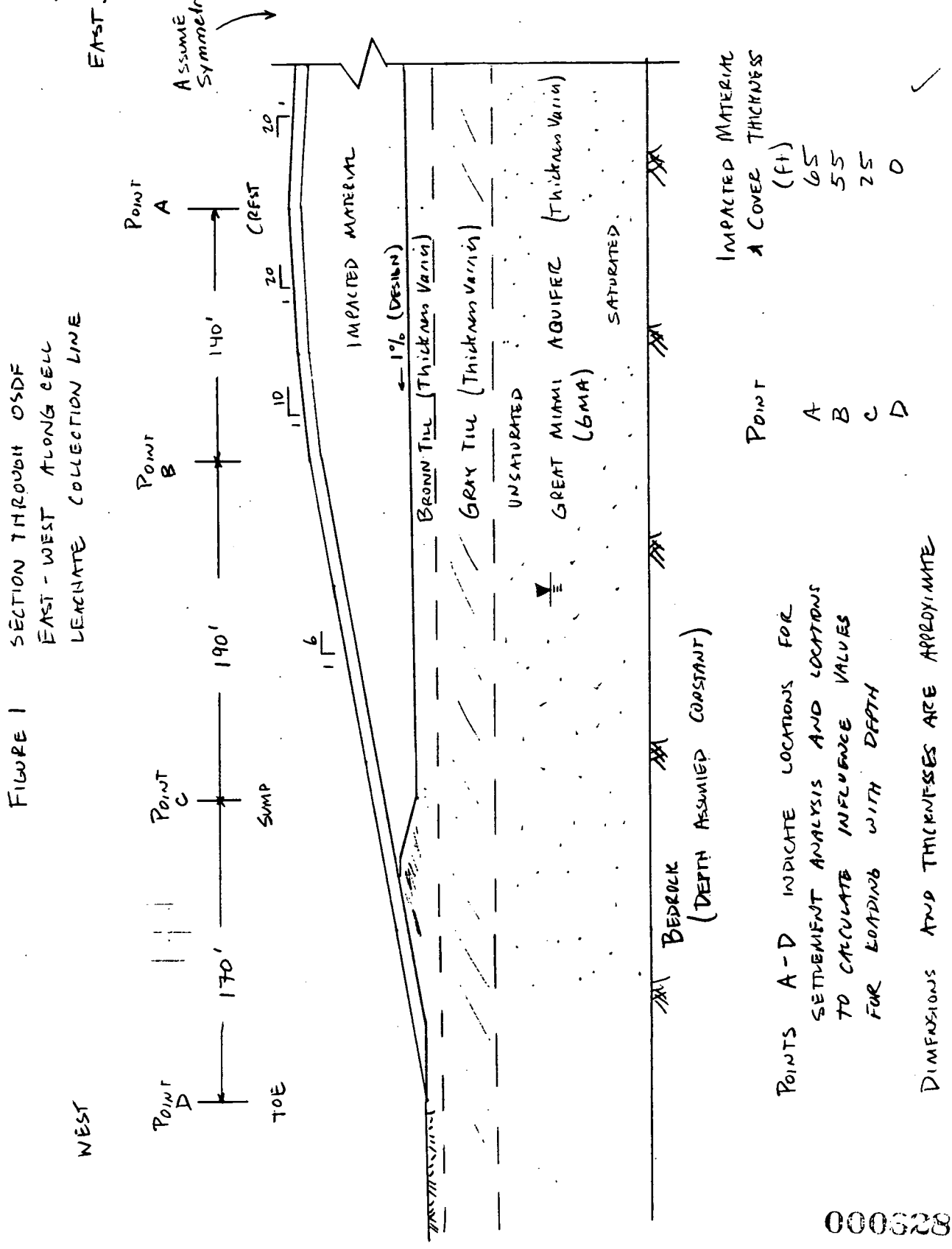

FIGURE 1 SECTION THROUGH OSDF EAST - WEST ALONG CELL LEACHATE COLLECTION LINE

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Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 9.9

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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
υ = Poisson's Ratio

E.1.a. Settlement of Cohesive Soils, Elastic Settlement

Undrained Tangent Modulus, E_{ut} (from Reference 3)

$$E_{ut} = kPa\,(\sigma_c/pa)^n\,[1 - Rf\,(\sigma_1 - \sigma_3)/(2\,S_u)]^2$$

where pa = atmospheric pressure (2117 psf)
k, n, Rf = modulus parameters
$\sigma_c = \sigma_3$ = minor principal stress (total stress)
σ_1 = major principal stress (total stress)
S_u = undrained shear strength

E.1.b. Primary Consolidation Settlement, S_p (or Δh_p for each layer)

$$\Delta h_p = C_r \frac{H_o}{1 + e_o} \log \frac{\sigma_p}{\sigma_{vo}} + C_c \frac{H_o}{1 + e_o} \log \frac{\sigma_{vo} + \Delta\sigma_r}{\sigma_p}$$

where C_c = coefficient of compression
Cr = coefficient of recompression
p_o = initial layer void ratio
σ_{vo} = initial vertical effective stress
$\Delta\sigma_v$ = additional vertical effective stress
σ_p = past maximum pressure due to overconsolidation or desiccation
H_o = initial layer thickness

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E.1.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% x primary) and t_2 is a future time of interest (i.e., 200 years or 1,000 years)

Assume t_1 = 10 years and t_2 = 1,000 years

E.2 Settlement of Cohesionless Soils (Granular Non-Plastic Soils)

Granular settlement is elastic and immediate.

$$\Delta h_s = \left[\frac{\Delta\sigma_v}{M}\right] H_o$$

where Δh_s = elastic settlement of sand layer
$\Delta\sigma_v$ = 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
υ = Poisson's Ratio

$$E_t = K_{pa} \left(\bar{\sigma}_3/p_a\right)^n \left[1 - R_f (1-\sin\phi)(\bar{\sigma}_1 - \bar{\sigma}_3)/(2\bar{\sigma}_3 \sin\phi)\right]^2$$

where p_a = atmospheric pressure
$\bar{\sigma}_1$ = major principal effective stress
$\bar{\sigma}_3$ = minor principal effective stress

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FOUNDATION SETTLEMENT

$\bar{\phi}$ = effective stress angle of internal friction

K, n, R_f = hyperbolic model parameters

E.3 TOTAL SETTLEMENT = Cohesive Soil Settlement + Cohesionless Settlement

E.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 groundwater 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-ft thick clay liner is not included in this table.
4) Perched water table is not considered for this analysis.
5) Material thicknesses show account for range of conditions expected at OSDF.

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 = total settlement at Point A

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b. Grade Change

Grade change % = (Δ_s/L) 100

where L = horizontal distance between points of concern

c. Tensile Strain,

$$\varepsilon = 8/3\left(\Delta_s/L\right)^2(100)$$

where Δ_s, L, as described above.

G. Finally, for the cohesive soils, calculate the time for primary consolidation of the cohesive soils (i.e., time rate of settlement). Granular soil settlements are immediate.

$$t = \frac{THdr^2}{Cv}$$

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.

Hdr = the length of the longest drainage path for water to escape the cohesive layer.

Cv ~~Cr~~ MMB = coefficient of consolidation (property of the ~~day~~ clay MMB).

t varies with cohesive soil thickness. Calculate t for several cohesive soil thicknesses.

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Written by: M. GLEASON Date: 95/9/6 (YY MM DD) Reviewed by: JM Date: 95/10/5 (YY MM DD)

Client: FERMILO Project: OSDF Project/Proposal No.: GE 3900 Task No.: C9.9

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, $C_{\alpha E}$	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, S_u, psf	1200	1200	1900
	✓		✓

Written by: M. GLEASON Date: 95/9/6 (YY/MM/DD) Reviewed by: JM Date: 95/10/5 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: 6E 3900 Task No.: 09.9

RB 95/9/15

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 7.11 (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

$C_{\alpha e}$ = 0.0001 w_n for NC Clays w_n = 15.7 (post consolidation)

$C_{\alpha e}$ = 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)

$C_{\alpha e}$ = 0.0001 w_n w_n = 12.8%

$C_{\alpha e}$ = 0.0013

GEOSYNTEC CONSULTANTS

Written by: M. Gleason Date: 95/9/6 (YY MM DD) Reviewed by: TM Date: 95/10/5 (YY MM DD)

Client: Fernio Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.9

Foundation Settlement RB 95/9/15

BORING 11479 cont.

ESTIMATE Cv use $\sqrt{t}$ method (Semi log method gives similar results).

	load (psf)	Cv
Average ~ 6×10^{-3} cm²/s ✓	3200	5.5×10^{-3} cm²/s
	6400	6×10^{-3} cm²/s
~ 0.056 in²/min ✓	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 Pre design 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 C_v = 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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Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

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 6.3)

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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Client: Fernco Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement

RB 95/9/15

MATERIAL PROPERTIES

CONSOLIDATION SETTLEMENT OF GRAY TILL

Based on consolidation tests performed by Parsons for 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 $C_v \simeq 3.3 \times 10^{-3}$ 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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Client: Fernco Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement RB 95/9/15

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

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 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	Cv 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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Client: Fernco Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

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 (i.e. S_u = 1200 psf)
∴ Assume S_u = 1000 psf

Assume $\sigma_1 = \sigma_1$ $\sigma_3 = 0.8\,\sigma_1$

Poisson's 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 Soil: 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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Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 09.9

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)

$$E_t = k P_a \left(\bar{\sigma}_3 / p_a\right)^n \left[1 - R_f (1 - \sin\bar{\phi})(\bar{\sigma}_1 - \bar{\sigma}_3) / 2 \sin\bar{\phi}\, \bar{\sigma}_3\right]^2$$

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.

Written by: M. GLEASON Date: 95/9/12 (YY MM DD) Reviewed by: JM Date: 95/10/5 (YY MM DD)

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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 correlations 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 $k = 300 + 900\,\phi_{rel}$ (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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Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 9.9

FOUNDATION SETTLEMENT

REFERENCES

1) Disposal Facility Pre-Design Geotechnical Investigation, *Soil Investigation Data Report*, Summary Document, Operable Unit 2, Project Order 132, July 1995 by Parsons, Fairfield, Ohio.

2) Kulhawy, F.H., and Mayne, P.W., "*Manual on Estimating Soil Properties for Foundation Design*", Report No. EL-6800, Electric Power Research Institute, Palo Alto, CA, 1990.

3) Duncan, J.M., and Chang, C.K., "Nonlinear Analysis of Stress and Strain in Soils", *Journal of the Soil Mechanics and Foundation Division*, ASCE Vol. 96 No. SM5, Sept 1970, pp. 1629-1653.

4) *Remedial Investigation Report for Operable Unit 5*, Fernald Environmental Management Project, Fernald, Ohio, U.S. Department of Energy, March 1995.

5) Peck, R.B., Hanson, W.E., and Thornburn, T.H., *Foundation Engineering*, 2nd Edition, John Wiley and Sons, New York, 1974, 514 p.

6) Jaky, J., "The Coefficient of Earth Pressure at Rest", *Journal of the Society of Hungarian Architects and Engineers*, Vol. 78, No. 22, po. 355-358.

7) Holtz, R.D., and Kovacs, W.D., "*An Introduction to Geotechnical Engineering*", Prentice Hall, Englewood Cliffs, NJ, 1981, 733 p.

8) Osterberg, J.O., "Influence Values for Vertical Stresses in a Semi-Infinite Mass Due to an Embankment Loading", *Proceedings, 4th Conference on Soil Mechanics and Foundation Engineering*, London, Vol. 1, pp. 393-394, 1957.

9) U.S. Navy, "Soil Mechanics, Foundations, and Earth Structures", *NAVFAC Design Manual DM-7*, Washington, D.C., 1971.

10) *Geotechnical Investigation Report, On-Site Disposal Facility Operable Unit 2*, Project Order 140, Revision A, Parsons, Fairfield, Ohio, Sept 1995.

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Client: FERMCO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 9.9

FOUNDATION SETTLEMENT

REFERENCES (continued)

11) Giroud, J.P., "Conception de l'etancheite des ouvrages hydrauliques par geomembranes", *Proceedings of the International R.I.L.E.M. Symposium on Plastic and Rubber Waterproofing in Civil Engineering*, Session 3, Liege, Belgium, June 1977 (French).

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)

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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	12	7.5'	(15.5)
4	TILL	19	7.5'	23
5		29	12'	35'
6	GMA unsaturated	42.5'	15'	50'
7		60'	20'	70'
CASE 1				
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

BEDROCK (INCOMPRESSIBLE)

CASE 2

LAYER #		MIDPOINT	LAYER THICKNESS	DEPTH
1	LINER	1.5	3'	3'
2	Br Till	5.5	5'	
3		10.5	5'	13'
4		15.5	5'	18'
5		23	10'	28'
6	Gray Till	33	10'	38'
7		43	10'	48
8		53	10'	58'
9	GMA Unsat	64	12'	70'
10		80	20'	90'
11		100'	20'	110'
12	GMA SATURATED	120'	20'	130'
13		140'	20'	150'
14		160'	20'	170'
15		185'	30'	200'
16		215'	30'	230'

826'
988'

Written by: M. GLEASON Date: 96 / 2 / 3 (YY MM DD) Reviewed by: R.D Espinoza Date: 96 / 2 / 16 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

FOUNDATION SETTLEMENT - TOTAL SETTLEMENT

INFLUENCE VALUE CALCULATION

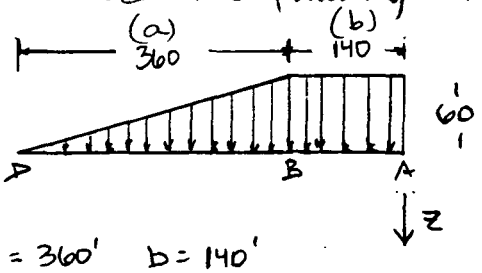
Calculate Influence Values at the following depths (mid point depths of strata on previous page)

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, & D

POINT A

- Calculate Influence Values at center of OSDF
- Model OSDF as an 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 (Figure 1)



Assume embankment is uniformly loaded

Average embankment thickness $= \frac{A+B}{2}$

$= \frac{65ft + 55ft}{2} = 60ft.$ ✓

a = 360' b = 140'

USE attached chart to solve for a/z and b/z

Double Influence Value for minor half of embankment

DEPTH	a/z	b/z	I	2I	DEPTH	a/z	b/z	I	2I
1.5	240	93	0.5	1.0	53	6.8	2.6	0.5	1.0
5.5	65	25	↓	↓	60	6	2.3	0.5	1.0
10.5	34	13.3			64	5.6	2.2	0.495	0.99 ✓
13	28	10.8			80	4.5	1.8	0.49	0.98
15.5	23	9.0			100	3.6	1.4	0.485	0.97
18	20	7.8			120	3	1.2	0.48	0.96
23	16	6.1			140	2.6	1.0	0.475	0.95
29	12	4.8			160	2.3	0.88	0.47	0.94
33	11	4.2			185	1.9	0.76	0.46	0.92
42.5	8.4	3.3			215	1.7	0.65	0.445	0.89
43	8.4	3.3							

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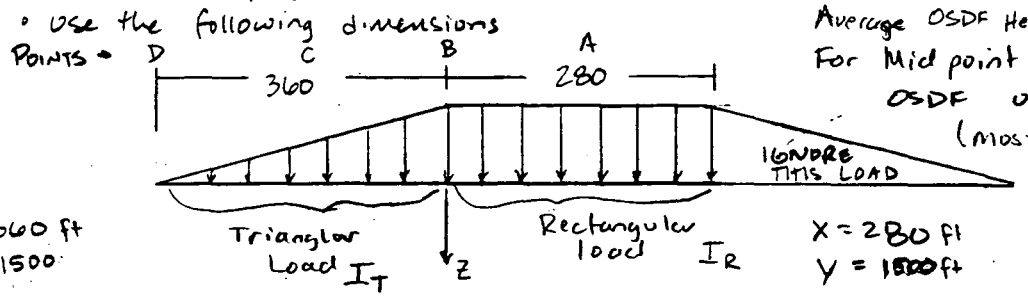
FOUNDATION SETTLEMENT - TOTAL SETTLEMENT

CALCULATE INFLUENCE VALUES (VERTICAL STRESS INCREASE)

FOR POINT B

- Calculate influence values at location on OSDF where grade changes from 10H:1V to 6H:1V
- Model OSDF as uniformly loaded rectangular area and triangular load. Sum the values for each influence using the method presented in Holtz and Kovacs (1981) after U.S. Navy (1971).
- Use the following dimensions

Average OSDF Height = 60'
For Mid point length of OSDF use 1500 ft (most locations will be less)



B = 360 ft
L = 1500

X = 280 ft
Y = 1500 ft

$I = 2I_R + 2I_T$

DEPTH	$m = L/z$	$n = B/z$	I_T	$2I_T$	$m = X/z$	$n = Y/z$	I_R	$2I_R$	I_{TOTAL}
	Triangular Load				Rectangular Load				
1.5	1000	240	0.25	0.5	187	1000	0.25	0.5	1.0
5.5	273	65	0.25	0.5	51	273			1.0
10.5	143	34	0.25	0.5	27	143			1.0
13	115	28	0.25	0.5	22	115			1.0
15.5	97	23	0.25	0.5	18	97			1.0
18	83	20	0.248	0.496	16	83			0.996
23	65	16	0.245	0.49	12	65			0.99
29	52	12	0.24	0.48	9.7	52			0.98
33	46	11	0.235	0.47	8.5	46			0.97
42.5/43	35	8.4	0.23	0.46	6.5	35			0.96
53	28	6.8	0.225	0.45	5.3	28			0.95
60	25	6.0	0.22	0.44	4.7	25			0.94
64	23	5.6	0.22	0.44	4.4	23			0.94
80	19	4.5	0.21	0.42	3.5	19	0.248	0.496	0.916
100	15	3.6	0.205	0.41	2.8	15	0.245	0.49	0.9
120	12.5	3.0	0.20	0.40	2.3	12.5	0.242	0.484	0.884
140	10.7	2.6	0.185	0.37	2.0	10.7	0.24	0.48	0.85
160	9.4	2.3	0.18	0.36	1.8	9.4	0.238	0.476	0.836
185	8.1	1.9	0.175	0.35	1.5	8.1	0.235	0.47	0.82
215	7.0	1.7	0.17	0.34	1.3	7.0	0.23	0.46	0.80

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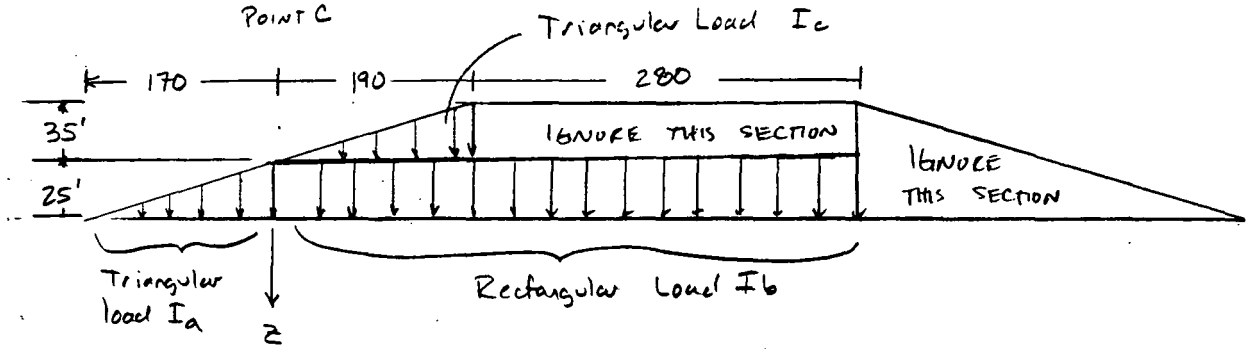
Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

FOUNDATION SETTLEMENT - TOTAL SETTLEMENT

CALCULATE INFLUENCE VALUES

POINT C - OSDF LOW POINT

- Calculate Influence Values with depth at location of lowest elevation of leachate collection.
- Use the methods presented in Holtz and Kovacs (1981) after U.S. Navy 1971
- Use the following dimensions:



I_a = Triangular load (heel)

Maximum stress increase = 25' x 125 psf = 3125 psf

L = 1500 B = 170

I_b = Rectangular Load

Maximum stress increase 25' x 125 psf = 3125 psf ✓

x = (190 + 280) = 470 y = 1500

I_c = Triangular Load (toe load)

Maximum stress increase 35' x 125 psf = 4375 psf ✓

B = 190' y = 1500' Add 25' 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 C

	Triangular Load (heel) B = 170 L = 1500				Rectangular Load L = 1500 x = 470'				Triangular Load (toe) B = 190 L = 1500				Rounded to nearest 10 psf
DEPTH (z)	m = L/z	n = B/z	I_a	$2I_a$	n = x/z	I_b	$2I_b$	Depth (z)	m = L/z	n = B/z	I_c	$2I_c$	*$\Delta\sigma_v$ psf
1.5	1000	113	0.25	0.5	313	0.25	0.5	26.5	57	7.2	.022	.044	3320
5.5	273	31	0.25	0.5	85			30.5	49	6.2	.025	.05	3340
10.5	143	16	0.25	0.5	45			35.5	42	5.4	.029	.058	3380
13	115	13	0.24	0.48	36			38	39	5.0	.030	.06	3330
15.5	97	11	0.235	0.47	30			40.5	37	4.7	.034	.068	3330
18	83	9.4	0.23	0.46	26			43	35	4.4	.038	.076	3330
23	65	7.4	0.225	0.45	20			48	31	4.0	.040	.08	3320
29	52	5.9	0.223	0.446	16			54	28	3.5	.044	.088	3340
33	46	5.2	0.22	0.44	14			58	26	3.3	.047	.094	3350
43	35	4.0	0.21	0.42	11			68	22	2.8	.051	.102	3320
53	28	3.2	0.20	0.40	8.9			78	19	2.4	.055	.110	3290
60	25	2.8	0.195	0.39	7.8			85	18	2.2	.058	.116	3290
64	23	2.7	0.19	0.38	7.3			89	17	2.1	.060	.120	3280
80	19	2.1	0.18	0.36	5.9	0.25	0.5	105	14	1.8	.065	.130	3260
100	15	1.7	0.17	0.34	4.7	0.249	0.498	125	12	1.5	.072	.144	3250
120	12.5	1.4	0.15	0.30	3.9	0.248	0.496	145	10	1.3	.075	.150	3140
140	10.7	1.2	0.135	0.27	3.6	0.247	0.494	165	9	1.2	.078	.156	3070
160	9.4	1.06	0.13	0.26	2.9	0.246	0.492	185	8.1	1.0	.08	.160	3050
185	8.1	0.92	0.12	0.24	2.5	0.245	0.49	210	7.1	0.9	.078	.156	2960
215	7.0	0.79	0.108	0.216	2.2	0.243	0.486	240	6.3	0.8	.077	.154	2870

$$* \quad \Delta\sigma_v = 2I_a(3125) + 2I_b(3125) + 2I_c(4375)$$

$$= (2I_a + 2I_b)\,3125 + 2I_c(4375)$$

Written by: M. GLEASON Date: 96 / 2 / 3 (YY MM DD) Reviewed by: R. DE Date: 96 / 2 / 16 (YY MM DD)

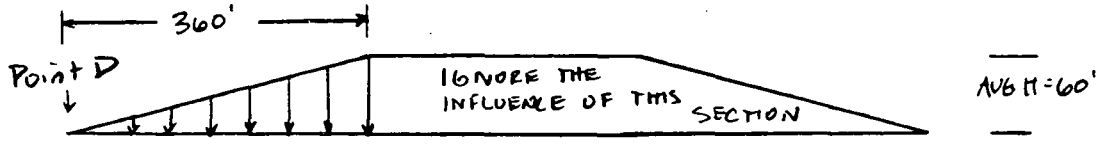
Client: FERMCO Project: OSDF Project/Proposal No.: GE 3400 Task No.: 9.9

FOUNDATION SETTLEMENT - TOTAL SETTLEMENT

CALCULATE INFLUENCE VALUES (VERTICAL STRESS INCREASE)

FOR POINT D TOE

- Calculate Influence values with depth at toe of OSDF
- Model OSDF as uniformly loaded area
- Use the method presented in Holtz and Kovacs (1981) after U.S. Navy (1971) to calculate the vertical stress increase at the toe of a uniformly loaded triangular area.
- Use the following dimensions.



Z B = 360' m = 4/z
L = 1500' n = B/z

DEPTH	m = 4/z	n = B/z	I	2I
1.5	1000	240	0	0.0
5.5	273	65	.002	0.004
10.5	143	34	.004	0.008
13	115	28	.006	0.012
15.5	97	23	.007	0.014
18	83	20	.008	0.016
23	65	16	.010	0.02
29	52	12	.012	0.024
33	46	11	.014	0.028
43	35	8.4	.018	0.036
53	28	6.8	.020	0.04
60	25	6.0	.024	0.048
64	23	5.6	.028	0.056
80	19	4.5	.033	0.066
100	15	3.6	.04	0.08
120	12.5	3.0	.048	0.096
140	10.7	2.6	.056	0.112
160	9.4	2.3	.06	0.120
185	8.1	1.9	.066	0.136
215	7.0	1.7	.070	0.140

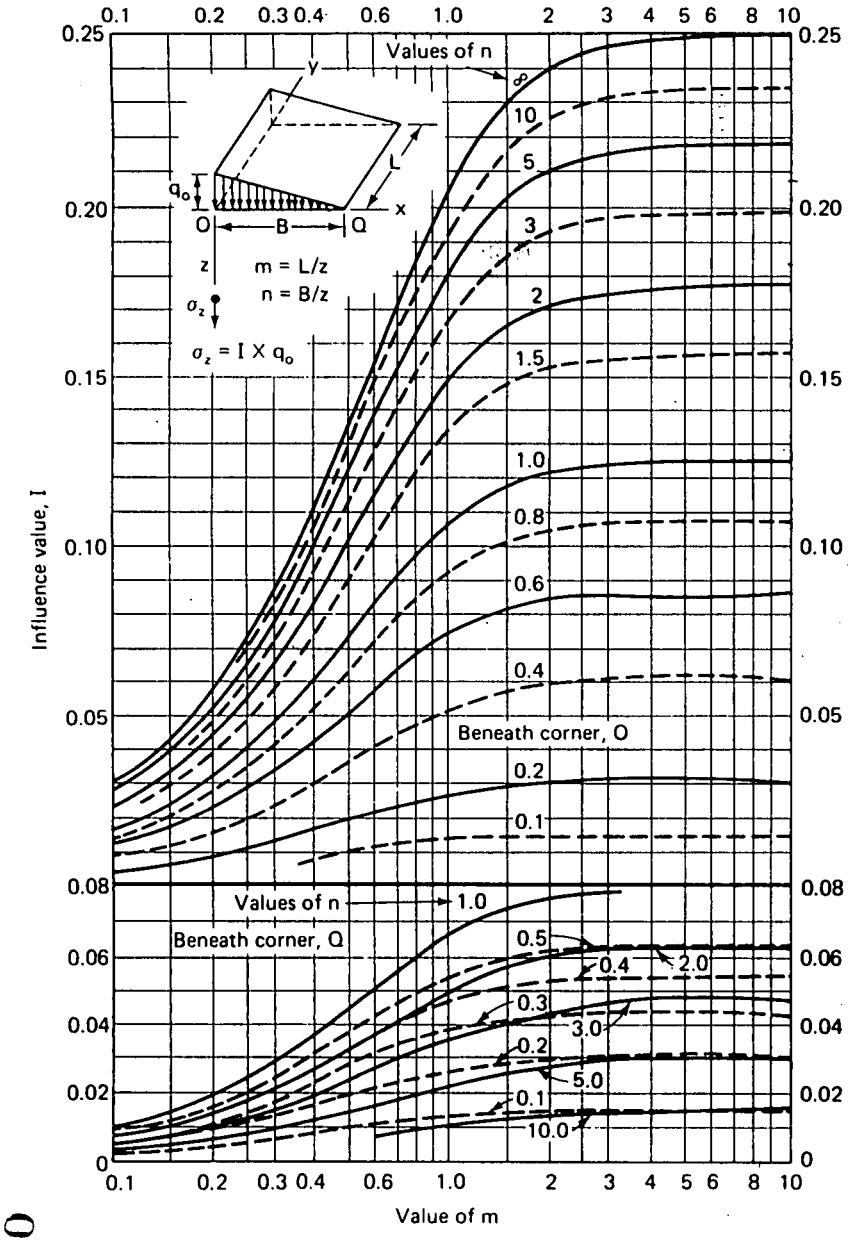


Fig. 8.24 Influence values for vertical stress under the corners of a triangular load of limited length (after U.S. Navy, 1971).

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.

$$a/z = 6/3 = 2$$
$$b/z = 5/3 = 1.67$$

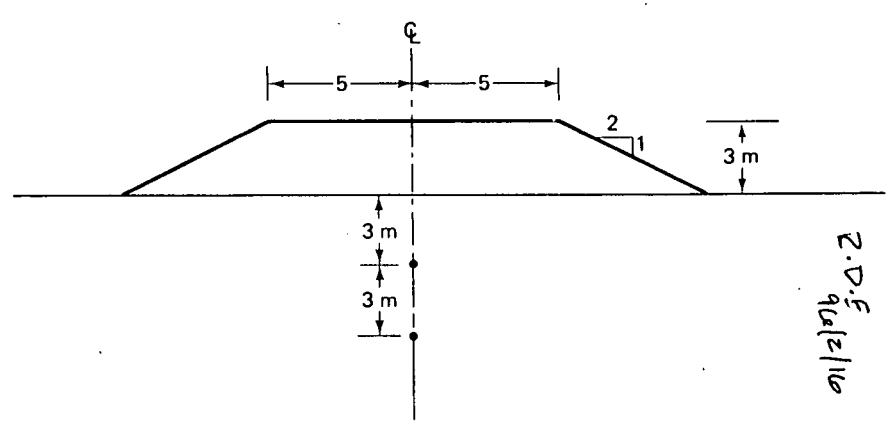


Fig. Ex. 8.21

M. Bilgin
3 Feb 96

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6/12/96

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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.

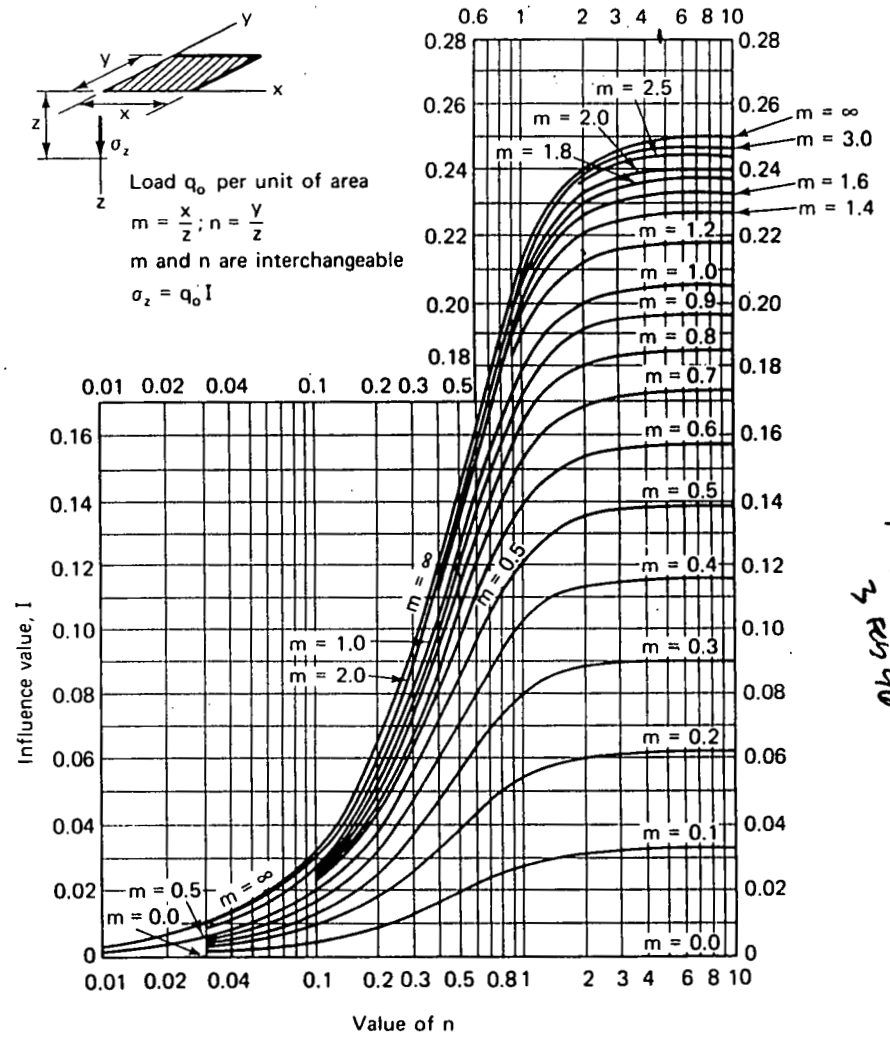

Fig. 8.21 Influence value for vertical stress under corner of a uniformly loaded rectangular area (after U.S. Navy, 1971).

0005556

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.

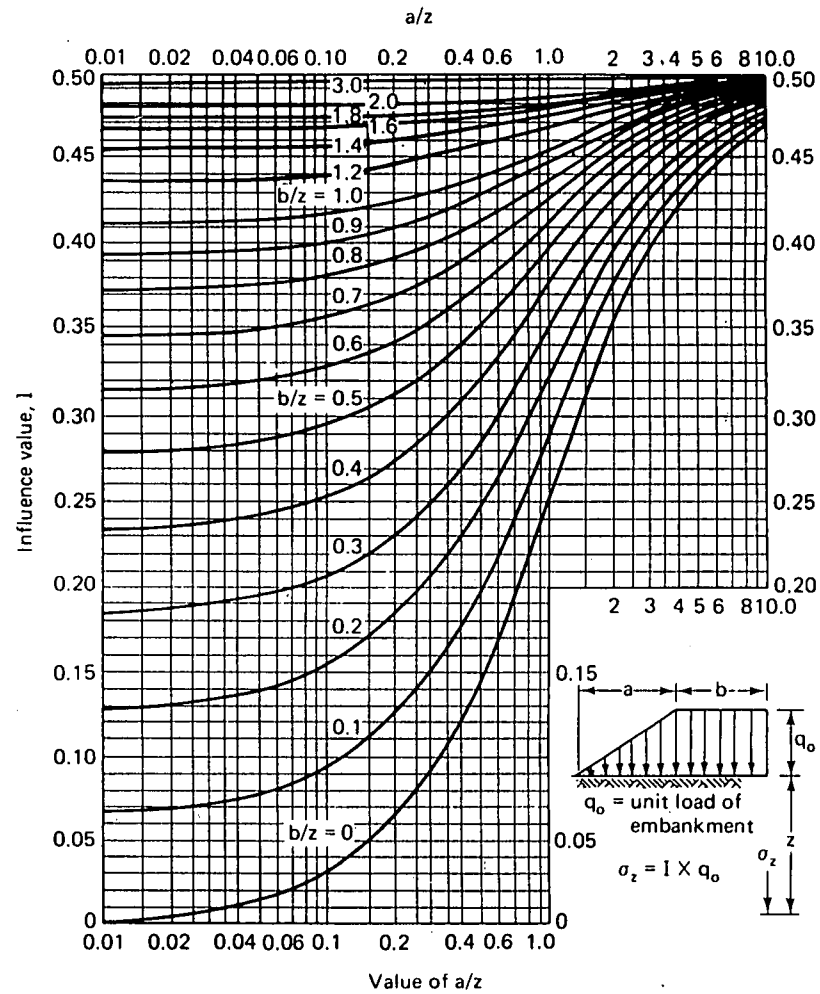

Fig. 8.23 Influence values for vertical stress under a very long embankment; length = ∞ (from U.S. Navy, 1971, after Osterberg, 1957).

00065

Written by: M. GLEASON Date: 95/12/15 (YY MM DD) Reviewed by: R.D.E. Date: 96/2/16 (YY MM DD)

Client: FEEMCO Project: OSDF Project/Proposal No.: 6E 3900 Task No.: 9.9

Foundation Settlement - Calculation

Overburden from OSDF

- Assume Uniform unit weight - Average weight of impacted material and Final Cover System = 125 pcf
- Calculate settlement of Liner System for Final OSDF Configuration
- Maximum OSDF Height ≈ 65 ft at CREST
  ≈ 55 ft at 6H:1V – 10H:1V Transition
  Assume Average Height = 60 ft.
- Overburden Pressure for analysis

$$\sigma_{n\,max} = 60\text{ft} \times 125\text{ pcf} = 7500\text{ psf}$$

- For Foundation Settlement - assume load is placed at one time.
  - Calculate Ultimate Foundation Settlement for this condition.

Calculate Foundation Settlement at Points A, B, C, & D

For Each Case

CASE 1		CASE 2	
Clay Liner	3ft thick	Clay Liner	3ft thick
Brown Till	5 ft thick	Brown Till	10ft thick
Gray Till	15 ft thick	Gray Till	45 ft thick
GMA Soil	210 ft thick	GMA Soils	175 ft thick
Water Table at	70ft Depth	Water Table at	70 ft Depth

Written by: M. GLEASON Date: 95/2/15 (YY MM DD) Reviewed by: R.D.E Date: 96/2/16 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement

CASE 1 POINT A.

Layer 1 3ft Compacted Clay Liner

$\gamma = 130$ $C_{\Delta E} = 0.0015$ $R_f = 0.9$ $e_p = 0.32$

$C_o = 0.43$ $\sigma_p = 1000$ psf $\nu = 0.475$

$C_c = 0.13$ $k = 150$ $S_u = 1200$

$C_r = 0.035$ $n = 1$ mid pt @ 1.5 ft

$I_f = 1.0$ $\Delta\sigma_v = 7500$ psf $\sigma_1 = 1.5(130 \text{ pcf}) = 195$ psf

Assume $\sigma_3 = 0.8\sigma_1$ for undrained loading of clayey materials

$\sigma_3 = 156$ psf

$$E_{ut} = K_{pa}\left(\sigma_c/p_a\right)^n\left[1 - R_f(\sigma_1 - \sigma_3)/2S_u\right]^2$$

$$E_{ut} = 150(2117)\left(150/2117\right)^1\left[1 - 0.9(195 - 156)/2(1200)\right]^2$$

$E_{ut} = 21846$ psf

$$M = \frac{E_{ut}(1-\nu)}{(1+\nu)(1-2\nu)} = \frac{21846(1-0.475)}{1.475(1-0.95)} = 155{,}500$$

$$\Delta h_{i1} = \left(7500/155{,}500\right)3\text{ft} = 0.145\text{ ft}$$

$$\Delta h_{p1} = 0.035\frac{3}{1+0.43}\log\frac{1000}{195} + 0.13\frac{3}{1+0.43}\log\frac{195+7500}{1000}$$

$$\Delta h_{p1} = 0.052 + 0.242 = 0.294\text{ ft}$$

$$\Delta h_{s1} = 0.0015\frac{3}{1+0.32}\log 1000/10 = 0.007\text{ ft}$$

$$\Delta h_1 = 0.145 + 0.294 + 0.007 = 0.446\text{ ft}$$

Written by: M. GLEASON Date: 96 / 2 / 5 (YY MM DD) Reviewed by: R.A.E Date: 96 / 2 / 16 (YY MM DD)

Client: FERMCO Project: DSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement

CASE 1 Point A

Layer 2 5ft Brown Till

$\gamma = 135$ $e_0 = 0.29$ $e_p = 0.22$ $R_f = 0.9$

$C_c = 0.075$ $C_r = 0.015$ $k = 175$ $\nu = 0.475$

$C_{\alpha e} = 0.0015$ $OCL = 1.7$ $n = 1$ $S_u = 1200$

$I_f = 1.0$ $\Delta\sigma_v = 7500$ psf

At Midpoint of Layer @ 5.5ft $\sigma_0 = (3 \times 130) + (2.5 \times 135) = 730$ psf

$\sigma_3 = 584$ psf

$$E_{ut} = 175\,(2117)\left(584/2117\right)^1 \left[1 - 0.9\,(730 - 584)/2\,(1200)\right]^2$$

$E_{ut} = 91{,}300$

$$M = \frac{91300\,(1 - 0.475)}{1.475\,(1.05)} = 650{,}000 \text{ psf}$$

$$\Delta h_{i_2} = \left(7500/650{,}000\right) 5\text{ft} = 0.058 \text{ ft}$$

$$\Delta h_{p_2} = 0.015 \frac{5}{1+0.29} \log 1.7 + 0.075 \frac{5}{1+0.29} \log \frac{730 + 7500}{1200}$$

$$\Delta h_{p_2} = 0.013 + 0.243\text{ft} = 0.256 \text{ ft}$$

$$\Delta h_{s_2} = 0.0015 \frac{5}{1+0.22} \log 1000/20 = 0.012 \text{ ft}$$

Layer 2

$$\Delta h = (0.058 + 0.256 + 0.012) \text{ ft}$$

$$\Delta h_2 = 0.326 \text{ ft.}$$

Written by: M. GLEASON Date: 96/12/15 (YY MM DD) Reviewed by: R.D.E Date: 96/12/16 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement

CASE 1 Point A

Layer 3 7.5' gray till

$\gamma = 145$ $C_{\alpha\epsilon} = 0.0013$ $R_f = 0.9$

$e_0 = 0.38$ $\epsilon_p = 0.29$ $\nu = 0.49$

$C_c = 0.074$ $k = 175$ $S_u = 1900$

$C_r = N/A$ OCR = 1 $n = 1$

$I_f = 1.0$ $\Delta\sigma_v = 7500$ psf

$\sigma_1 = 3(130) + 5(135) + 3.75(145) = 1600$ psf $\sigma_3 = 1300$ psf

$E_{ut} = 175(2117)(1300/2117)^1[1 - 0.9(1600-1300)/2(1900)]^2$

$E_{ut} = 196{,}000$ $M = \dfrac{196{,}000(1-0.49)}{(1+0.49)(0.02)} = 3.35 \times 10^6$

$\Delta h_{i_3} = (7500/3.35 \times 10^6)\,7.5' = 0.017$ ft

$\Delta h_{p_3} = 0.074 \dfrac{7.5}{1+0.38} \log\left(\dfrac{1600+7500}{1600}\right) = 0.304$ ft

$\Delta h_{s_3} = 0.0013 \dfrac{7.5}{1+0.29} \log 1000/10 = 0.015$ ft

Layer 3 $\Delta h_{T_3} = 0.017$ ft $+ 0.304$ ft $+ 0.015$ ft $= 0.336$ ft ✓

Layer 4 7.5' gray till parameters as in Layer 3 – Depth @ 19'

$I_f = 1.0$ $\Delta\sigma_v = 7500$ psf $\sigma_1 = 390 + 675 + 11.25(145) = 2700$ psf

$\sigma_3 = 2150$ psf

$E_{ut} = 175 \cdot 2117 (2150/2117)^1 [1 - .9(2700-2150)/2(1900)]^2 = 284{,}600$ psf

$M = 284{,}600$ psf $\left(\dfrac{0.51}{1.49(0.02)}\right) = 284{,}600(17.1) = 4.9 \times 10^6$ psf

$\Delta h_{i_4} = (7500/4.9 \times 10^6)\,7.5$ 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 ✓

Written by: M. GLEASON Date: 96/2/5 (YY MM DD) Reviewed by: R.D.G. Date: 96/2/16 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement CASE 1 Point A

Layer 4 cont.

$$\Delta h_{S4} = 0.0013 \frac{7.5}{1+0.29} \log 1000/10 = 0.015 \text{ ft}$$

$$\Delta h_{T4} = 0.012 + 0.232 + 0.015 = 0.259 \text{ ft}$$

Layer 5 12' unsaturated GMA soils $I_f = 1.0$ $\Delta\sigma_v = 7500$ psf

$\gamma_T = 135$ pcf $\phi = 35$ $K = 900$ $n = 0.5$ $R_f = 0.7$ $\nu = 0.3$

$\sigma_1 = 3(130) + 5(135) + 15(145) + 6(135) = 4050$ psf

$\sigma_3 = \sigma_1(1 - \sin\phi) = 1730$ psf $1 - \sin\phi = 0.426$

$$E_t = K p_a (\sigma_3/p_a)^n [1 - R_f(1-\sin\phi)(\sigma_1 - \sigma_3)/2\sin\phi\,\sigma_3]^2$$

$$E_t = 900(2117)(1730/2117)^{1/2}[1 - 0.7(0.426)(4050-1730)/2(.574)1730]^2$$

$$E_t = 7.3 \times 10^5 \text{ psf}$$

$$M = E_t \frac{1-0.3}{1+0.3(1-2(0.3))} = 7.3 \times 10^5 \text{ psf}(1.35) = 9.8 \times 10^5 \text{ psf}$$

$$\Delta h_5 = (7500/9.8 \times 10^5)\, 12 \text{ ft} = 0.091 \text{ ft}$$

Layer 6 15' unsaturated GMA soils $I_f = 1.0$

- same parameters as layer 5 $\Delta\sigma_v = 7500$ psf

$\sigma_1 = 4050 \text{ psf} + (6 + 7.5)(145) = 5870$ psf $\sigma_3 = 2500$ psf

$$E_t = 900(2117)(2500/2117)^{1/2}[1 - .7(.426)(5870-2500)/2(.574)(2500)]^2$$

$E_t = 8.7 \times 10^5$ $M = 8.7 \times 10^5 (1.35) = 1.2 \times 10^6$ psf

$$\Delta h_6 = (7500/1.2 \times 10^6 \text{ psf})\, 15 \text{ ft} = 0.096 \text{ ft}$$

Written by: M. GLEASON Date: 96/2/5 (YY/MM/DD) Reviewed by: R.D.E Date: 96/2/16 (YY/MM/DD)

Client: FEEMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement Case 1 Point A

Layer 7 20' Unsaturated GMA Depth = 60 ft @ midpoint

$I_f = 1.0$ $\Delta\sigma_v = 7500$ psf $\sigma_1 = 5870 + 17.5(145) = 8200$ psf

$\sigma_3 = 3500$ psf

$$E_t = 900(2117)\left(3500/2117\right)^{1/2}\left[1 - .7(.426)(8200-3500)/2(.574)3500\right]^2$$

$E_t = 1.0\times10^6$ $M = 1.0\times10^6 \times 1.35 = 1.4\times10^6$ psf

$$\Delta h_7 = \left(7500/1.4\times10^6\right)20\text{ft} = 0.107\text{ ft}$$

Layer 8 20' Saturated GMA Depth = 80 ft @ midpoint
GWT @ 70'

$\sigma_1 = 8200 + 10(135) + 10(72.6)$
$= 10{,}280$ psf

$I_f = 0.98$ $\Delta\sigma_v = 7350$ psf

$\sigma_3 = 4380$ psf

$$E_t = 900(2117)\left(4380/2117\right)^{1/2}\left[1 - 0.35\right]^2 = 1.1\times10^6\text{ psf}$$

$$M = 1.1\times10^6\text{ psf}(1.35) = 1.5\times10^6\text{ psf}$$

$$\Delta h_8 = \left(7350/1.5\times10^6\text{ psf}\right)20\text{ft} = 0.095\text{ ft}$$

Layer 9

20' saturated GMA Depth to Mid Point = 100 ft

$I_f = 0.97$ $\Delta\sigma_v = 7275$ psf

$\sigma_1 = 10{,}280\text{ psf} + 20(72.6\text{ psf}) = 11730$ psf $\sigma_3 = 5000$ psf

$$E_t = 900(2117)\left(5000/2117\right)^{1/2}\left[1 - .35\right]^2 = 1.24\times10^6\text{ psf}$$

$$M = 1.24\times10^6\text{ psf}\times1.35 = 1.67\times10^6\text{ psf}$$

$$\Delta h_9 = \left(7275/1.67\times10^6\right)\times20\text{ft} = 0.087\text{ ft}$$

Written by: M. GLEASON Date: 95 / 12 / 15 (YY MM DD) Reviewed by: R.D.E. Date: 96 / 2 / 16 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement Case 1 Point A

Layer 10

20' GMA soils Saturated Depth to Midpoint = 120'

$I_f = 0.96$ $\Delta\sigma_v = 7200$ psf

$\sigma_1 = 11730 + 20(72.6) = 13180$ $\sigma_3 = 5600$ psf

$E_t = 900(2117)\left(5600/2117\right)^{1/2}[1-.35]^2 = 1.31 \times 10^6$ psf

$M = 1.35\ E_t = 1.76 \times 10^6$ psf

$\Delta h_{10} = \left(7200/1.76 \times 10^6 \text{psf}\right) 20\text{ft} = 0.082$ ft

Layer 11 20' GMA Depth to midpoint = 140'

$I_f = 0.95$ $\Delta\sigma_v = 7125$ psf $\sigma_1 = 13180 + 20(72.6) = 14630$ psf

$\sigma_3 = 6230$ psf

$E_t = 900(2117)\left(6230/2117\right)^{1/2}[1-.35]^2 = 1.38 \times 10^6$ psf

$M = 1.35\ E_t = 1.86 \times 10^6$ psf

$\Delta h_{11} = \left(7125/1.86 \times 10^6 \text{psf}\right) 20\text{ft} = 0.077$ ft

Layer 12 20' GMA Soils Mid pt depth @ 160 ft

$I_f = 0.94$ $\Delta\sigma_v = 7050$ psf $\sigma_1 = 14630 + 20(72.6) = 16100$ psf

$\sigma_3 = 6860$

$E_t = 900(2117)\left(6860/2117\right)^{1/2}[1-.35]^2 = 1.44 \times 10^6$ psf

$M = E_t \times 1.35 = 1.9 \times 10^6$ psf

$\Delta h_{12} = \left(7050/1.9 \times 10^6\right) 20\text{ft} = 0.074$ ft

Written by: M. GLEASON Date: 96/2/5 (YY MM DD) Reviewed by: R.D.E. Date: 96/2/16 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement CASE 1 Point A

Layer 13 30' GM Soils Mid depth @ 185 ft

$I_f = 0.92$ $\Delta\sigma_v = 6900$ psf $\sigma_1 = 16100 + 25(72.6) = 17910$ psf

$\sigma_3 = 764.0$ psf

$E_t = 900(2117)\left(7640/2117\right)^{1/2}[1-.35]^2 = 1.52 \times 10^6$

$M = 1.35\ E_t = 2.06 \times 10^6$ psf

$\Delta h_{13} = \left(6900/2.06 \times 10^6\right) 30\text{ft} = 0.100$ ft

Layer 14 30' GM Soils Middepth @ 215 ft

$I_f = 0.89$ $\Delta\sigma_v = 6675$ psf $\sigma_1 = 17910 + 30(72.6) = 20{,}100$ psf

$\sigma_3 = 8560$ psf

$E_t = 900(2117)\left(8560/2117\right)^{1/2}[1-.35]^2 = 1.62 \times 10^6$ psf

$M = E_t \times 1.35 = 2.2 \times 10^6$ psf

$\Delta h_{13} = \left(6675/2.2 \times 10^6 \text{ psf}\right) 30\text{ft} = 0.091$ ft

CASE 1 Point A

TOTAL SETTLEMENT

LAYER	SETTLEMENT ft
1	.446
2	.326
3	.336
4	.232
5	.091
6	.096
7	.107
8	.095
9	.087
10	.082
11	.077
12	.074
13	.100
14	.091
TOTAL	2.24 ft

Written by: M. GLEASON Date: 96/2/5 (YY/MM/DD) Reviewed by: R.D.E. Date: 96/2/16 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

FOUNDATION SETTLEMENT CASE 1 POINT B

POINT B

BECAUSE INFLUENCE VALUES FOR LAYERS 1, 2, and 3 ARE IDENTICAL FOR POINT A, SETTLEMENT IS IDENTICAL.

Layer 1 Δh_T = 0.446 ft
Layer 2 Δh_T = 0.326 ft
Layer 3 Δh_T = 0.336 ft

Layer 4 7.5 ft of Gray Till parameters obtained from Point A calculation
Mid Point @ 19 ft.
I_f = 0.996 $\Delta\sigma_v$ = 7470 psf σ_1 = 2700 psf

Elastic Settlement Parameters Et and M are unchanged.
Et = 284,600, M = 4.9×10^6

$\Delta h_{i4} = (7470/4.9\times10^6)\,7.5\text{ft} = 0.011\text{ft}$

$\Delta h_{p4} = 0.074 \frac{7.5}{1+0.38} \log\left(\frac{2700+7470}{2700}\right) = 0.231\text{ft}$

Δh_{s4} is not influenced by $\Delta\sigma_v$ ∴ is equal to Δh_{s4} for Point A

$\Delta h_{T4} = 0.011 + 0.231 + 0.015\text{ft} = 0.257\text{ft}$

Layer 5 12' Unsaturated GMA Mid depth = 29 ft
values as in Layer 5 Point A

M = 9.8×10^5 I_f = 0.98 $\Delta\sigma_v$ = 7350

$\Delta h_5 = (7350/9.8\times10^5)\,12\text{ ft} = 0.090\text{ft}$

Layer 6 15' Unsaturated GMA Mid depth = 42.5 ft

M = 1.2×10^6 I_f = 0.96 $\Delta\sigma_v$ = 7200 psf

$\Delta h_6 = (7200/1.2\times10^6)\,15\text{ft} = 0.090\text{ft}$

Written by: M. GLEASON Date: 96/2/5 (YY MM DD) Reviewed by: R.D.E. Date: 96/2/16 (YY MM DD)

Client: FERNICO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement CASE 1 POINT B

Layer 7 20' Unsaturated GMA Mid depth = 60 ft

$M = 1.4 \times 10^6$ psf $I_f = 0.94$ $\Delta\sigma_v = 7050$ psf

$\Delta h_7 = (7050 / 1.4 \times 10^6)\, 20' = 0.101$ ft

Layer 8 20' Saturated GMA Mid depth = 80'

$M = 1.5 \times 10^6$ psf $I_f = 0.916$ $\Delta\sigma_v = 6870$ psf

$\Delta h_8 = (6870 / 1.5 \times 10^6)\, 20' = 0.092$ ft

Layer 9 20' Saturated GMA Mid depth = 100'

$M = 1.67 \times 10^6$ psf $I_f = 0.9$ $\Delta\sigma_v = 6750$

$\Delta h_9 = (6750 / 1.67 \times 10^6 \text{ psf})\, 20$ ft $= 0.081$ ft

Layer 10 20' GMA (Sat) Mid depth @ 120'

$M = 1.76 \times 10^6$ psf $I_f = 0.884$ $\Delta\sigma_v = 6630$

$\Delta h_{10} = (6630 / 1.76 \times 10^6 \text{ psf})\, 20$ ft $= 0.075$ ft

Layer 11 20' GMA (Sat) Mid depth @ 140'

$M = 1.86 \times 10^6$ psf $I_f = 0.85$ $\Delta\sigma_v = 6375$ psf

$\Delta h_{11} = (6375 / 1.86 \times 10^6 \text{ psf})\, 20' = 0.069$ ft

Layer 12 20' GMA Sat Mid depth @ 160'

$M = 1.9 \times 10^6$ psf $I_f = 0.836$ $\Delta\sigma_v = 6270$ psf

$\Delta h_{12} = (6270 / 1.9 \times 10^6)\, 20' = 0.066$ ft

Written by: M. GLEASON Date: 96 / 2 / 5 (YY MM DD) Reviewed by: R.P.E. Date: 96 / 2 / 16 (YY MM DD)

Client: FEMCO Project: GSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement Case 1 Point B

Layer 13 30' GMA Soils (Sw) Mid depth = 185 ft

$M = 2.06 \times 10^6$ psf $I_f = 0.82$ $\Delta\sigma_v = 6150$ psf

$\Delta h_{13} = (6150 / 2.06 \times 10^6)\ 30' = 0.090$ ft

Layer 14 30' GMA (Swt) Mid depth = 215 ft

$M = 2.2 \times 10^6$ psf $I_f = 0.80$ $\Delta\sigma_v = 6000$

$\Delta h_{14} = (6000 / 2.2 \times 10^6)\ 30' = 0.082$ ft

CASE 1 POINT B

TOTAL SETTLEMENT

LAYER	SETTLEMENT (FT)
1	.446
2	.326
3	.336
4	.257
5	.090
6	.090
7	.101
8	.092
9	.081
10	.075
11	.069
12	.066
13	.090
14	.082
TOTAL	2.201 ft

Written by: M. GLEASON Date: 96/2/5 (YY/MM/DD) Reviewed by: R.D.E. Date: 96/2/16 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement CASE 1 POINT C

POINT C - See Influence value Pages for $\Delta\sigma_v$

Layer 1 3' Clay Liner Mid pt @ 1.5 $\sigma_o = 195$ $\Delta\sigma_v = 3320$ psf

From Point A $M = 155,500$ psf

$\Delta h_{i_1} = (3320/155,500)\,3' = 0.064$ ft

$\Delta h_{p_1} = 0.035 \frac{3}{1+.43} \log \frac{1000}{195} + 0.13 \frac{3}{1+.43} \log \frac{195+3320}{1000} = 0.201'$

$\Delta h_{s_1} = 0.0015 \frac{3}{1+.32} \log 1000/10 = 0.007$ ft

$\Delta h_{T_1} = 0.272$ ft

Layer 2 5 ft Brown Till Mid pt @ 5.5' $\sigma_o = 730$ psf

$\Delta\sigma_v = 3340$ psf $M = 650,000$ psf OCR = 1.7 $\sigma_p = 1200$

$\Delta h_{i_2} = (3340/650,000)\,5\text{ft} = 0.0026$ ft

$\Delta h_{p_2} = 0.015 \frac{5}{1+.29} \log 1.7 + 0.075 \frac{5}{1+.29} \log \frac{730+3340}{1200} = 0.168$ ft

$\Delta h_{s_2} = 0.0015 \frac{5}{1+.22} \log 1000/10 = 0.012$ ft

$\Delta h_{T_2} = 0.206$ ft

Layer 3 7.5 ft Gray Till Mid pt @ 13' $\sigma_o = 1600$ psf

$M = 3.35 \times 10^6$ $\Delta\sigma_v = 3330$ psf

$\Delta h_{i_3} = (3330/3.35 \times 10^6)\,7.5\text{ft} = 0.007$ ft

$\Delta h_{p_3} = 0.074 \frac{7.5}{1+0.38} \log \left(\frac{1600 + 3330\text{psf}}{1600}\right) = 0.196$ ft

$\Delta h_{s_3} = 0.0013 \frac{7.5}{1+0.29} \log 1000/10 = 0.015$ ft

$\Delta h_{T_3} = 0.218$ ft

Written by: M. GLEASON Date: 96 / 2 / 5 (YY MM DD) Reviewed by: R.D.E. Date: 96 / 2 / 16 (YY MM DD)

Client: FERMIO Project: GSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement CASE 1 POINT C

Layer 4 7.5' Gray Till Mid Pt @ 19' $\sigma_o = 2700$ psf

$M = 4.9 \times 10^6$ psf $\Delta\sigma_v = 3330$ psf

$\Delta h_{i_4} = (3330/4.9\times10^6)7.5 = 0.005$ ft

$\Delta h_{p_4} = 0.074 \frac{7.5}{1.38} \log\left(\frac{3330+2700}{2700}\right) = 0.140$ ft

$\Delta h_{s_4} = 0.015$ ft

$\Delta h_{T_4} = 0.160$ ft

Layer 5 12' Unsaturated GMA Mid pt @ 29' $\Delta\sigma_v = 3340$ psf

$M = 9.8\times10^5$ psf $\Delta h_5 = (3340/9.8\times10^5)12' = 0.041$ ft

Layer 6 15' unsat GMA Midpoint @ 42.5' $\Delta\sigma_v = 3320$ psf

$M = 1.2\times10^6$ psf $\Delta h_6 = (3320/1.2\times10^6 \text{ psf})\,15' = 0.042$ ft

Layer 7 20' Unsaturated GMA Mid pt @ 60' $\Delta\sigma_v = 3290$ psf

$M = 1.4\times10^6$ psf $\Delta h_7 = (3290/1.4\times10^6 \text{ psf})\,20' = 0.047$ ft

Layer 8 20' Saturated GMA Mid Pt @ 80' $\Delta\sigma_v = 3260$ psf

$M = 1.5\times10^6$ psf $\Delta h_8 = (3260/1.5\times10^6)\,20' = 0.043$ ft

Layer 9 20' Saturated GMA Mid Pt @ 100' $\Delta\sigma_v = 3250$ psf

$M = 1.67\times10^6$ psf $\Delta h_9 = (3250/1.67\times10^6)\,20' = 0.039$ ft

Written by: M. GLEASON Date: 96/2/5 (YY MM DD) Reviewed by: R.P.E. Date: 96/2/16 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement CASE 1 POINT C

Layer 10 20' Sat GMA Midpt @ 120' $\Delta\sigma_v$ = 3140 psf

$M = 1.76 \times 10^6$ psf $\Delta h_{10} = (3140/1.76\times10^6)\,20' = 0.037$ ft

Layer 11 20' Sat GMA Midpt @ 140' $\Delta\sigma_v$ = 3070 psf

$M = 1.86 \times 10^6$ psf $\Delta h_{11} = (3070/1.86\times10^6)\,20' = 0.033$ ft

Layer 12 20' Sat GMA Midpt @ 160' $\Delta\sigma_v$ = 3050 psf

$M = 1.9 \times 10^6$ psf $\Delta h_{12} = (3050/1.9\times10^6)\,20' = 0.032$ ft

Layer 13 30' Sat GMA Midpt @ 185' $\Delta\sigma_v$ = 2960 psf

$M = 2.06 \times 10^6$ psf $\Delta h_{13} = (2960/2.06\times10^6)\,30' = 0.043$ ft

Layer 14 30' Sat GMA Mid Pt @ 215' $\Delta\sigma_v$ = 2870 psf

$M = 2.2 \times 10^6$ psf $\Delta h_{14} = (2870/2.2\times10^6\text{ psf})\,30' = 0.039$ ft

CASE 1 POINT C
TOTAL SETTLEMENT

LAYER	SETTLEMENT (ft)
1	.272
2	.206
3	.218
4	.160
5	.041
6	.042
7	.047
8	.043
9	.039
10	.037
11	.033
12	.032
13	.043
14	.039
TOTAL	1.252 ft

Written by: M. GLEASON Date: 96/2/5 (YY MM DD) Reviewed by: R.D.E. Date: 96/2/16 (YY MM DD)

Client: FERMILAB Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement CASE 1 POINT D - TOE

POINT D - USE MATERIAL PARAMETERS FROM POINT A

LAYER 1 CLAY 3ft Mid depth @ 1.5'

$I = 0.0$ $\Delta h_1 = 0.00$ ft

Layer 2 5' Brown Till Mid depth @ 5.5'

$I_f = 0.004$ $\Delta\sigma_v = 30$ psf $M = 650{,}000$ psf $\sigma_v = 730$ psf

$\Delta h_{i_2} = (30/650{,}000)\,5' = 0.00$ ft

$\Delta h_{p_2} = 0.015 \frac{5}{1+.29} \log \frac{730+30}{730} = 0.00$ ft

$\Delta h_{s_2} = 0.012$ ft

$\Delta h_2 = 0.012$ ft

Layer 3 7.5' Gray Till Mid depth @ 12' $\sigma_o = 1600$ psf

$M = 3.35 \times 10^6$ psf $I_f = 0.008$ $\Delta\sigma_v = 60$ psf

$\Delta h_{i_3} = (60/3.35 \times 10^6)\,7.5 = 0.00$ ft

$\Delta h_{p_3} = 0.074 \frac{7.5}{1+.38} \log \frac{1600+60}{1600} = 0.006$ ft

$\Delta h_{s_3} = 0.015$ ft (From Point A)

$\Delta h_3 = 0.021$ ft

Layer 4 7.5' Gray till Mid depth @ 19' $I_f = 0.016$ $\Delta\sigma_v = 120$ psf $\sigma_o = 2700$ psf

$M = 4.9 \times 10^6$ psf $\Delta h_{i_4} = (120/4.9 \times 10^6)\,7.5 = 0.00$ ft

$\Delta h_{p_4} = 0.074 \frac{7.5}{1.38} \log \left(\frac{2700+120}{2700}\right) = 0.008$ ft

$\Delta h_{s_4} = 0.015$ ft

$\Delta h_4 = 0.023$ ft

Written by: M. GLEASON Date: 96/2/5 (YY MM DD) Reviewed by: R.P.E. Date: 96/2/16 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement CASE 1 POINT D

Layer 5 12' Unsaturated GMA Mid depth - 29' σ_o = 4050 psf

$M = 9.8 \times 10^5$ $I_f = 0.024$ $\Delta\sigma_v = 180$ psf

$\Delta h_5 = (180/9.8\times10^5)\,12' = 0.002$ ft

Layer 6 15' unsat GMA Mid depth @ 42.5' $M = 1.2\times10^6$ psf

$I_f = 0.036$ $\Delta\sigma_v = 270$ psf $\Delta h_6 = (270/1.2\times10^6)\,15' = 0.003$ ft

Layer 7 20' unsat GMA Middepth @ 60' $M = 1.4\times10^6$ psf

$I_f = 0.048$ $\Delta\sigma_v = 360$ psf $\Delta h_7 = (360/1.4\times10^6\text{ psf})\,20' = 0.005$ ft

Layer 8 20' sat GMA Middepth @ 80' $M = 1.5\times10^6$ psf

$I_f = 0.066$ $\Delta\sigma_v = 495$ psf $\Delta h_8 = (495/1.5\times10^6)\,20' = 0.007$ ft

Layer 9 20' Sat GMA Middepth @ 100' $M = 1.67\times10^6$ psf

$I_f = 0.08$ ft $\Delta\sigma_v = 600$ psf $\Delta h_9 = (600/1.67\times10^6)\,20' = 0.007$ ft

Layer 10 20' Sat GMA Mid depth @ 120' $M = 1.76\times10^6$ psf

$I_f = 0.096$ $\Delta\sigma_v = 720$ psf $\Delta h_{10} = (720/1.76\times10^6)\,20' = 0.008$ ft

Layer 11 20' Sat GMA Middepth @ 140' $M = 1.86\times10^6$ psf

$I_f = 0.112$ $\Delta\sigma_v = 840$ psf $\Delta h_{11} = (840/1.86\times10^6)\,20' = 0.009$ ft

Layer 12 20' Sat GMA Middepth @ 160' $M = 1.9\times10^6$ psf

$I_f = 0.120$ $\Delta\sigma_v = 900$ psf $\Delta h_{12} = (900/1.9\times10^6\text{ psf})\,20' = 0.009$ ft

Written by: M. GLEASON Date: 96/2/5 (YY/MM/DD) Reviewed by: R.D.E. Date: 96/2/16 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement CASE 1 POINT D

Layer 13 30' GMA Middepth @ 185'

$M = 2.06 \times 10^6$ psf $I_f = 0.136$ $\Delta\sigma_v = 1020$ psf

$\Delta h_{13} = (1020/2.06 \times 10^6)\, 30' = 0.015$ ft ✓

Layer 14 30' GMA Middepth @ 215'

$M = 2.2 \times 10^6$ psf $I_f = 0.140$ $\Delta\sigma_v = 1050$ psf

$\Delta h_{14} = (1050/2.2 \times 10^6)\, 30' = 0.014$ ft ✓

CASE 1 POINT D

TOTAL SETTLEMENT

LAYER	SETTLEMENT
1	—
2	.012
3	.021
4	.023
5	.002
6	.003
7	.005
8	.007
9	.007
10	.008
11	.009
12	.009
13	.015
14	.014
TOTAL	0.135 ft ✓

Written by: M GLEASON Date: 96 / 2 / 5 (YY MM DD) Reviewed by: R.D.E. Date: 96 / 2 / 16 (YY MM DD)

Client: FERRO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement CASE 2 POINT A

POINT A

Layer 1 and 2 have the same values as for CASE 1

Layer 1 $\Delta h_T = 0.446$ ft
Layer 2 $\Delta h_T = 0.326$ ft

Layer 3 5' Thick Brown Till Mid depth @ 10.5' $\Delta\sigma_v = 7500$ psf
Material properties as in CASE 1
$\sigma_0 = 3(130) + 7.5(135) = 1400$ psf $\sigma_3 = 1100$ psf

$$E_{ut} = 175(2117)\left(1100/2117\right)^1 \left[1 - 0.9(1400-1100)/2(1200)\right]^2$$

$$E_{ut} = 1.5\times10^5 \text{ psf} \quad M = \frac{E_{ut}(1-.475)}{(1+.475)(1-.95)} = 1.07\times10^6 \text{ psf}$$

$$\Delta h_{i_3} = \left(7500/1.07\times10^6\right)5' = 0.035 \text{ ft} \qquad \sigma_p = 1.7\times\sigma_0 = 2380$$

$$\Delta h_{p_3} = 0.015\frac{5}{1+.29}\log 1.7 + 0.075\frac{5}{1+0.29}\log\frac{1400+7500}{2380} = 0.180 \text{ ft}$$

$$\Delta h_{s_3} = 0.0015\frac{5}{1+.22}\log 1000/10 = 0.012 \text{ ft}$$

$$\Delta h_{T_3} = 0.227 \text{ ft}$$

Layer 4 5' Gray Till $\Delta\sigma_v = 7500$ psf Mid depth = 15.5'

$\sigma_1 = 3(130) + 10(135) + 2.5(145) = 2100$ psf $\sigma_3 = 1700$ psf

$$E_{ut} = 175(2117)\left(1700/2117\right)^1\left[1 - .9(2100-1700)/2(1900)\right]^2 = 2.4\times10^5 \text{ psf}$$

$$M = \frac{E_{ut}(1-.49)}{1+.49(0.02)} = 4.2\times10^6 \text{ psf}$$

$$\Delta h_{i_4} = \left(7500/4.2\times10^6 \text{ psf}\right)5' = 0.009 \text{ ft}$$

$$\Delta h_{p_4} = 0.074\times\frac{5}{1+0.38}\log\frac{2100+7500}{2100} = 0.177 \text{ ft}$$

$$\Delta h_{s_4} = 0.0013\frac{5}{1+0.29}\log 1000/10 = 0.010 \text{ ft}$$

$$\Delta h_{T_4} = 0.196 \text{ ft}$$

Written by: M. GLEASON Date: 96 / 2 / 5 (YY MM DD) Reviewed by: R.D.E. Date: 96 / 2 / 16 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement CASE 2 · Point A

Layer 5

10' Gray Till $\Delta\sigma_v = 7500$ ($I_f = 1.0$) Middepth = 23'

$\sigma_0 = 390 + 1350 + 10(145) = 3190$ psf $\sigma_3 = 2550$ psf

$E_{ut} = 175(2117)(2550/2117)^1 [1 - .9(3190-2550)/2(1900)]^2$

$E_{ut} = 3.2 \times 10^5$ $M = E_{ut}(17.1) = 5.5 \times 10^6$ psf

$\Delta h_{i_5} = (7500/5.5 \times 10^6)\,10' = 0.014$ ft

$\Delta h_{p_5} = 0.074 \frac{10'}{1+.38} \log\left(\frac{7500+3190}{3190}\right) = 0.282$ ft

$\Delta h_{s_5} = 0.0013 \frac{10}{1+.29} \log 1000/10 = 0.020$ ft

$\Delta h_5 = 0.316$ ft

Layer 6 10' Gray Till Middepth = 33' $\Delta\sigma_v = 7500$ psf

$\sigma_1 = 390 + 1350 + 20(145) = 4640$ psf $\sigma_3 = 3700$ psf

$E_{ut} = 175(2117)(3700/2117)^1 [1 - .9(4640-3700)/2(1900)]^2$

$E_{ut} = 3.9 \times 10^5$ $M = E_{ut}(17.1) = 6.7 \times 10^6$ psf

$\Delta h_{i_6} = (7500/6.7 \times 10^6 \text{ psf})\,10' = 0.011$ ft

$\Delta h_{p_6} = 0.074 \frac{10'}{1+.38} \log \frac{4640+7500}{4640} = 0.224$ ft

$\Delta h_{s_6} = 0.0013 \frac{10}{1+.29} \log 1000/10 = 0.020$ ft

$\Delta h_6 = 0.255$ ft.

Written by: M. GLEASON Date: 96/12/15 (YY/MM/DD) Reviewed by: R.D.E. Date: 96/12/16 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement CASE 2 POINT A

Layer 7 10' Gray Till Mid depth @ 43' $\Delta\sigma_v = 7500$ psf

$\sigma_1 = 390 + 1350 + 30(145) = 6090$ psf $\sigma_3 = 4870$ psf

$E_{ut} = 175(2117)(4870/2117)^1 [1 - .9(6090 - 4870)/2(1900)]^2$

$E_{ut} = 4.3 \times 10^5$ psf $M = E_{ut} \times 17.1 = 7.4 \times 10^6$ psf

$\Delta h_{i7} = (7500/7.4 \times 10^6 \text{ psf})10' = 0.010$ ft

$\Delta h_{p7} = 0.074 \frac{10}{1+.38} \log \frac{6090 + 7500}{6090} = 0.187$ ft

$\Delta h_s = 0.020$ ft

$\Delta h_7 = 0.217$ ft

Layer 8 10' Gray Till Mid depth = 53' $\Delta\sigma_v = 7500$ psf

$\sigma_1 = 390 + 1350 + 40(145) = 7540$ psf $\sigma_3 = 6030$ psf

$E_{ut} = 175(2117)(6030/2117)^1 [1 - .9(7540 - 6030)/2(1900)]^2$

$E_{ut} = 4.4 \times 10^5$ psf $M = 7.4 \times 10^6$ psf

$\Delta h_{i8} = (7500/7.4 \times 10^6)10' = 0.010$ ft

$\Delta h_{p8} = 0.074 \frac{10}{1+.38} \log \left(\frac{7540 + 7500}{7540}\right) = 0.161$ ft

$\Delta h_{s8} = 0.020$ ft

$\Delta h_8 = 0.191$ ft

Written by: M. GLEASON Date: 96/2/5 (YY/MM/DD) Reviewed by: R.P.E. Date: 96/2/16 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement CASE 2 POINT A

Layer 9 12' GMA Soils Middepth = 64ft $I_f = 0.99$ $\Delta\sigma_v = 7425$ psf

$\sigma_1 = 390 + 1350 + 45(145) + 6(135) = 9075$ psf $\sigma_3 = 3870$ psf

$$E_t = 900(2117)\left(3870/2117\right)^{1/2}\underbrace{\left[1 - .7\,(1-\sin 35)(9075-3870)/2\sin 35(3870)\right]^2}_{=0.65}$$

$E_t = 1.09 \times 10^6$ psf $M = 1.35\,E_t = 1.47 \times 10^6$ psf

$\Delta h_9 = \left(7425/1.47\times10^6\right)12' = 0.061$ ft

Layer 10 20' Saturated GMA Soils Mid dpth = 80'

$I_f = 0.98$ $\Delta\sigma_v = 7350$ psf

$\sigma_1 = 825 + 12(135) + 10(72.6) = 10{,}600$ 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

$\Delta h_{10} = \left(7350/1.6\times10^6\right)20' = 0.093$ ft

Layer 11 20' GMA Mid depth @ 100' $I_f = 0.97$ $\Delta\sigma_v = 7275$ psf

$\sigma_1 = 9885 + 30(72.6) = 12060$ psf $\sigma_3 = 5140$ psf

$E_t = 900(2117)\left(5140/2117\right)^{1/2}[.65]^2 = 1.26\times10^6$ psf

$M = 1.35\,E_t = 1.7\times10^6$ psf

$\Delta h_{11} = \left(7275/1.7\times10^6\right)$psf $20' = 0.086$ ft

Written by: M. GLEASON Date: 96/12/15 (YY MM DD) Reviewed by: R.D.E. Date: 96/12/16 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement CASE 2 POINT A

LAYER 12 20' GMA Middepth @ 120' $I_f = 0.96$ $\Delta\sigma_v = 7200$ psf

$\sigma_1 = 9885 + 50(72.6) = 13515$ psf $\sigma_3 = 5760$ psf

$E_t = 900(2117)(5760/2117)^{1/2}(.65)^2 = 1.3\times10^6$ psf $M = 1.7\times10^6$ psf

$\Delta h_{12} = (7200/1.7\times10^6)\cdot 20' = 0.085'$

Layer 13 20' GMA Middepth @ 140' $I_f = 0.95$ $\Delta\sigma_v = 7125$ psf

$\sigma_1 = 9885 + 70(72.6) = 14970$ psf $\sigma_3 = 6370$ psf

$E_t = 900(2117)(6370/2117)^{1/2}[.65]^2 = 1.4\times10^6$ psf $M = 1.9\times10^6$ psf

$\Delta h_{13} = (7125/1.9\times10^6)\,20' = 0.075$ ft

Layer 14 20' GMA Middepth @ 160' $I_f = 0.94$ $\Delta\sigma_v = 7050$ psf

$\sigma_1 = 9885 + 90(72.6) = 16400$ psf $\sigma_3 = 7000$ psf

$E_t = 900(2117)(7000/2117)^{1/2}(.65)^2 = 1.46\times10^6$ psf $M = 1.98\times10^6$ psf

$\Delta h_{14} = (7050/1.98\times10^6)\,20' = 0.071$ ft

Layer 15 30' GMA Mid @ 185' $I_f = 0.92$ $\Delta\sigma_v = 6900$ psf

$\sigma_1 = 9885 + 115(72.6) = 18230$ psf $\sigma_3 = 7770$ psf

$E_t = 900(2117)(7770/2117)^{1/2}(.65)^2 = 1.54\times10^6$ psf $M = 2.07\times10^6$ psf

$\Delta h_{15} = (6900/2.07\times10^6)\,30' = 0.100$ ft

Written by: M. GLEASON Date: 96/2/5 Reviewed by: R.D.S. Date: 96/2/16

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement CASE 2 POINT A

Layer 16 30' GMA Mid pt @ 215' $I_f = 0.89$ $\Delta\sigma_v = 6675$ psf

$\sigma_1 = 9885 + 145(72.6) = 20{,}400$ psf $\sigma_3 = 8700$ psf

$E_t = 900(2117)\left(8700/2117\right)^{1/2}(.65)^2 = 1.63\times10^6$ $M = 2.2\times10^6$ psf

$\Delta h_{16} = \left(6675/2.2\times10^6\right)30' = 0.091$ ft

CASE 2 POINT A

TOTAL SETTLEMENT

LAYER	SETTLEMENT (FT)
1	.446
2	.326
3	.227
4	.196
5	.316
6	.255
7	.217
8	.191
9	.061
10	.093
11	.086
12	.085
13	.075
14	.071
15	.100
16	.091
TOTAL	2.836 ft

Written by: M. GLEASON Date: 96/2/15 (YY/MM/DD) Reviewed by: R.D.E. Date: 96/2/16 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement CASE 2 POINT B

POINT B - VALUES FROM POINT A

Because Influence Values for Points 1, 2, 3 and 4 are the same as for Point A, total settlements are also the same

Layer 1 $\Delta h_1 = .446$ ft
Layer 2 $\Delta h_2 = .326$ ft
Layer 3 $\Delta h_3 = .227$ ft
Layer 4 $\Delta h_4 = .196$ ft

Layer 5 10' Gray Till Midpt @ 23 ft $I_f = 0.99$ $\Delta\sigma_v = 7425$ psf

From Point A $M = 5.5 \times 10^6$ psf $\sigma_1 = 3190$ psf

$\Delta h_{i_5} = (7425/5.5\times10^6)10' = 0.014$ ft

$\Delta h_{p_5} = 0.074 \frac{10}{1+.38} \log \frac{7425+3190}{3190} = 0.2800$ ft

$\Delta h_{s_5} = 0.020$ ft (Point A, 5)

$\Delta h_5 = 0.314$ ft

Layer 6 10' Gray Till Midpt @ 33 ft $I_f = 0.97$ $\Delta\sigma_v = 7275$

$M = 6.7 \times 10^6$ psf $\sigma_1 = 4640$ psf

$\Delta h_{i_6} = (7275/6.7\times10^6)10 = 0.011$ ft

$\Delta h_{p_6} = 0.074 \frac{10}{1+.38} \log \frac{4640+7275}{4640} = 0.220$ ft

$\Delta h_{s_6} = 0.02$ ft

$\Delta h_6 = 0.251$ ft

Written by: M. GLEASON Date: 96/2/5 (YY/MM/DD) Reviewed by: R.D.E. Date: 96/2/16 (YY/MM/DD)

Client: FEMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement CASE 2 POINT B

LAYER 7 10' Gray Till Midpt @ 43' $I_f = 0.96$ $\Delta\sigma_v = 7200$ psf

$M = 7.4 \times 10^6$ psf $\sigma_o = 6090$ psf

$\Delta h_{i_7} = (7200/7.4\times10^6)\,10' = 0.010$ ft

$\Delta h_{p_7} = 0.074 \frac{10}{1.38} \log \frac{6090+7200}{6090} = 0.182$ ft

$\Delta h_{s_7} = 0.020$ ft ✓

$\Delta h_7 = 0.212$ ft

Layer 8 10' Gray Till Midpt @ 53' $I_f = 0.95$ $\Delta\sigma_v = 7125$ psf

$M = 7.4 \times 10^6$ $\sigma_o = 7540$ psf

$\Delta h_{i_8} = (7125/7.4\times10^6)\,10' = 0.010$ ft

$\Delta h_{p_8} = 0.074 \frac{10}{1.38} \log \frac{7540+7125}{7540} = 0.155$ ft

$\Delta h_{s_8} = 0.020$ ft

$\Delta h_8 = 0.185$ ft ✓

Layer 9 12' GMA Soils Midpt @ 64' $I_f = 0.94$ $\Delta\sigma_v = 7050$ psf

$M = 1.47\times10^6$ $\Delta h_9 = (7050/1.47\times10^6)\,12' = 0.058$ ft

Layer 10 20' GMA Soils Midpt @ 80' $I_f = 0.916$ $\Delta\sigma_v = 6870$ psf

$M = 1.6\times10^6$ psf $\Delta h_{10} = (6870/1.6\times10^6)\,20' = 0.086$ ft

Layer 11 20' GMA Soils Midpt @ 100' $I_f = 0.90$ $\Delta\sigma_v = 6750$ psf

$M = 1.7\times10^6$ psf $\Delta h_{11} = (6750/1.7\times10^6)\,20' = 0.079$ ft ✓

Written by: M. GLEASON Date: 96/2/15 (YY MM DD) Reviewed by: R.D.E. Date: 96/2/16 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: 6E 3900 Task No.: 9.9

Foundation Settlement CASE 2 POINT B

Layer 12 20' GMA Soils Midpt @ 120' $I_f = 0.884$ $\Delta\sigma_v = 6630$ psf

$M = 1.7 \times 10^6$ psf $\Delta h_{12} = (6630/1.7 \times 10^6)\,20' = 0.078$ ft

Layer 13 20' GMA Soils Midpt @ 140' $I_f = 0.85$ $\Delta\sigma_v = 6375$ psf

$M = 1.9 \times 10^6$ psf $\Delta h_{13} = (6375/1.9 \times 10^6)\,20' = 0.067$ ft

Layer 14 20' GMA Soils Mid pt @ 160' $I_f = 0.836$ $\Delta\sigma_v = 6270$ psf

$M = 1.98 \times 10^6$ psf $\Delta h_{14} = (6270/1.98 \times 10^6)\,20' = 0.063$ ft

Layer 15 30' GMA Soils Mid Pt @ 185' $I_f = 0.82$ $\Delta\sigma_v = 6150$ psf

$M = 2.07 \times 10^6$ psf $\Delta h_{15} = (6150/2.07 \times 10^6)\,30' = 0.089$ ft

Layer 16 30' GMA Soils Mid pt @ 215' $I_f = 0.80$ $\Delta\sigma_v = 6000$ psf

$M = 2.2 \times 10^6$ psf $\Delta h_{16} = (6000/2.2 \times 10^6)\,30' = 0.082$ ft

CASE 2 POINT B TOTAL SETTLEMENT

LAYER	SETTLEMENT	LAYER	SETTLEMENT
1	.446	11	.079
2	.326	12	.078
3	.227	13	.067
4	.196	14	.063
5	.314	15	.089
6	.251	16	.082
7	.212		
8	.185	TOTAL	2.758 ft
9	.058		
10	.086		

Written by: M. GLEASON Date: 96/2/6 (YY/MM/DD) Reviewed by: R.D.E. Date: 96/2/16 (YY/MM/DD)

Client: FERMIO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement CASE 2 POINT C

POINT C

Calculated Settlement for Layers 1 and 2 are equal to calculated settlements for CASE 1 Point C 1 & 2

Layer 1 $\Delta h_1 = 0.272$ ft
Layer 2 $\Delta h_2 = 0.206$ ft

Layer 3 5' Brown Till Mid pt @ 10.5' $\Delta\sigma_v = 3380$ psf (from If chart)

From point A, $M = 1.07 \times 10^6$ psf $\sigma_o = 1400$ psf $\sigma_3 = 1100$ psf

$\Delta h_{i_3} = \left(3380/1.07 \times 10^6\right) 5' = 0.016$ ft $\sigma_p = 2380$

$\Delta h_{p_3} = 0.015 \frac{5}{1+.29} \log 1.7 + 0.075 \frac{5}{1+.29} \log \frac{1400+3380}{2380} = 0.101$ ft

$\Delta h_{s_3} = 0.0015 \frac{5}{1+.22} \log 1000/10 = 0.012$ ft

$\Delta h_3 = 0.129$ ft

Layer 4 5' Gray Till Mid pt @ 15.5 ft $\Delta\sigma_v = 3330$ psf

$M = 4.2 \times 10^6$ psf $\sigma_o = 2100$ psf

$\Delta h_{i_4} = \left(3330/4.2 \times 10^6 \text{ psf}\right) 5' = 0.004$ ft

$\Delta h_{p_4} = 0.074 \frac{5}{1+.38} \log \frac{3330+2100}{2100} = 0.111$ ft

$\Delta h_{s_4} = 0.0013 \frac{5}{1+.29} \log 1000/10 = 0.010$ ft

$\Delta h_4 = 0.125$ ft

Written by: M. GLEASON Date: 96/2/6 (YY MM DD) Reviewed by: R.D.E. Date: 96/2/16 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement CASE 2 POINT C

LAYER 5 10' Gray Till Midpt @ 23' $\Delta\sigma_v = 3320$ psf

$M = 5.5 \times 10^6$ $\sigma_o = 3190$ psf

$\Delta h_{i_5} = (3320/5.5\times10^6)10' = 0.006$ ft

$\Delta h_{p_5} = 0.074 \frac{10}{1+.38} \log \frac{3320+3190}{3190} = 0.166$ ft

$\Delta h_{s_5} = 0.0013 \frac{10}{1+.29} \log 1000/10 = 0.020$ ft

$\Delta h_5 = 0.192$ ft

Layer 6 10' Gray Till Midpt @ 33' $\Delta\sigma_v = 3350$ ft

$M = 6.7\times10^6$ psf $\sigma_o = 4640$ psf

$\Delta h_{i_6} = (3350/6.7\times10^6)10' = 0.005$ ft

$\Delta h_{p_6} = 0.074 \frac{10}{1+.38} \log \frac{4640+3350}{4640} = 0.127$ ft

$\Delta h_{s_6} = 0.020$ ft

$\Delta h_6 = 0.152$ ft

Layer 7 10' Gray Till Midpt @ 43' $\Delta\sigma_v = 3320$ psf

$M = 7.4\times10^6$ psf $\sigma_o = 6090$

$\Delta h_{i_7} = (3320/7.4\times10^6)10' = 0.004$ ft

$\Delta h_{p_7} = 0.074 \frac{10}{1+.38} \log \frac{3320+6090}{6090} = 0.102$ ft

$\Delta h_{s_7} = 0.020$ ft

$\Delta h_7 = 0.126$ ft

Written by: M. GLEASON Date: 96/2/16 (YY/MM/DD) Reviewed by: R.P.E. Date: 96/2/16 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement CASE 2 POINT C

LAYER 8 10' Gray Till Midpt @ 53' $\Delta\sigma_v = 3290$ psf

$M = 7.4 \times 10^6$ psf $\sigma_o = 7540$ psf

$\Delta h_{ig} = (3290/7.4 \times 10^6)10' = 0.004$ ft

$\Delta h_{p_8} = 0.074 \frac{10}{1.38} \log\left(\frac{3290 + 7540}{7540}\right) = 0.084$ ft

$\Delta h_{s_8} = 0.020$ ft

$\Delta h_8 = 0.108$ ft ✓

Layer 9 12' GMA Soils Midpt @ 64 ft $\Delta\sigma_v = 3280$ psf

$M = 1.47 \times 10^6$ psf $\Delta h_9 = (3280/1.47 \times 10^6)12' = 0.027$ ft ✓

Layer 10 20' GMA Soils Midpt @ 80' $\Delta\sigma_v = 3260$ psf

$M = 1.6 \times 10^6$ psf $\Delta h_{10} = (3260/1.6 \times 10^6)20' = 0.041$ ft ✓

Layer 11 20' GMA Soils Midpt @ 100' $\Delta\sigma_v = 3250$ psf

$M = 1.7 \times 10^6$ psf $\Delta h_{11} = (3250/1.7 \times 10^6)20' = 0.038$ ft ✓

Layer 12 20' GMA Soils Midpt @ 120' $\Delta\sigma_v = 3140$ psf

$M = 1.7 \times 10^6$ psf $\Delta h_{12} = (3140/1.7 \times 10^6)20' = 0.037$ ft ✓

Layer 13 20' GMA Soils Midpt @ 140' $\Delta\sigma_v = 3070$ psf

$M = 1.9 \times 10^6$ psf $\Delta h_{13} = (3070/1.9 \times 10^6)20' = 0.032$ ft ✓

Layer 14 20' GMA Soils Midpt @ 160' $\Delta\sigma_v = 3050$ psf

$M = 1.98 \times 10^6$ psf $\Delta h_{14} = (3050/1.98 \times 10^6)20' = 0.031$ ft ✓

GEOSYNTEC CONSULTANTS

Written by: M. GLEASON Date: 96/2/6 (YY/MM/DD) Reviewed by: R.D.E. Date: 96/2/16 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement CASE 2 POINT C

Layer 15 30' GMA Midpt @ 185' $\Delta\sigma_v$ = 2960 psf

$M = 2.07 \times 10^6$ psf $\Delta h_{15} = (2960/2.07 \times 10^6)\,30' = 0.043$ ft

Layer 16 30' GMA Midpt @ 215' $\Delta\sigma_v$ = 2870 psf

$M = 2.2 \times 10^6$ psf $\Delta h_{16} = (2870/2.2 \times 10^6)\,30' = 0.039$ ft

CASE 2 POINT C

TOTAL SETTLEMENT

Layer	Settlement (ft)
1	.272
2	.206
3	.129
4	.125
5	.192
6	.152
7	.126
8	.108
9	.027
10	.041
11	.038
12	.037
13	.032
14	.031
15	.043
16	.039
TOTAL	1.598 ft

Written by: M. GLEASON Date: 96/2/16 (YY/MM/DD) Reviewed by: R.D.B. Date: 96/2/16 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

FOUNDATION SETTLEMENT CASE 2 POINT D (TOE)

POINT D

For Layers 1 & 2 use Parameters and Settlements from CASE 1 POINT D

Layer 1 $\Delta h_1 = 0.000$ ft
Layer 2 $\Delta h_2 = 0.012$ ft

Layer 3 5' Brown Till Midpt @ 10.5' $I_f = 0.008$ $\Delta\sigma_v = 60$ psf

From POINT A, CASE 2 $M = 1.07 \times 10^6$ psf $\sigma_o = 1400$ psf OCR = 1.7

$\Delta h_{i_3} = (60/1.07 \times 10^6)5' = 0.000$ ft

$\Delta h_{p_3} = 0.015 \frac{5}{1+.29} \log \frac{1400+60}{1400} = 0.001$ ft

$\Delta h_{s_3} = 0.012$ ft

$\Delta h_3 = 0.013$ ft

Layer 4 5' Gray Till Midpt @ 15.5' $I_f = 0.014$ $\Delta\sigma_v = 105$ psf

$M = 4.2 \times 10^6$ psf $\sigma_o = 2100$ psf

$\Delta h_{i_4} = (105/4.2 \times 10^6)5' = 0.000$ ft

$\Delta h_{p_4} = 0.074 \frac{5}{1.38} \log \frac{2100+105}{2100} = 0.006$ ft

$\Delta h_{s_4} = 0.0013 \frac{5}{1+.29} \log 1000/10 = 0.010$ ft

$\Delta h_4 = 0.016$ ft

Written by: M. GLEASON Date: 96/2/6 (YY/MM/DD) Reviewed by: R.D.E. Date: 96/2/16 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement CASE 2 POINT D

Layer 5 10' Gray Till Midpt @ 23' $I_f = 0.02$ $\Delta\sigma_v = 150$ psf

$M = 5.5 \times 10^6$ psf $\sigma_o = 3190$ psf

$\Delta h_{i_5} = (150/5.5 \times 10^6)\,10' = 0.000$ ft

$\Delta h_{p_5} = 0.074 \frac{10}{1+1.38} \log \frac{150+3190}{3190} = 0.011$ ft

$\Delta h_{s_5} = 0.0015 \frac{10}{1+.29} \log 1000/10 = 0.020$ ft

$\Delta h_5 = 0.031$ ft

Layer 6 10' Gray Till Middepth @ 33' $I_f = 0.028$ $\Delta\sigma_v = 210$ psf

$M = 6.7 \times 10^6$ psf $\sigma_o = 4640$ psf

$\Delta h_{i_6} = (210/6.7 \times 10^6)\,10' = 0.000$ ft

$\Delta h_{p_6} = 0.074 \frac{10'}{1+.38} \log \frac{210+4640}{4640} = 0.010$ ft

$\Delta h_{s_6} = 0.020$ ft

$\Delta h_6 = 0.030$ ft

Layer 7 10' Gray Till Middepth @ 43' $I_f = 0.036$ $\Delta\sigma_v = 270$ psf

$M = 7.4 \times 10^6$ psf $\sigma_o = 6090$ psf

$\Delta h_{i_7} = (270/7.4 \times 10^6)\,10' = 0.000$ ft

$\Delta h_{p_7} = 0.074 \frac{10}{1.38} \log \frac{270+6090}{6090} = 0.010$ ft

$\Delta h_{s_7} = 0.020$ ft

$\Delta h_7 = 0.030$ ft

Written by: M. GLEASON Date: 96/2/6 (YY/MM/DD) Reviewed by: R.D.E. Date: 96/2/16 (YY/MM/DD)

Client: FERMILAB Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement CASE 2 POINT D

Layer 8 10' Gray Till Midpt @ 53' $I_f = 0.04$ $\Delta\sigma_v = 300$ psf

$M = 7.4 \times 10^6$ psf $\sigma_o = 7540$ psf

$\Delta h_{i8} = (300/7.4\times10^6)\,10' = 0.000$ ft

$\Delta h_{p8} = 0.074 \frac{10'}{1+1.38} \log \frac{7540+300}{7540} = 0.009$ ft

$\Delta h_{s8} = 0.020$ ft

$\Delta h_8 = 0.029$ ft ✓

Layer 9 12' GMA Soils Midpt @ 64' $I_f = 0.056$ $\Delta\sigma_v = 420$ psf

$M = 1.47\times10^6$ psf $\Delta h_9 = (420/1.47\times10^6)\,12' = 0.003$ ft ✓

Layer 10 20' GMA Midpt @ 80' $I_f = 0.066$ $\Delta\sigma_v = 495$ psf

$M = 1.6\times10^6$ psf $\Delta h_{10} = (495/1.6\times10^6)\,20' = 0.006$ ft ✓

Layer 11 20' GMA Midpt @ 100' $I_f = 0.08$ $\Delta\sigma_v = 600$ psf

$M = 1.7\times10^6$ psf $\Delta h_{11} = (600/1.7\times10^6)\,20' = 0.007$ ft ✓

Layer 12 20' GMA Midpt @ 120' $I_f = 0.096$ $\Delta\sigma_v = 720$ psf

$M = 1.7\times10^6$ psf $\Delta h_{12} = (720/1.7\times10^6)\,20' = 0.008$ ft

Layer 13 20' GMA Midpt @ 140' $I_f = 0.112$ $\Delta\sigma_v = 840$ psf

$M = 1.9\times10^6$ psf $\Delta h_{13} = (840/1.9\times10^6)\,20' = 0.009$ ft ✓

Layer 14 20' GMA Midpt @ 160' $I_f = 0.120$ $\Delta\sigma_v = 900$ psf

$M = 1.98\times10^6$ psf $\Delta h_{14} = (900/1.98\times10^6)\,20' = 0.009$ ft ✓

Written by: M. GLEASON Date: 96/2/6 (YY/MM/DD) Reviewed by: R.D.E. Date: 96/2/16 (YY/MM/DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement CASE 2 POINT D

Layer 15 30' GMA Midpt @ 185' $I_f = 0.136$ $\Delta\sigma_v = 1020$ psf

$M = 2.07 \times 10^6$ psf $\Delta h_{15} = (1020/2.07 \times 10^6)\,30' = 0.015$ ft

Layer 16 30' GMA Midpt @ 215' $I_f = 0.140$ $\Delta\sigma_v = 1050$ psf

$M = 2.2 \times 10^6$ psf $\Delta h_{16} = (1050/2.2 \times 10^6)\,30' = 0.014$ ft

CASE 2 POINT D

TOTAL SETTLEMENT

LAYER	SETTLEMENT (FT)
1	.000
2	.012
3	.013
4	.016
5	.031
6	.030
7	.030
8	.029
9	.003
10	.006
11	.007
12	.008
13	.009
14	.009
15	.015
16	.014
TOTAL	0.232 ft

Written by: M. GLEASON Date: 96/2/6 (YY MM DD) Reviewed by: R.D.E. Date: 96/2/16 (YY MM DD)

Client: FRESNO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.9

Foundation Settlement

DIFFERENTIAL SETTLEMENT, GRADE CHANGE, TENSILE STRAIN

	CASE 1	CASE 2	(Rounded to nearest 100th)
POINT A	2.24 ft	2.84 ft	
POINT B	2.20 ft	2.76 ft	
POINT C	1.25 ft	1.60 ft	
POINT D	0.14 ft	0.23 ft	→ POINT NOT Important for Liner System Analysis

CASE 1

POINTS A-B Differential Settlement, $\Delta_s = 0.04$ $L = 140$ ft

Grade Change = 0.03 %

Tensile Strain $\varepsilon = 8/3\left(\Delta_s/L\right)^2 100$ ε = very small

POINTS B-C

$\Delta_s = (2.20 - 1.25)$ ft = 0.95 ft $L = 190$ ft

Grade Change $(0.95/190) \times 100 = 0.50$ %

Tensile Strain $\varepsilon = 8/3\left(.95/190\right)^2 100 = < 0.01$ %

CASE 2

POINTS A-B

$\Delta_s = (2.84 - 2.76) = 0.08$ ft $L = 140$ ft

Grade Change $= (.08/140) \times 100 = 0.06$ %

Tensile Strain ε = very small

POINTS B-C

$\Delta_s = (2.76 - 1.60) = 1.16$ ft $L = 190$ ft

Grade Change $(1.16/190)\,100 = 0.61$ %

Tensile Strain $\varepsilon = 8/3\left(1.16/190\right)^2 100 = 0.01$ %

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.: GE 3900 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 $t_{90} = \frac{0.848 (23 ft)^2}{0.02 in^2/min} \times \frac{144 in^2}{1 ft^2} = 6.1$ yrs ✓ (Converted from minutes to years)

CASE 2 $t_{90} = \frac{0.848 (58 ft)^2}{0.02 in^2/min} \times \frac{144 in^2}{ft^2} = 39$ yrs ✓

TIME TO 95% CONSOLIDATION $T = 1.163$

CASE 1 $t_{95} = \frac{1.163 (23 ft)^2}{0.02 in^2/min} \times 144 = 8.4$ yrs ✓

CASE 2 $t_{95} = \frac{1.163 (58 ft)^2}{0.02 in^2/min} \times \frac{144 in^2}{ft^2} = 54$ yrs ✓

5.2 Localized Impacted Material Settlement

COMPUTATION COVER SHEET

SUBJECT OF CALCULATION: LOCALIZED IMPACTED MATERIAL SETTLEMENT

Computations By: (Cognizant Engineer)
Signature: [signature] Date: 05 APR 96
Printed Name and Title: DAVID W. WARREN, STAFF ENGINEER

Assumptions and Procedures Checked by: (Checker)
Signature: [signature] Date: 5 April 96
Printed Name and Title: Kara L Olen, Asst Proj Engr

Computations Checked by:
Signature: [signature] Date: 5 April 96
Printed Name and Title: Kara L Olen, Asst Proj Eng.

Computations Backchecked by: (Cognizant Engineer)
Signature: [signature] Date: 05 APR 96
Printed Name and Title: DAVID W. WARREN, STAFF ENGINEER

Approved by: (PDP)
Signature: [signature] Date: 05 April 96
Printed Name and Title: Kara L. Olen, Asst. Proj Engr.

Approved by: (DTL and TETL)
Signature: [signature] Date: 7 Apr 96
Printed Name and Title: Kenneth W Cargill, Associate

Record of Revision (Number and initial all revisions)

Rev. No.	Reason	Date	By	Checked	Approval
0					

Written by: DWW Date: 5 April 1996 Reviewed by: K-Olen Date: 4/5/96

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE3900 Task No.: 8.8

LOCALIZED IMPACTED MATERIAL SETTLEMENT

EXECUTIVE SUMMARY

The possible extent of localized settlements in the impacted material are calculated in this section. The largest localized settlements are most likely to occur in locations where Category 2 impacted material (i.e., construction debris) is placed. The Category 2 impacted material has the greatest potential for the development of large voids into which overlying soils may enter and possibly create a depression in the surface of the overlying soils. These large voids could potentially occur ~~dut~~ due to soil raveling or the disintegration of certain types of debis over the extended life of the OSDF. The magnitude of possible settlements that may occur in the surface of the overlying soils due to localized development of voids in the Category 2 impacted material was calculated using the methods described in Sagaseta (1987) which analyses the strains induced in an incompressible soil caused by ground losses at moderate depths below the ground surface. The results of the calculation indicate depressions at the surface of the overlying soils (whether the overlying soils are an intermediate soil or the final cover soils) due to localized settlements in the Category 2 impacted material should be very small (i.e., approximately one inch or less). and are not expected to have any detrimental impact on any intermediate soil layers or the final cover system.

Written by: DWW Date: 5 April 1996 Reviewed by: K. Olen Date: 4/5/96

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE3900 Task No.: 8.8

LOCALIZED IMPACTED MATERIAL SETTLEMENT

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Written by: DWW Date: 5 April 1996 Reviewed by: K. Oler Date: 4/5/96

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE3900 Task No.: 8.8

CALCULATION PROCEDURES

Sagaseta's plane strain formulation for maximum deflection due to a void developing in the underlying material is:

$$S_z = S_{z1} + S_{z2} + S_{z3}$$

where:

$$S_{z1} = -(a^2/2)([z-h]/[r_1^2])$$

$$S_{z2} = (a^2/2)([z+h]/[r_2^2])$$

$$S_{z3} = (a^2 z/r_2^2)(1-2[x^2/r_2^2])$$

and where:

x = x coordinate (horizontal position) of point of interest

y = y coordinate (vertical position) of point of interest

a = void radius

h = vertical distance between center of void and point of interest

r_1 = radius from point of interest to void center
= $(x^2 - [z-h]^2)^{1/2}$

r_2 = radius from point of interest to mirror image of void center
= $(x^2 + [z+h]^2)^{1/2}$

During placement of impacted material in the OSDF, Category 2 waste will be placed in waste horizons consisting of (from bottom to top):

- 18-inch thick category 2 waste;
- 3-inch thick category 1 soil;
- 18-inch thick category 2 waste;
- 3-inch thick category 1 soil; and
- 4-foot thick category 1 soil (during construction of the final horizon this will be replaced with the 3-foot thick select impacted material layer overlain by the 1-foot thick contouring layer)

Based on the Sagaseta equations, the magnitude of localized settlement will increase as the proximity of the void to the point of interest (i.e., the point on the surface of the soil overlying the Category 2 waste located directly above the void center) decreases. Based on this, for any one Category 2 horizon, the largest deflection at the surface of the 4-foot thick Category 1 soil layer would occur if a void developed at the top of the uppermost 18-inch thick Category 2 lift. Therefore, for this calculation a void is assumed to develop in a Category 2 horizon at the top of the uppermost lift of Category 2. The magnitude of localized settlement that would then result at the surface of the overlying 4-foot thick layer of Category 1 soil is then calculated. Various void diameters (i.e., 9", 12", and 15") are investigated with Sagaseta's equation. For the purposes of this calculation it is assumed that once a 3-inch thick Category 1 lift is placed and compacted over an 18-inch thick Category 2 lift, the three inches of Category 1 soil is substantially worked into the surficial voids of the Category 2 waste so that the net thickness of the two lifts is 18 inches. It is also assumed that depressions due to localized settlements within a Category 2 horizon are not cumulative because of the soil arching in the intervening Category 1 soil layers.

Written by: DWW Date: 5 April 1996 Reviewed by: K. Olen Date: 4/5/96

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE3900 Task No.: 8.8

COLLECTION AND VERIFICATION OF DATA

In one 18-inch thick Category 2 lift a range of possible void sizes that may develop is conservatively estimated to be 9 inches to 15 inches. Given this, the data used in the calculation are presented below.

For all voids of any diameter x and y are arbitrarily set to zero:

$x = 0$

$y = 0$

For a 9-inch diameter void:

$a = 4.5$ inches

$h = r_1 = r_2 = 52.5$ inches

For a 12-inch diameter void:

$a = 6$ inches

$h = r_1 = r_2 = 54$ inches

For a 15-inch diameter void:

$a = 7.5$ inches

$h = r_1 = r_2 = 55.5$ inches

Written by: DWW Date: 96/04/05 (YY MM DD) Reviewed by: K. Oler Date: 96/4/5 (YY MM DD)

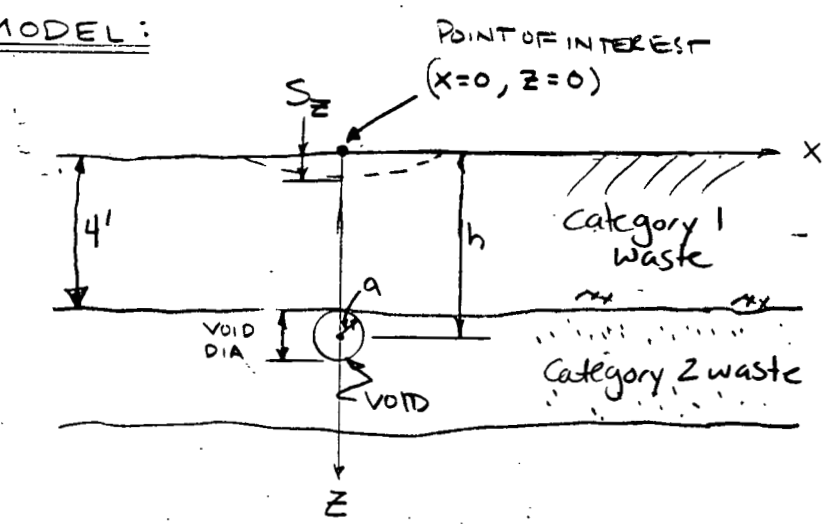
Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 08.8

Calculation

MAXIMUM VERTICAL DEFLECTION OF GROUND SURFACE DUE TO VOID

(METHOD OF SAGA SETA [1987])

MODEL:



a = VOID RADIUS = ½ VOID DIA.
h = DEPTH TO VOID CENTER = 4' + a
S_z = MAX. VERTICAL DEFLECTION
MAX. VERTICAL DEFLECTION WILL TAKE PLACE AT (x=0, z=0)
ASSUME PLANE STRAIN CONDITION.

S_z HAS 3 COMPONENTS $S_z = S_{z1} + S_{z2} + S_{z3}$

$$S_{z1} = \frac{-(a^2)}{2} \frac{z-h}{r_1^2}$$ Eq. 4 in Saga seta [1987]

$$S_{z2} = \frac{a^2}{2} \frac{z+h}{r_2^2}$$ Eq. 4 in Saga seta [1987]

$$S_{z3} = \frac{a^2 z}{r_2^2} \left[1 - 2\frac{x^2}{r_2^2}\right]$$ Eq. 7 in Saga seta [1987]

Where:
z = z coordinate of point of interest = 0
r_1 = radius from point of interest to void center
r_2 = radius from point of interest to mirror image of void center

CON'T →

Written by: DWW Date: 96/04/05 (YY MM DD) Reviewed by: K. Olsen Date: 96/4/5 (YY MM DD)

Client: FERMCO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 08.8

$$r_1^2 = x^2 + (z-h)^2$$
$$r_2^2 = x^2 + (z+h)^2$$

Eq. 4 in Sagaseta [1987]

Where: x = x-coordinate of point of interest = 0

EXAMPLE: FOR 12-INCH DIA VOID:

$a = 12''/2 = 6''$

$h = (4\,ft + 2\,ft)12 + 6'' = 78''$

$x = 0, \quad z = 0$

$r_1^2 = 0^2 + (0 - 78'')^2 = 6084\ in^2$

$r_2^2 = 0^2 + (0 + 78'')^2 = 6{,}084\ in^2$

$$S_{z1} = \frac{-(6^2)}{2} \cdot \frac{0-78}{6084} = 0.231\ in.$$

$$S_{z2} = \frac{6^2}{2} \cdot \frac{0+78}{6084} = 0.231\ in$$

$$S_{z3} = \frac{6^2 \cdot 0}{6084}\left[1 - 2\left(\frac{0^2}{6084}\right)\right] = \underline{0\ in.}$$

$$\boxed{S_z = \underline{0.462}\ in.}$$

RESULTS FOR DIFFERENT VOID DIAMETERS ARE SHOWN ON PP. AND SUMMARIZED BELOW:

VOID DIA. (in.)	S_z (in.)
9	0.386
12	0.667
15	1.104

Written by: DJW Date: 96/04/05 (YY MM DD) Reviewed by: K. Allen Date: 96/4/5 (YY MM DD)

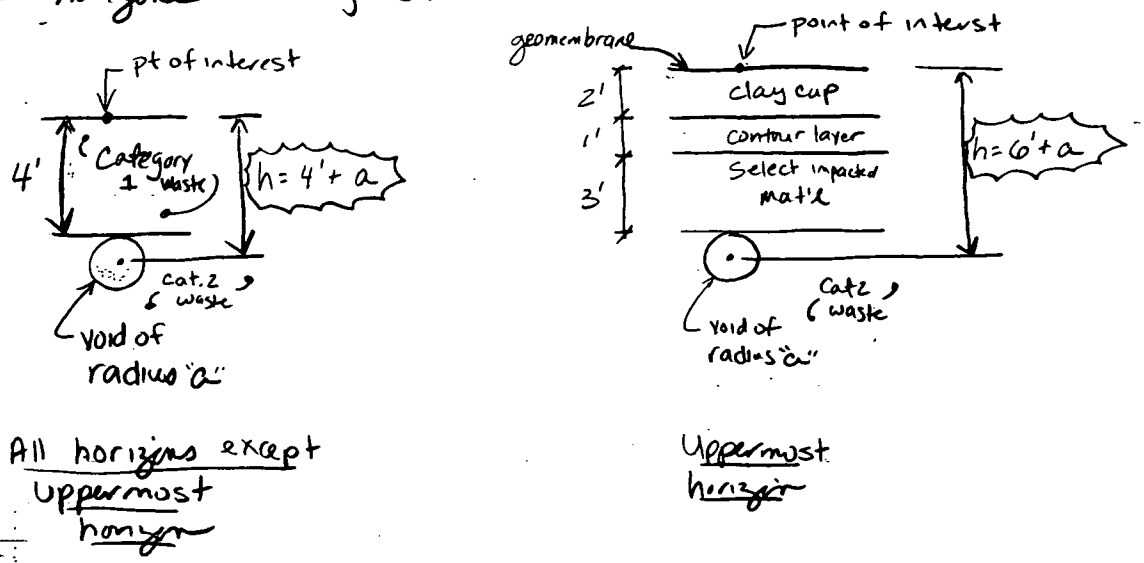
Client: FERMCO Project: OSDF Project/Proposal No.: GE 3100 Task No.:

REFERENCES:

Sagaseta, C., "Analysis of undrained soil deformation due to ground loss", Geotechnique, Vol. 37, No. 3, 1987, pp. 301-320

Note: (added by checker):

Because the magnitude of settlement will decrease as the distance from the void to the point of interest (i.e., h) increases, the magnitude of settlements at the geomembrane portion of the final cover due to localized settlement of the category 2 waste in the uppermost horizon will be less than those calculated at the surface of the 4-foot category 1 soil layer in lower horizons (See figure)



Figure

Chk'd K. Olsen 4/5/96

DWW 4/5/96

Check Maximum Vertical Deformation of Ground Surface Due to Void
Method of Sagaseta [1987]

Void Diameter =	9	in.
Depth to Top of Void =	48	in.
Void Radius, a =	4.5	in.
Depth to Center of Void, h =	52.5	in.

Maximum vertical deformation of ground surface will occur directly above void.

Coordinates for this point are:	X =	0	in.
	Z =	0	in.

Radii from this point to center of void (and mirror image of void) are:

Void: r_1^2 =	2756.25	in.
Mirror Image: r_2^2 =	2756.25	in.

Assume plane-strain condition: - vertical deflections are:

S_{z1} =	0.193	in.
S_{z2} =	0.193	in.
S_{z3} =	0.000	in.
Total, S_z =	**0.386**	**in.**

000704

DWW 4/5/96

Chk'd K. Olm 4/5/96

Check Maximum Vertical Deformation of Ground Surface Due to Void
Method of Sagaseta [1987]

Void Diameter =	12 in.
Depth to Top of Void =	48 in.
Void Radius, a =	6 in.
Depth to Center of Void, h =	54 in.

Maximum vertical deformation of ground surface will occur directly above void.
Coordinates for this point are: X = 0 in.
Z = 0 in.

Radii from this point to center of void (and mirror image of void) are:

Void: r_1^2 =	2916 in.
Mirror Image: r_2^2 =	2916 in.

Assume plane-strain condition: - vertical deflections are:

S_{z1} =	0.333 in.
S_{z2} =	0.333 in.
S_{z3} =	0.000 in.
Total, S_z =	**0.667 in.**

000705

DWW 4/5/96

Chk'd K.Olen 4/5/96

Check Maximum Vertical Deformation of Ground Surface Due to Void
Method of Sagaseta [1987]

Void Diameter =	15	in.
Depth to Top of Void =	48	in.
Void Radius, a =	7.5	in.
Depth to Center of Void, h =	55.5	in.

Maximum vertical deformation of ground surface will occur directly above void.

Coordinates for this point are:	X =	0	in.
	Z =	0	in.

Radii from this point to center of void (and mirror image of void) are:

Void: r_1^2 =	3080.25	in.
Mirror Image: r_2^2 =	3080.25	in.

Assume plane-strain condition: - vertical deflections are:

S_{z1} =	0.507	in.
S_{z2} =	0.507	in.
S_{z3} =	0.000	in.
Total, S_z =	**1.014**	**in.**

000706

5.3 Overall Impacted Material Settlement

COMPUTATION COVER SHEET

SUBJECT OF CALCULATION: Overall A 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 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	—	—	—	—
Ø	30% SUBMITTAL	N/A	N/A	N/A	N/A
B	Preliminary Design, EPA Submittal	14 Dec 95	[illegible]	—	—
C	60% Submittal	19 Feb 96	MHG	No changes	—
D	Intermediate Design, EPA Submittal	5 Apr 96	[illegible]	—	—

E3900-09.8/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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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

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: [illegible] Date: 95/10/23

Client: FERMLO Project: OSDF Proj./Proposal No.: GE3900 Task No.: 9.8

RB 24 Oct 95

Overall

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: SQ 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.

Written by: M. GLEASON Date: 95/10/23 Reviewed by: SR Date: 95/10/23

Client: FERMILO 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;

Written by: M. GLEASON Date: 95/10/__ Reviewed by: SR 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)

- 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. (See calculation for Localized Impacted Material Settlement)

Long-Term Settlement

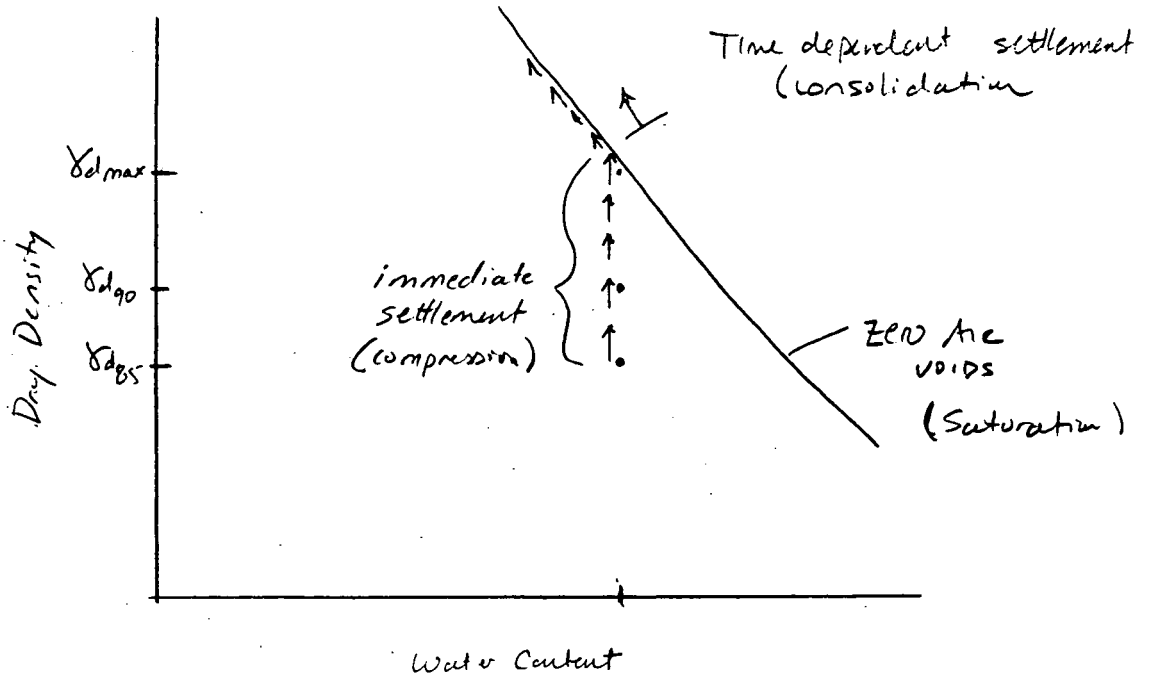
Once settlements are calculated for the points indicated on Figure 2, an analysis of the final cover system integrity is made. Considered in the analysis is the differential settlement, grade change, and tensile strain in the final cover system.

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 . 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.

Written by: M. GLEASON Date: 95/10/22 (YY/MM/DD) Reviewed by: SB Date: 95/10/23 (YY/MM/DD)

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)

Written by: M. Gleeson Date: 95/10/22 (YY MM DD) Reviewed by: SR Date: 95/10/23 (YY MM DD)

Client: FERNALD Project: OSDF Project/Proposal No.: GF 3900 Task No.: 9.8

Impacted Materials Settlement - Data Verification RB 24 Oct 95

MATERIAL PROPERTIES:

- The following relationships 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 γ_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 ϵ_α = 0.0015 (same value assumed in Foundation Settlement calculation Package Document # F9530021)
- Specific Gravity G_s = 2.75 (Table 6-2)

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.: 9.6

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 pcf × 1 ft³ = 115 lb

$W_w = W_c W_s = (0.18)(115\text{ lb}) = 20.7\text{ lb}$

$V_s = \frac{W_s}{G \gamma_w} = \frac{115\text{ lb}}{2.75(62.4)} = 0.67\text{ ft}^3$ $V_v = 0.33\text{ ft}^3$

$V_w = \frac{W_w}{\gamma_w} = \frac{20.7}{62.4} = 0.33\text{ ft}^3$ $V_w/V_v = 1$ - 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 $W_s = \gamma_d V_T = 103.5\text{ lb}$

$W_w = 103.5(0.18) = 18.6\text{ lb}$ $V_w = \frac{18.6}{62.4} = 0.30$

$V_s = \frac{W_s}{G \gamma_w} = \frac{103.5}{2.75(62.4)} = 0.60$

Written by: M. GLEASON Date: 95/10/22 (YY MM DD) Reviewed by: SQ 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 $W_s = 97.8 lb$ $W_w = 97.8(.18) = 17.6 lb$

$V_s = \frac{W_s}{G_s \gamma_w} = \frac{97.8}{2.75(62.4)} = 0.57 ft^3$ $V_v = 1 - V_s = 0.43 ft^3$

$V_w = \frac{W_w}{\gamma_w} = 0.28 ft^3$ $V_{AIR} = 0.15 ft^3$

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.

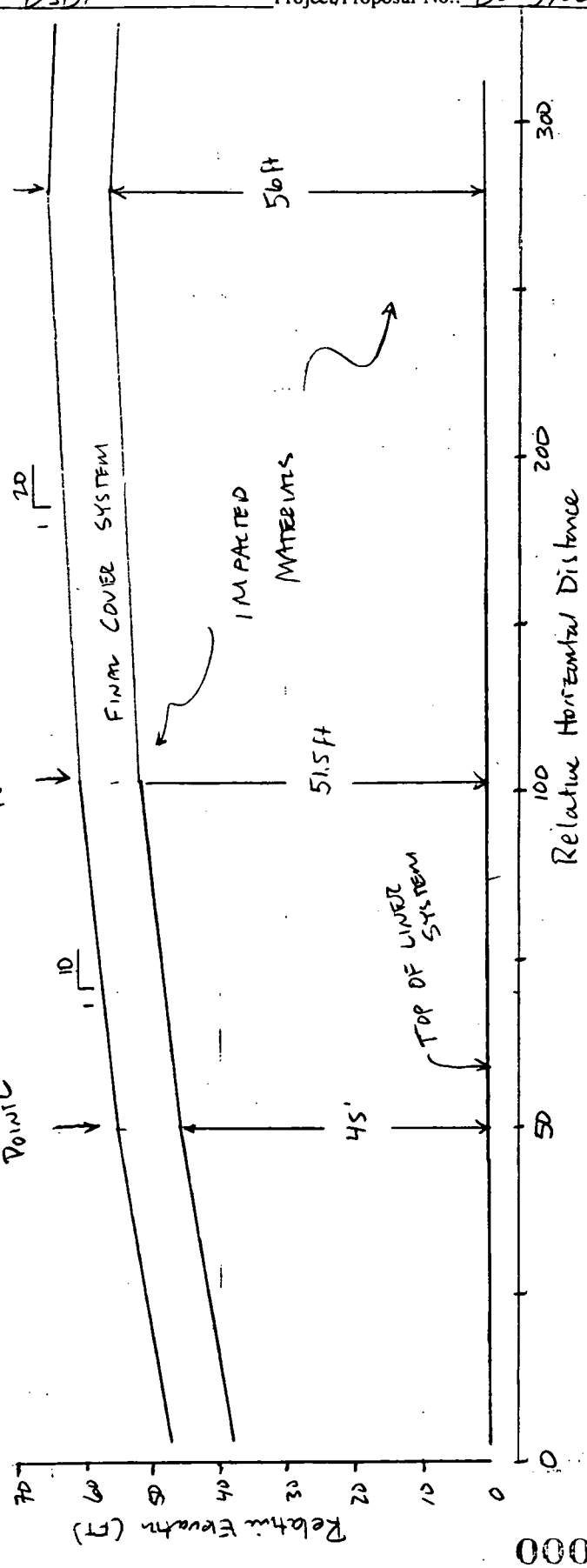
For soil compacted at 85% of γ_{dmax} & at Optimum Moisture Content, immediate settlement will occur until 15% volume change (15% of initial volume is air) and $e = 0.49$.

Written by: M. GLEASON Date: 95/10/22 (YY MM DD) Reviewed by: SQ Date: 95/10/23 (YY MM DD)

Client: FERMIO 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



DISTANCE BETWEEN POINT A & B 88 ft
POINT B & C 53 ft

FINAL COVER SYSTEM THICKNESS = 9 ft

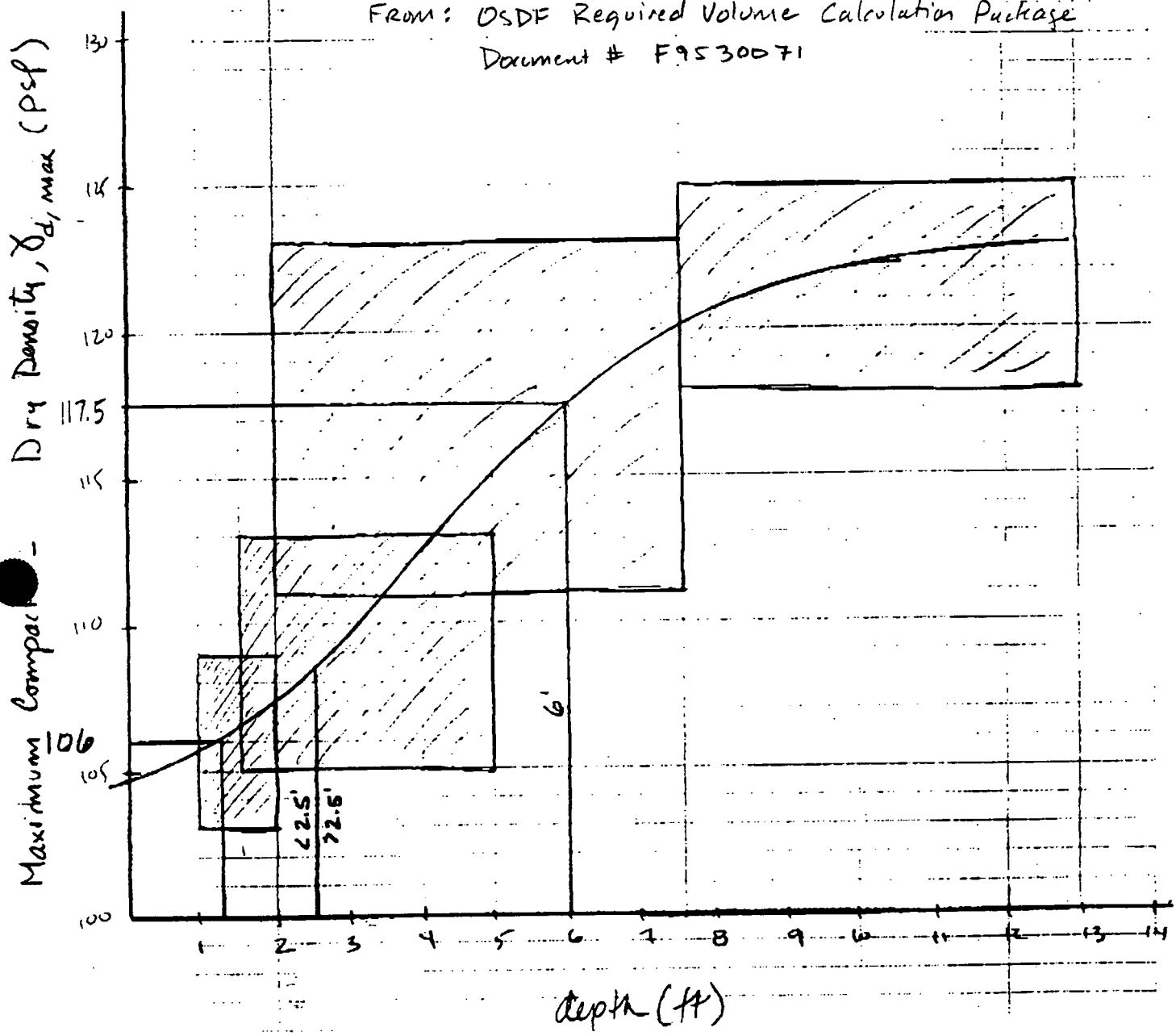
Written by: VANDERLINDE Date: 95/10/7 (YY/MM/DD) Reviewed by: K. Olk Date: 95/10/7 (YY/MM/DD) 253

Client: FERMCO Project: OSDF Project/Proposal No.: GE3900 Task No.: 8.12

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.: GE 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 $\Delta\sigma_v = 10(122 pcf) = 1220 psf$

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 Reviewed by: SR Date: 95/10/23

Client: FERMCO Project: DSDF Project/Proposal No.: GE 3400 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: FERMILO 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

$$\sigma_0 = 122 \text{ pcf } (25 \text{ ft}) = 3050 \text{ psf}$$

$$\Delta h_{1_4} = 0.2 \frac{10 \text{ ft}}{1 + 0.56} \log \frac{3050 + 1220}{3050}$$

$$\Delta h_{1_4} = 0.19 \text{ ft}$$ ✓

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. GILLEASON Date: 95/10/22 (YY MM DD) Reviewed by: SD Date: 95/10/23 (YY MM DD)

Client: FERMILO Project: OSDF Project/Proposal No.: GE 3900 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

$$V_{W15} = V_{W14} \times 1.014 = 0.326 \times 1.014 = 0.33$$

$$V_{S15} = V_{S14} \times 1.014 = 0.652 \times 1.014 = 0.66$$

$$V_{V15} = 0.34$$ ✓

$$e_{15} = 0.34/0.66 = 0.515$$ → Compression from Layer 5 is Immediate.

$$S = 0.33/0.34 = 97\%$$ ✓

Written by: M. Gleason Date: 95/10/22 (YY MM DD) Reviewed by: SQ Date: 95/10/23 (YY MM DD)

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_0 = 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 $V_{w_{1_6}} = V_{w_{1_5}} \times 1.007 = 0.33 \times 1.007 = 0.332$

$V_{s_{1_6}} = V_{s_{1_5}} \times 1.007 = 0.66 \times 1.007 = 0.665$

$V_{v_{1_6}} = 0.335$ ✓

$e_{1_6} = 0.335/0.665 = 0.50$

$S_{1_6} = .332/.335 = 99\%$

Compression from Layer 6 is Immediate. Assume Additional Settlement is Consolidation (time dependent)

Settlement of Layer 2

σ_0 = 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: Fernco Project: OSDF Project/Proposal No.: GE 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 Settlement

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: SR 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.: 6E 3900 Task No.: 9.8

Impacted Material Settlement - Calcs

Point A - 90% RC. Final Cover $\Delta\sigma_v = 1125$ psf

Layer 3

$\sigma_0 = 31ft \times 122 = 3782$ $e_{3_6} = 0.54$

$\Delta h_{3_7} = 0.2 \frac{10}{1.54} \log \frac{3782+1125}{3782} = 0.15$ ft immediate

Layer 4

$\sigma_0 = 21ft \times 122 = 2562$ psf $e_{4_6} = 0.572$

$\Delta h_{4_7} = 0.2 \frac{10}{1.572} \log \frac{2562+1125}{2562} = 0.20$ ft immediate

Layer 5

$\sigma_0 = 11' \times 122$ pcf $= 1342$ psf $e_{5_6} = 0.634$

$\Delta h_{5_7} = 0.2 \frac{10}{1.634} \log \frac{1125+1342}{1342} = 0.32$ ft immediate

Layer 6

$\sigma_0 = 3 \times 122$ pcf $= 366$ psf $e_6 = e_1 = 0.66$

$\Delta h_{6_7} = 0.035 \frac{10}{1+.66} \log \frac{1000}{366} + 0.2 \frac{10}{1.66} \log \frac{1125+366}{1000}$

$\Delta h_{6_7} = 0.30$ ft

TOTAL SECONDARY SETTLEMENT

$\Delta h_s = C_{\alpha\epsilon} \frac{H_0}{1+e_p} \log t_1/t_2$

Assume $t_1 = 1$ yr
$t_2 = 1000$ yr
$H_0 = 56$ ft
$e_p = 0.5$ avg.
$C_{\alpha\epsilon} = 0.0015$

$\Delta h_s = 0.0015 \frac{56}{1+.5} \log 1000$

$\Delta h_s = 0.17$ 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	0.22	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

INDUCED 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

$V_{W_4} = V_{W_1} = 0.3$ $V_{S_4} = V_{S_1} = 0.6$ (From Point A)

$V_{W_{45}} = 0.3(1.041) = 0.312$ $V_{S_{4_5}} = 0.625$ $V_{V_{4_5}} = 0.375$

$e_{4_5} = .375/.625 = 0.60$

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.: GE 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 $\sigma_o = 26.5ft \times 122pcf = 3233 psf$ $e_{3_5} = 0.55$

$$\Delta h_{3_6} = .2 \frac{10}{1.55} \log \frac{3233+1125}{3233}$$

$$\Delta h_{3_6} = 0.17 ft$$

- 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 $\sigma_o = 5.75ft \times 122pcf = 702 psf$ $e_5 = e_1 = 0.66$

$$\Delta h_{5_6} = 0.035 \frac{11.5}{1.66} \log \frac{1000}{702} + 0.2 \frac{11.5}{1.66} \log \frac{702+1125}{1000}$$

$$\Delta h_{5_6} = 0.40 ft$$

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 Reviewed by: SQ Date: 95/10/23

Client: FERRO Project: OSDF Project/Proposal No.: GE 3900 Task No.: 9.3

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_{1_2} = 0.36 ft (From Pt A)
- Layer 3 Placed (10')
  - Layer 1 Δh_{1_3} = 0.28 ft (Pt A)
  - Layer 2 Δh_{2_3} = 0.36 ft (Pt A)
- Layer 4 Placed (10')
  - Layer 1 Δh_{1_4} = 0.19 ft
  - Layer 2 Δh_{2_4} = 0.28 ft } (Pt A)
  - Layer 3 Δh_{3_4} = 0.36 ft
- Layer 5 Placed 5 ft

$\Delta\sigma_v$ = 5 ft × 122 pcf = 610 psf

- Layer 1

σ_o = 35' × 122 psf = 4270 psf e_{1_4} = 0.53 (Pt A)

$\Delta h_{1_5} = 0.2 \frac{10}{1.53} \log \frac{4270+610}{4270}$

Δh_{1_5} = 0.08 ft = 0.8% Settlement

$V_{W_{1_4}}$ = 0.326 $V_{S_{1_4}}$ = 0.652 (From Pt A)

$V_{W_{1_5}}$ = .326 × 1.008 = 0.329 V_S = .652 × 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: FERMICO Project: OSDF 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: SR 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 $\sigma_0 = 40' \times 122 = 4880 psf$ $e_{1_5} = 0.52$

$$\Delta h_{1_6} = .2 \frac{10}{1.52} \log \frac{4880 + 1125}{4880}$$ ✓

$$\Delta h_{1_6} = 0.12 ft.$$

- Layer 2 $\sigma_0 = 30' \times 122 = 3660 psf$ $e_{2_5} = 0.55$

$$\Delta h_{2_6} = .2 \frac{10}{1.55} \log \frac{3660 + 1125}{3660}$$ ✓

$$\Delta h_{2_6} = 0.15 ft$$

- Layer 3 $\sigma_0 = 20' \times 122 pcf = 2440 psf$ $e_{3_5} = 0.57$

$$\Delta h_{3_6} = .2 \frac{10}{1.57} \log \frac{2440 + 1125}{2440}$$ ✓

$$\Delta h_{3_6} = 0.21 ft$$

- Layer 4 $\sigma_0 = 10' \times 122 psf = 1220 psf$ $e_{4_5} = 0.64$

$$\Delta h_{4_6} = .2 \frac{10}{1.64} \log \frac{1220 + 1125}{1220}$$ ✓

$$\Delta h_{4_6} = 0.32 ft$$

- Layer 5 $\sigma_0 = 2.5' \times 122 psf = 305 psf$ $e_5 = e_1 = 0.66$

$$\Delta h_{5_6} = 0.035 \frac{5}{1.66} \log \frac{1000}{305} + 0.2 \frac{.5}{1.66} \log \frac{305 + 1125}{1000}$$

$$\Delta h_{5_6} = 0.15 ft$$ ✓

SECONDARY $H_0 = 45'$

$$\Delta H_s = 0.0015 \frac{45'}{1.5} \log 1000/1 \simeq 0.14 ft$$

IMPACTED MATERIAL SETTLEMENT

POINT C 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
5'	Layer 5	.08	.10	.16	.15	—	.49
	Total	.91	.74	.52	.15	—	2.32 ft

Immediate Settlement During Placement = 2.32 ft

9ft	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: FERMCO 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

$\sigma_o = 5\text{ft} \times 125\text{pcf} = 575$ 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: Fermco 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: SD Date: 95/10/23 (YY/MM/DD)

Client: Fermco 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 ✓

$V_{s_{1_6}} = V_{s_{1_5}} \times 1.007 = 0.624 \times 1.007 = 0.628$ $V_{v_{1_6}} = 0.372$

$e_{1_6} = .372/.628 = 0.592$ - 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 ✓

$V_{s_{2_5}} = V_{s_{1_4}} = .616$ $V_{s_{2_6}} = V_{s_{2_5}} \times 1.008 = .616 \times 1.008 = 0.62$

$V_{v_{1_6}} = 0.38$ $e_{2_6} = .38/.62 = 0.61$ - 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 ✓

$V_{s_{3_5}} = V_{s_{1_3}} = 0.605$ $V_{s_{3_6}} = V_{s_{3_5}} \times 1.011 = 0.605 \times 1.011 = 0.612$

$V_{v_{3_6}} = .388$ $e_{3_6} = .388/.612 = .634$ ✓

Written by: M. Gleason Date: 95/10/23 (YY/MM/DD) Reviewed by: SR Date: 95/10/23 (YY/MM/DD)

Client: Fermco 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

$\sigma_0 = 15\text{ ft} \times 115\text{ pcf} = 1725\text{ psf}$ $e_{4_5} = e_{1_2} = 0.696$

$\Delta h_{4_6} = .2 \frac{10}{1+.696} \log \frac{1725+690}{1725}$

$\Delta h_{4_6} = 0.17\text{ ft}$ 1.7 % Settlement

$V_{s_{4_5}} = V_{s_{1_2}} = 0.59$ $V_{s_{4_6}} = V_{s_{4_5}} \times 1.017 = 0.59 \times 1.017 = 0.60$

$V_{v_{4_6}} = 0.40$ $e_{4_6} = .40/.60 = 0.667$

- Layer 5

$\sigma_0 = 5\text{ ft} \times 115\text{ pcf} = 575\text{ psf}$ $e_5 = e_1 = 0.75$

$\Delta h_{5_6} = 0.035 \frac{10}{1.75} \log \frac{950}{575} + 0.2 \frac{10}{1.75} \log \frac{575+690}{950}$

$\Delta h_{5_6} = 0.19\text{ ft} = 1.9\%$ Settlement

$V_{s_5} = V_{s_1} = 0.57$ $V_{s_{5_6}} = V_{s_5} \times 1.019 = 0.57 \times 1.019 = 0.581$

$V_{v_{5_6}} = 0.419$ $e_{5_6} = 0.72$

FINAL COVER (LAYER 7)

9 ft thick @ 125 pcf = 1125 psf

- Layer 1

$\sigma_0 = 51' \times 115\text{ pcf} = 5865\text{ psf}$ $e_{1_6} = 0.592$

$\Delta h_{1_7} = 0.2 \frac{10}{1.592} \log \frac{5865+1125}{5865}$

$\Delta h_{1_7} = 0.10\text{ ft}$ - immediate

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.: 6E 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.

Written by: M. Gleason Date: 95/10/23 (YY MM DD) Reviewed by: SQ Date: 95/10/23 (YY MM DD)

Client: Fernco 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 $\sigma_o = 35' \times 115$ 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) $V_{s_{1_5}} = V_{s_{1_4}} \times 1.015 = 0.625$ $V_{V_{1_5}} = 0.375$

$e_{1_5} = .375/.625 = 0.60$

- Layer 2 $\sigma_o = 25' \times 115$ 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: USDF 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. $\sigma_o = 15' \times 115$ 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 $\sigma_o = 5' \times 115 = 575$ 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 $\sigma_o = 46.5' \times 115$ 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 $\sigma_o = 36.5' \times 115$ 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

$$\Delta H_s = 0.0015 \frac{51.5}{1.5} \log 1000/1 = 0.15 \text{ ft}$$

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. Eliason Date: 95/10/23 (YY MM DD) Reviewed by: SQ Date: 95/10/23 (YY MM DD)

Client: Femco Project: OSDF Project/Proposal No.: GF 3900 Task No.: 9.8

Impacted Material: 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 $\sigma_o = 35' \times 115\text{pcf} = 4025\text{psf}$ $e_{14} = .624$ (Pt A)

$$\Delta h_{15} = 0.2 \frac{10}{1.624} \log \frac{4025 + 575}{4025}$$

$\Delta h_{15} = 0.07$ 0.7 % Settlement

$V_{s_{14}} = 0.616$ (Pt A) $V_{s_{15}} = V_{s_{14}} \times 1.007 = 0.62$ $V_{v_{15}} = 0.38$

$e_{15} = .38/.62 = 0.613$

- Layer 2 $\sigma_o = 25' \times 115\text{pcf} = 2875\text{psf}$ $e_{24} = e_{13} = 0.652$

$$\Delta h_{25} = 0.2 \frac{10}{1.652} \log \frac{2875 + 575}{2875}$$

$\Delta h_{25} = 0.10$ ft 1% Settlement

$V_{s_{24}} = 0.605$ (Pt A) $V_{s_{25}} = V_{s_{14}} \times 1.01 = 0.611$ $V_{v_{25}} = 0.389$

$e_{25} = .389/.611 = 0.637$

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Impacted Materials Settlement

Point C 85% E.C.

Layer 5 Placed $\Delta\sigma_v = 575$ psf

• Layer 3 $\sigma_0 = 15' \times 115$ pcf $= 1725$ psf $e_{3_4} = e_{1_2} = 0.696$ (PtA)

$$\Delta h_{3_5} = 0.2 \frac{10}{1.696} \log \frac{1725 + 575}{1725}$$

$\Delta h_{3_5} = 0.15$ ft 1.5% Settlement – immediate ✓

$V_{s_{3_4}} = 0.59$ (PtA) $V_{s_{3_5}} = V_{s_{3_4}} \times 1.015 = 0.60$ $V_{v_{3_5}} = 0.40$

$e_{3_5} = .4/.6 = 0.667$

• Layer 4 $\sigma_0 = 5' \times 115$ pcf $= 575$ psf $e_4 = e_0 = 0.75$

$$\Delta h_{4_5} = 0.035 \frac{10}{1.75} \log \frac{950}{575} + 0.2 \frac{10}{1.75} \log \frac{575 + 575}{950}$$

$\Delta h_{4_5} = 0.14$ 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 $\sigma_0 = 40' \times 115$ 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 $\sigma_0 = 30' \times 115$ 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

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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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Impacted Materials Settlement

Summary of Settlements

- Immediate Settlement During Material Placement

	Point A	Point B	Point C
90% Relative Compaction	3.46 ft	2.42 ft	2.32 ft
85% Relative Compaction	3.75 ft	2.75 ft	2.18 ft

There 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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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 Settlement result in less than 0.2 percent grade change

  90% R.C. Pt A - Pt B $= \frac{1.36 - 1.19}{83 ft} \times 100 = 0.19\ \%$

  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%.