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TRANSMITTAL OF FINAL SOIL-GEOSYNTHETIC INTERFACT DIRECT SHEAR TESTING WORK PLAN FOR THE ON-SITE DISPOSAL FACILITY

08/15/96

DOE-1229-96
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WORK PLAN

SOIL- GEOSYNTHETIC INTERFACE DIRECT SHEAR TESTING WORK PLAN

ON-SITE DISPOSAL FACILITY

REVISION 0
AUGUST 1996

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

FOR INFORMATION ONLY

prepared by
GEOSYNTEC CONSULTANTS
1100 Lake Hearn Drive, NE, Suite 200
Atlanta, Georgia 30342

under
Fernald Environmental Restoration Management Corporation
Subcontract 95PS005028

Department of Energy
Ohio Field Office
Fernald Area Office
P. O. Box 538705
Cincinnati, Ohio 45253-8705
(513) 648-3155

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AUG 15 1996

DOE-1229-96

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

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

Dear Mr. Saric and Mr. Schneider:

TRANSMITTAL OF FINAL SOIL-GEOSYNTHETIC INTERFACE DIRECT SHEAR TESTING WORK PLAN FOR THE ON-SITE DISPOSAL FACILITY

This letter transmits the *Final Soil-Geosynthetic Interface Direct Shear Testing Work Plan* for the On-Site Disposal Facility as requested by U.S. Environmental Protection Agency (EPA). This document incorporates comments from EPA and Ohio Environmental Protection Agency (OEPA).

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

Sincerely,

Johnny Reising

Johnny W. Reising
Fernald Remedial Action
Project Manager

FN:Warner

Enclosure: As Stated

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cc w/enc:

R.L. Nace, EM-425/GTN
F. Bell ATSDR
S. McClellan, PRC
G Jablonowski, U.S. EPA
R. Vandegrift, ODH
D. Ward, GeoTrans
Manager TPSS/DERR, OEPA, Columbus
OEPA (2 additional copies to T. Schneider)
AR Coordinator/78

No. 2

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SOIL-GEOSYNTHETIC INTERFACE DIRECT SHEAR TESTING WORK PLAN

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1. INTRODUCTION

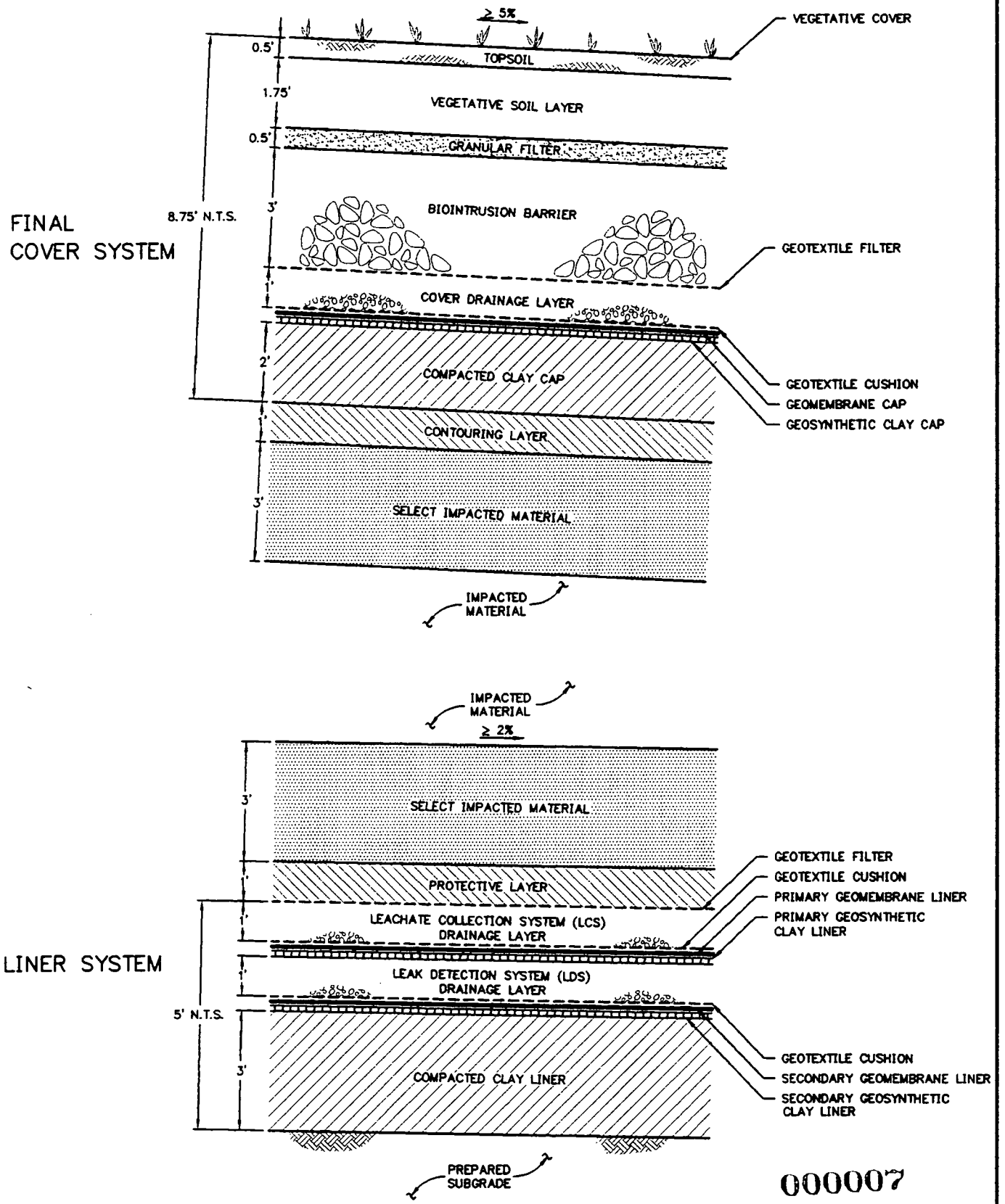
The Fernald Environmental Management Project (FEMP), located in Fernald, Ohio, is undergoing remediation pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Remediation at the FEMP is being addressed as five interrelated sets of activities, with each set identified as an "operable unit" (OU).

As described in the *Record of Decision* (ROD) [DOE, 1995a] for Operable Unit 2 (OU2), the selected remedy for OU2 involves construction of an on-site disposal facility (OSDF) for permanent disposal of impacted material meeting waste acceptance criteria (WAC) for the OSDF. Impacted materials include soil, flyash, lime sludge, and solid waste excavated as part of the OU2 remedial action. The conceptual design of the OSDF was developed as an alternative in the OU2 *Feasibility Study* (FS) [DOE, 1995b] and identified as the selected remedial alternative in the OU2 ROD.

On-site disposal of impacted material meeting WAC for the OSDF is also the preferred alternative for Operable Unit 1, 3, 4, and 5 at the FEMP. The final Records of Decision for these operable units are anticipated in 1996. DOE intends to build only one on-site disposal facility; therefore, the OSDF will be designed to accommodate all or any portion of the total volume of impacted material resulting from the four other operable units requiring permanent on-site disposal. The total volume of material requiring on-site disposal, considering all five operable units, is presently estimated to be 2.5 million bank/unbulked cubic yards (1.9 million bank/unbulked cubic meters). The engineered features of the OSDF will include a liner system and final cover system, both of which contain layers of compacted low-permeability clay and geosynthetic materials. The liner and final cover systems in the preliminary OSDF design are shown in Figure 1-1.

This document presents a work plan for conducting laboratory interface and internal direct shear testing for components of the liner and final cover systems of the OSDF. The purpose of the testing is to measure the shear strength of select components of the liner and final cover systems. The testing will be conducted in support of the slope stability evaluations of the liner and final cover systems and is intended to support preparation of the OSDF design and construction packages.

PRELIMINARY LINER AND COVER SYSTEM DESIGN
ON-SITE DISPOSAL FACILTY



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GEOSYNTEC CONSULTANTS
ATLANTA, GEORGIA

FIGURE NO.	1-1
PROJECT NO.	GE3900-9.1
DOCUMENT NO.	F954S006
FILE NO.	F95a001.DWG

2. LABORATORY TESTING PROGRAM

2.1 Background and Scope

The interface and internal direct shear testing described in this work plan will be conducted by GeoSyntec Consultants (GeoSyntec) at its Soil-Geosynthetic Interaction Testing (SGI) Laboratory in Atlanta, Georgia. The testing will be performed under Fernald Environmental Restoration Management Corporation (FERMCO) Subcontract 95PS005028. The testing will be conducted following procedures and methods given in the GeoSyntec *Soil-Geosynthetic Interaction Testing Laboratory Operations and Procedures Manual* (SGIOPM), the GeoSyntec *Quality Assurance Project Plan* (QAPP), and the Sitewide CERCLA Quality Assurance Plan (SCQ).

The testing program in this work plan is designed to provide data necessary to prepare the OSDF design and construction packages. Interface and internal direct shear testing will also be required as part of the construction quality assurance (CQA) program that will be implemented during OSDF construction. The testing program in this work plan also involves index property testing (i.e., Atterberg limits tests) and compaction testing of the site-specific clay soil needed to support the interface direct shear tests that involve compacted clay.

The scope of the testing program in this work plan is based on the range of interfaces and materials present in the liner and final cover systems for the OSDF (Figure 1-1) and on the information available in the technical literature regarding the shear strength of these types of interfaces and materials. A categorization of all the interfaces and materials present in the liner and final cover systems and a list of corresponding technical references on shear strength are presented in Tables 2-1 and 2-2. Examination of the tables indicates that insufficient shear strength information for design is available for the following categories of interfaces and materials: (i) site-specific clay soil-geosynthetic clay liner (GCL) interfaces; (ii) GCL-geomembrane interfaces; and (iii) GCL internal shear. Therefore, the testing program in this work plan has been designed to provide information on these types of interfaces and materials.

TABLE 2-1
CATEGORIZATION OF INTERFACES AND MATERIALS
LINER AND FINAL COVER SYSTEMS
ON-SITE DISPOSAL FACILITY
FERNALD ENVIRONMENTAL MANAGEMENT PROJECT

Interface or Material	Category
LINER SYSTEM (components from bottom to top) Site-specific compacted clay liner	Site-specific clay
Site-specific compacted clay liner/secondary GCL	GCL/site-specific clay interface
Secondary GCL	GCL internal shear
Secondary GCL/secondary geomembrane liner	GCL/geomembrane interface
Secondary geomembrane liner/geotextile cushion	Geomembrane/geotextile interface
Geotextile cushion/LDS drainage layer	Geotextile/granular soil interface
LDS drainage layer	Granular soil
LDS drainage layer/primary GCL	GCL/granular soil interface
Primary GCL	GCL internal shear
Primary GCL/primary geomembrane liner	GCL/geomembrane interface
Primary geomembrane liner/geotextile cushion	Geomembrane/geotextile interface
Geotextile cushion/LCS drainage layer	Geotextile/granular soil interface
LCS drainage layer	Granular soil
LCS drainage layer/geotextile filter/protective layer	Geotextile/granular soil interface
FINAL COVER SYSTEM (components from bottom to top) Site-specific compacted clay cap	Site-specific clay
Site-specific compacted clay cap/GCL cap	GCL/site-specific clay interface
GCL cap	GCL internal shear
GCL cap/geomembrane cap	GCL/geomembrane interface
Geomembrane cap/geotextile cushion	Geomembrane/geotextile interface
Geotextile cushion/cover drainage layer	Geotextile/granular soil interface
Cover drainage layer	Granular soil
Cover drainage layer/geotextile filter/biointrusion barrier	Geotextile/granular soil interface
Biointrusion barrier and Granular Filter	Granular soil

TABLE 2-2
SHEAR STRENGTH INFORMATION SOURCES
LINER AND FINAL COVER SYSTEMS
ON-SITE DISPOSAL FACILITY
FERNALD ENVIRONMENTAL MANAGEMENT PROJECT

Interface or Material Category	Shear Strength Information Sources	Comment on Information Sources	Sufficient Information to Design ?
GCL/site-specific clay interface	1, 6, 9, 10, 11	no information on site-specific clay	N
GCL/geomembrane interface	7, 8, 10, 12	GCL test conditions not representative	N
Geomembrane/geotextile interface	8, 10, 12		Y
Geotextile/granular soil interface	2, 4, 8, 9		Y
GCL/granular soil interface	2, 4, 8, 9		Y
Site-specific clay	13, 14		Y
GCL internal shear	3, 5, 7	GCL test conditions not representative	N
Granular soil and Vegetative soil	13		Y

Key to Information Source Numbers:

1. Bemben and Schulze; 1995
2. Bergado et al.; 1995
3. Daniel et al.; 1993
4. Eigenbrod and Locker; 1987
5. Bonaparte et al.; 1995
6. Koerner et al.; 1986
7. Manufacturer literature
8. Martin et al.; 1984
9. Nataraj et al.; 1995
10. Stark and Poeppel; 1994
11. Swan et al; 1991
12. Williams and Houlihan; 1987
13. geotechnical engineering references (e.g., Kulhawy and Mayne; 1990)
14. Parsons; 1995

2.2 ASTM Test Standard and Laboratory Procedures for Direct Shear Testing

The interface and internal direct shear tests will be performed in general accordance with the American Society for Testing and Materials (ASTM) Standard Test Method D 5321, *"Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method"*. Additional details of the testing procedures are given in the SGIOPM. A copy of ASTM D 5321 is presented in Appendix A of this work plan. The tests will be conducted in a large direct shear box, measuring approximately 12 in. by 12 in. (300 mm by 300 mm) in plan and 6 in. (150 mm) in depth. The shear box is constructed so that it can be separated into an upper and lower section, each 3 in. (75 mm) deep.

The specific procedures that will be used for all laboratory tasks, including sample control, testing, data review and reporting, and testing documentation are presented in the SGIOPM. Each test will be conducted using a specific direct shear testing device approved for use on the OSDF project, as listed in the SGIOPM.

2.3 Geosynthetic and Soil Samples

Geosynthetic Materials

Geosynthetic materials for the testing program (i.e., GCLs and geomembranes) will be obtained from each of the geosynthetic manufacturers by the GeoSyntec SGI Laboratory. Each geosynthetic sample will have a minimum size of the full roll width by 3 ft (1 m) long. Each sample will be examined, upon receipt, for visible manufacturing or material defects. Any defective samples will be returned to the manufacturer for replacement.

Soil Materials

Two samples of site-specific clay soil for the testing program have been obtained by FERMCO and shipped to the GeoSyntec SGI laboratory. Each sample consisted of approximately 200 lbs (90 kg) of brown till obtained from a depth of 2.5 to 7.5 ft (0.8

to 2.4 m). Each sample was shipped in four buckets, with each bucket weighing approximately 50 lbs (23 kg). The sampling locations, identified as G2-SB-48 and G2-SB-49, are located as shown on Figure 2-1.

The site-specific clay soil for the testing program has been selected to be representative of the soil anticipated to be used for the compacted clay components of the liner and final cover systems (i.e., the brown till). In addition, the site-specific clay soil for testing will be representative of the portions of the brown till with average or greater plasticity index (PI). This comparatively high PI material will be used because it is likely to produce measured shear strengths which are applicable for design, i.e., equal to or less than average site-specific values. Prior to initiation of direct shear testing involving the site-specific clay soil, the following steps will be taken to establish that the site-specific clay soil sample used for testing has the desired plasticity value:

- mix the soil within each of the eight sample buckets to establish relatively uniform soil composition within each bucket;

- perform an Atterberg limits test (ASTM D 4318) on a specimen from each of the eight buckets to obtain values of PI; these tests will be performed in accordance with the GeoSyntec Geotechnical and Environmental Laboratory Operations and Procedures Manual (GELOPM);

- identify which of the eight buckets have measured PI which exceeds the average value of PI for the brown till as reported in the GeoSyntec Test Pad Program Work Plan (i.e., PI = 17); and

- if the number of identified buckets is two or more, then mix the contents of up to six of the identified buckets to form a composite site-specific clay soil sample to be used in the testing program; if the number of identified buckets is less than two, then FERMCO will be notified that additional samples of the brown clay having greater plasticity must be obtained.

Once the composite site-specific clay soil sample to be used in the testing program is formed, a standard Proctor compaction test (ASTM D 698) will be performed. The

results of the test will provide the values of maximum dry density and optimum moisture content for the composite sample. The test will be performed in accordance with the GeoSyntec GELOPM.

Supplemental Soil Material

Two supplemental samples of site-specific clay soil will be obtained by FERMCO and shipped to the GeoSyntec SGI laboratory. The supplemental samples will be similar to the samples described above but will be representative of the portions of the brown till with the highest PI. This near upper-bound PI material will be evaluated through supplemental testing because it is possible that it may produce measured interface shear strengths that are lower than the interface shear strengths obtained from tests using the composite sample of the site-specific clay. Based on available information, samples of the brown till with sufficiently high PI can likely be obtained from a depth of 0 to 5 ft (1.6 m) in the vicinity of soil borings G2-SB-10 and G2-SB-05.

Prior to initiation of direct shear testing involving the supplemental site-specific clay soil, the same procedure described above will be used to establish that the supplemental site-specific clay soil sample used for testing has the desired plasticity value. The composite sample will be formed by mixing the contents of those buckets which have a measured PI which exceeds the average plus approximately one standard deviation value of PI for the upper brown till horizon, as reported in the GeoSyntec Test Pad Program Work Plan (i.e., PI $\approx$ 30).

Once the supplemental composite site-specific clay soil samples to be used in the testing program is formed, a standard Proctor compaction test (ASTM D 698) will be performed. The results of the test will provide the values of maximum dry density and optimum moisture content for the supplemental composite sample. The test will be performed in accordance with the GeoSyntec GELOPM.

At the completion of the interface direct shear testing, all geosynthetics and site-specific clay soil samples will be shipped to FERMCO in accordance with the provisions of the SGIOPM and other FERMCO requirements.

2.4 Interface and Internal Direct Shear Test Conditions

This work plan includes direct shear testing of two interfaces which will be present in the liner and final cover systems. These are a compacted clay-GCL interface and a GCL-textured HDPE geomembrane interface (Figure 1-1). The testing also includes internal direct shear testing of GCLs.

For both the interface and internal direct shear testing, three different levels of normal stress will be used, namely 5, 20, and 45 psi (35, 138, and 310 kPa). The lower stress represents the anticipated normal stress acting on the geomembrane within the final cover system. The higher two stresses represent anticipated medium-range and upper-bound normal stresses acting on the liner system. The term, test series, is generally used to refer to a set of three direct shear tests on the same interface, each using a different normal stresses.

The work plan includes testing at two different shear displacement rates. The faster rate, 0.04 in./min, is likely to represent loading similar to an undrained condition. The slower rate, 0.004 in./min, will provide information to assess the effect of slower shear which is more representative of a drained condition.

The effect of long-term creep on GCL products is addressed through the use of conservative design values for long-term GCL shear strength for OSDF stability calculations. The design values are conservative because they are based on fully hydrated conditions with no contribution from internal GCL reinforcement. In addition, both peak and residual shear strengths are considered. Therefore, because of the conservative shear strength values used for design, GCL creep testing is not required.

The work plan includes testing of two different types of textured HDPE geomembranes and four different types of GCLs. The different types of geosynthetic materials are included in order to obtain shear strength information for a representative range of geosynthetic products that may be used in OSDF construction. The work plan also includes testing at four different potential placement conditions for the site-specific clay and at two different shear rates. The combination of testing materials and

conditions results in 13 interface direct shear test series for the site-specific clay-GCL interface, six interface direct shear test series for the GCL-geomembrane interface, and three internal direct shear test series for the GCL. Each test will use new specimens of geosynthetic materials and each test involving soil will use a freshly remolded and compacted soil specimen. Tables 2-3 and 2-4 summarize the various testing conditions for each interface and internal direct shear test series.

The following information provides clarification of some details of the test specimen configurations that will be used for the testing.

- The interface test series (i.e., test series number 1 through 19) will be conducted with the upper component of the interface in the field used as the lower component in the test. This inverted interface configuration will be used because it places the soil component of the interface in the upper shear box. This approach is conservative because experience with the testing devices in the GeoSyntec laboratory indicates that if the soil component is placed in the lower shear box, compression of the soil component will cause a shift in the shear plane location which will result in measured shear strengths being artificially high.

- The interface test series will be conducted using a bedding layer of concrete sand in the lower shear box below the test interface. This bedding layer is positioned, relative to the test interface orientation, in the position where a granular drainage layer would be present in the liner and final cover systems. This bedding layer will be used because it provides a reasonable representation of the stiffness of a granular drainage layer and because experience indicate that it will not affect the magnitude of measured interface shear strengths.

- A textured steel gripping surface is used above and below the GCL in the internal direct shear tests (i.e., test series numbers 20 through 22). This gripping surface will be used because experience indicates that without such a surface a sufficiently uniform transfer of shear stress through the GCL specimen is unlikely to be achieved.

TABLE 2-3

SUMMARY OF TESTING CONDITIONS FOR CLAY/GCL INTERFACE DIRECT SHEAR TESTING ON-SITE DISPOSAL FACILITY FERNALD ENVIRONMENTAL MANAGEMENT PROJECT

Test Series Number	Test Specimen	GCL Type	Clay Target Conditions: A. Relative Compaction B. Percent above Optimum Moist. Content (ASTM D 698)		Time for Soaking and Soaking Stress	Consol. Stress	Time for Consol.	Test Normal Stress	Rate of Shear (in./min)
			A. (%)	B. (%)					
1	Clay/GCL	Bentomat	95	3.5	168 hours at 3 psi all test series	5 psi 20 psi and 45 psi	48 hours all test series	5 psi 20 psi and 45 psi	0.04
2	Clay/GCL	Bentofix	95	3.5					0.04
3	Clay/GCL	Claymax 500SP	95	3.5					0.04
4	Clay/GCL	Bentomat	95	3.5					0.004
5	Clay/GCL	Bentofix	95	3.5					0.004
6	Clay/GCL	Claymax 500SP	95	3.5					0.004
7	Clay/GCL	Bentomat	98	2					0.04
8	Clay/GCL	Bentofix	98	2					0.04
9	Clay/GCL	Claymax 500SP	98	2					0.04
10	Clay/GCL	Bentomat	95, 98[1]	2, 0[1]		20 psi		20 psi	0.004
11	Clay/GCL	Bentomat	95[2]	3.5[2]		5, 20 and 45 psi		5, 20 and 45 psi	0.004
12	Clay/GCL	Gundseal[3]	95, 98[4]	3.5, 2[4]		5 psi		5 psi	0.004
13	Clay/GCL	Gundseal[3]	95, 98[2][4]	3.5, 2[2][4]		5 psi		5 psi	0.004

Notes:
(1) Test Series No. 10 will consist of two tests. Clay target conditions for one test will be a relative compaction of 95 percent and 2 percent above optimum moisture content. The corresponding values for the second test will be 98 percent and equal to optimum moisture content.
(2) Test Series Nos. 11 and 13 will be conducted using the supplemental composite site-specific clay soil sample.
(3) Gundseal GCL will have a 40-mil textured HDPE backing. The test specimen will be constructed with the HDPE backing in contact with the compacted clay.
(4) Test Series Nos. 12 and 13 will each consist of two tests. Clay target conditions for one test will be a relative compaction of 95 percent and 3.5 percent above optimum moisture content. The corresponding values for the second test will be 98 percent and 2 percent above optimum moisture content.

TABLE 2-4

SUMMARY OF TESTING CONDITIONS FOR INTERFACE AND INTERNAL DIRECT SHEAR TESTING ON-SITE DISPOSAL FACILITY FERNALD ENVIRONMENTAL MANAGEMENT PROJECT

Test Series Number	Test Specimen	GCL Type	80-mil HDPE Geomembrane Texture Type	Time for Soaking and Soaking Stress	Consolidation Stress	Time for Consolidation	Test Normal Stress	Rate of Shear (in./min)
14	GCL/Geomembrane	Bentomat	spray-applied	168 hours at 3 psi all test series	5 psi 20 psi and 45 psi all test series	48 hours all test series	5 psi 20 psi and 45 psi all test series	0.004
15	GCL/Geomembrane	Bentomat	blown-film					0.004
16	GCL/Geomembrane	Bentofix	spray-applied					0.004
17	GCL/Geomembrane	Bentofix	blown-film					0.004
18	GCL/Geomembrane	Claymax 500SP	spray-applied					0.004
19	GCL/Geomembrane	Claymax 500SP	blown-film					0.004
20	GCL	Bentomat	N/A					0.004
21	GCL	Bentofix	N/A					0.004
22	GCL	Claymax 500SP	N/A					0.004

The configurations of test specimens in each test series will be as follows:

- *Test Series Number 1 through 6:* interface between compacted site-specific clay soil and select geotextile component of a GCL under soaked and consolidated conditions. Two different rates of shear will be used. From top to bottom, each test specimen will consist of:

  - site-specific clay soil specimen, compacted by hand tamping to approximately 95 percent relative compaction at 3.5 percentage points above optimum moisture content as defined by the standard Proctor compaction test (ASTM D 698); compaction of the clay will be conducted away from the GCL specimen; the compacted clay specimen will then be placed on the GCL specimen for testing;

  - GCL specimen; Bentomat, Bentofix, and Claymax 500SP GCLs will be evaluated; for the Bentomat and Bentofix GCLs, the nonwoven geotextile component will be placed in contact with the site-specific clay soil; for the Claymax 500SP GCL, either of the woven geotextile components will be placed in contact with the site-specific clay soil; and

  - bedding layer of concrete sand.

- *Test Series Number 7 through 9:* interface between compacted site-specific clay soil and select geotextile component of a GCL under soaked, consolidated, and relatively fast shear rate conditions. From top to bottom, each test specimen will consist of:

  - site-specific clay soil specimen, compacted by hand tamping to approximately 98 percent relative compaction at 2 percentage points above its optimum moisture content as defined by ASTM D 698; compaction of the clay will be conducted away from the GCL specimen; the compacted clay specimen will then be placed on the GCL specimen for testing;

- GCL specimen; Bentomat, Bentofix, and Claymax 500SP GCLs will be evaluated; for the Bentomat and Bentofix GCLs, the nonwoven geotextile component will be placed in contact with the site-specific clay soil; for the Claymax 500SP GCL, either of the woven geotextile components will be placed in contact with the site-specific clay soil; and

- bedding layer of concrete sand.

- *Test Series Number 10:* interface between compacted site-specific clay soil and select geotextile component of a GCL under soaked, consolidated, and relatively slow shear rate conditions at two different clay compaction conditions. From top to bottom, each test specimen will consist of:

  - site-specific clay soil specimen, compacted by hand tamping at the following two different placement conditions: (i) approximately 95 percent relative compaction at 2 percentage points above its optimum moisture content as defined by ASTM D 698 and (ii) approximately 98 percent relative compaction at its optimum moisture content as defined by ASTM D 698; compaction of the clay will be conducted away from the GCL specimen; the compacted clay specimen will then be placed on the GCL specimen for testing;

  - GCL specimen; Bentomat with the nonwoven geotextile component will be placed in contact with the site-specific clay soil; and

  - bedding layer of concrete sand.

- *Test Series Number 11:* interface between compacted supplemental site-specific clay soil and select geotextile component of a GCL under soaked, consolidated, and relatively slow shear rate conditions. This test series will be similar to test series no. 4, but will be performed using the supplemental site-specific clay soil material. From top to bottom, each test specimen will consist of:

- supplemental site-specific clay soil specimen, compacted by hand tamping to approximately 95 percent relative compaction at 3.5 percentage points above optimum moisture content as defined by the standard Proctor compaction test (ASTM D 698) performed on the supplemental site-specific clay soil sample; compaction of the clay will be conducted away from the GCL specimen; the compacted clay specimen will then be placed on the GCL specimen for testing;

- GCL specimen; Bentomat with the nonwoven geotextile component will be placed in contact with the site-specific clay soil; and

- bedding layer of concrete sand.

- *Test Series Number 12 and 13:* interface between compacted site-specific clay soil and HDPE backing of a GCL under soaked, consolidated, and relatively slow shear rate conditions at two different clay compaction conditions. Test series no. 12 will be performed using the site-specific clay soil material and test series no. 13 will be performed using the supplemental site-specific clay soil material. From top to bottom, each test specimen will consist of:

  - site-specific clay soil specimen or supplemental site-specific clay soil specimen compacted at the following two different placement conditions: (i) approximately 95 percent relative compaction at 3.5 percentage points above its optimum moisture content as defined by ASTM D 698 and (ii) approximately 98 percent relative compaction at 2 percentage points above its optimum moisture content as defined by ASTM D 698; compaction of the clay will be conducted away from the GCL specimen; the compacted clay specimen will then be placed on the GCL specimen for testing;

  - GCL specimen; Gundseal, consisting of a bentonite component and a 40-mil textured HDPE backing, with the HDPE backing placed in contact with the site-specific clay soil; and

  - bedding layer of concrete sand.

- *Test Series Number 14 through 19:* interface between select geotextile component of a GCL specimen and an 80-mil (2-mm) thick textured high density polyethylene (HDPE) geomembrane specimen under soaked, consolidated, and relatively slow shear rate conditions. From top to bottom, each test specimen will consist of:

  - GCL specimen; Bentomat, Bentofix, and Claymax 500SP GCLs will be evaluated; for the Bentomat and Bentofix GCLs, the woven geotextile component will be placed in contact with the 80-mil (2-mm) thick textured HDPE geomembrane; for the Claymax 500SP GCL, either of the woven geotextile components will be placed in contact with the 80-mil (2-mm) thick textured HDPE geomembrane; and

  - 80-mil (2-mm) thick textured HDPE geomembrane specimen; two types of textured geomembrane products will be evaluated; the first type is a spray-applied textured geomembrane formerly available from SLT North America, Inc. (SLT); the second type is a blown-film textured geomembrane formerly available from Gundle Lining Systems, Inc. (Gundle) ; it is noted that both products are currently available from GSE Lining Technology, Inc. (GSE); and

  - bedding layer of concrete sand.

- *Test Series Number 20 through 22:* internal direct shear strength testing of a GCL specimen under soaked, consolidated, and relatively slow shear rate conditions. From top to bottom, each test specimen will consist of:

  - textured steel gripping surface;

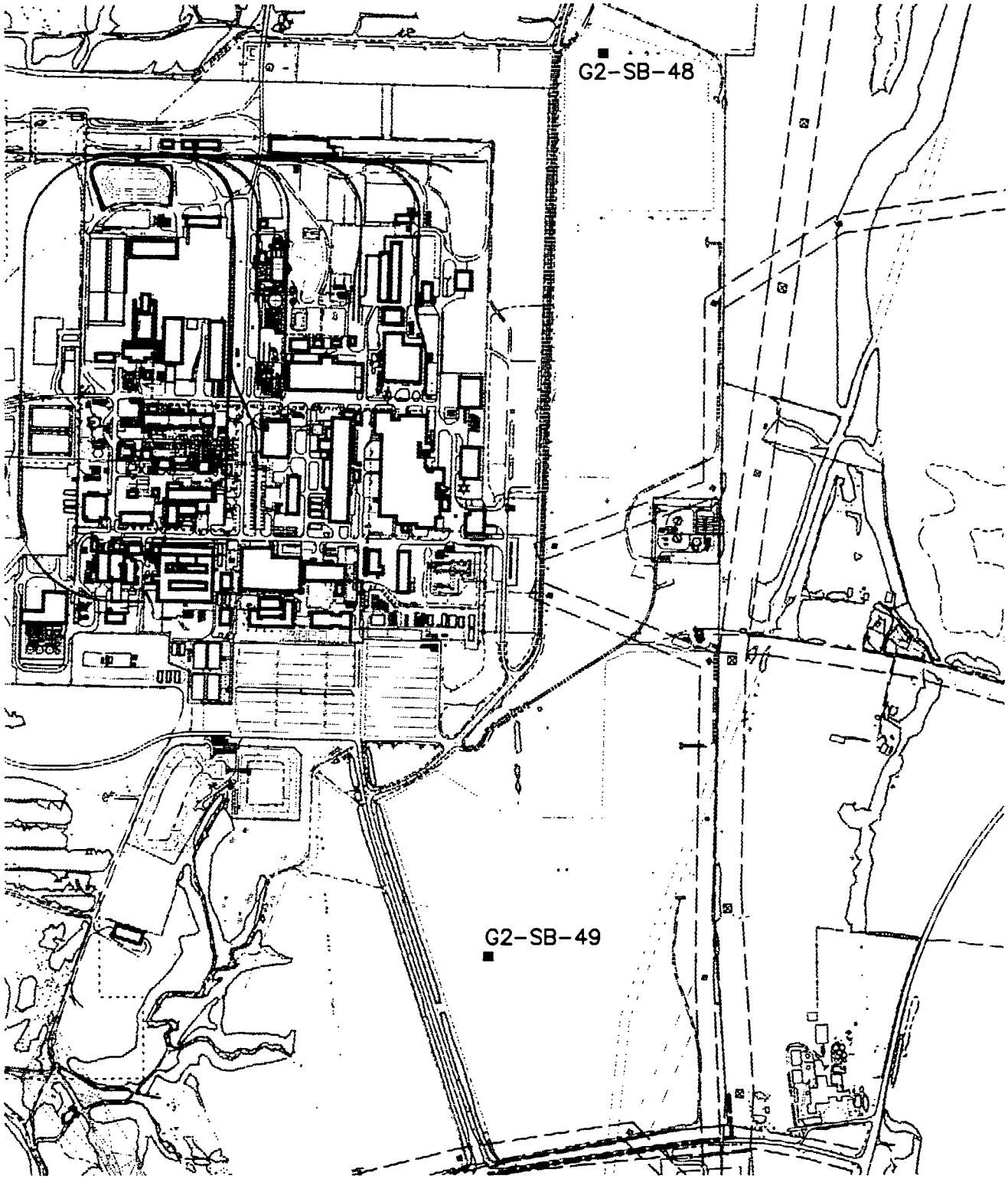
  - GCL specimen; Bentomat, Bentofix, and Claymax 500SP GCLs will be evaluated; and

  - textured steel gripping surface.

2.5 Data Processing and Reporting

Processing and reporting of data collected in the test program will be performed in accordance with the procedures detailed in the SGIOPM. The laboratory testing report will include a detailed description of testing procedures, shear force versus displacement curves for each test, and interpreted peak and residual shear strength parameters for each test series. A statement of data quality objectives (DQOs) for the test program is provided in Appendix B.

LOCATION OF SOIL SAMPLES FOR INTERFACE DIRECT SHEAR TESTING



GEOSYNTEC CONSULTANTS
ATLANTA, GEORGIA

FIGURE NO.	2-1
PROJECT NO.	GE3900-9.1
DOCUMENT NO.	F954S006
FILE NO.	F95A002

SECTION 3

3. SCHEDULE

An estimated testing schedule is provided in Table 3-1. The estimated completion date for the final testing report is 12 May 1996.

TABLE 3-1

ESTIMATED SCHEDULE
INTERFACE AND INTERNAL DIRECT SHEAR TESTING
ON-SITE DISPOSAL FACILITY
FERNALD ENVIRONMENTAL MANAGEMENT PROJECT

Activity	Estimated Duration (weeks)	Estimated Completion Date
1. Receive clay samples from FERMCO	NA	18 Oct 1995
2. Perform Atterberg limits tests on clay samples	1.0	28 Nov 1995
3. Form composite clay sample for testing and perform compaction test	0.5	5 Dec 1995
4. Receive geosynthetic samples from manufacturers	NA	15 Dec 1995(1)
5. Perform test series number 14 through 22	4.0	2 Feb 1996
6. Perform test series number 1 through 10 and 12	3.0	20 Feb 1996
7. Receive supplemental clay samples from FERMCO	NA	9 Feb 1996
8. Perform Atterberg limits tests on supplemental clay samples	1.0	16 Feb 1996
9. Form supplemental clay sample for testing and perform compaction test	0.5	20 Feb 1996
10. Perform test series number 11 and 13	1.0	28 Feb 1996
11. Prepare draft testing report for FERMCO review	2.0	17 Mar 1996
12. Receive FERMCO comments	NA	24 Mar 1996
13. Prepare 2nd draft report for DOE review	2.0	7 Apr 1996
14. Receive DOE comments	NA	28 Apr 1996
15. Prepare final report for submission to EPA	2.0	12 May 1996

Note: (1) Estimated date for receipt of Gundseal GCL sample is 31 January 1996.
Estimated date for receipt of Bentofix GCL sample is 20 January 1996.

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APPENDIX A

APPENDIX A

ASTM STANDARD TEST METHOD D 5321

"Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method"

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Standard Test Method for Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method[1]

This standard is issued under the fixed designation D 5321; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers a procedure for determining the shear resistance of a geosynthetic against soil, another geosynthetic, or a soil and geosynthetic in any combination.

1.1.1 The test method is intended to indicate the performance of the selected specimen by attempting to model certain field conditions.

1.2 The test method is applicable for all geosynthetics. Remolded or undisturbed soil samples can be used in the test device.

1.3 The test method is not suited for the development of exact stress-strain relationships within the test specimen due to the non-uniform distribution of shearing forces and displacement.

1.4 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.5 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 653 Terminology Relating to Soil, Rock and Contained Fluids[2]

D 698 Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures, Using 5.5-lb (2.49-kg) Rammer and 12-in. (304.8 mm) Drop[2]

D 1557 Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 10-lb (4.54-kg) Rammer and 18-in. (457-mm) Drop[2]

D 3080 Method for Direct Shear Test of Soils Under Consolidated Drained Conditions[2]

D 4354 Practice for Sampling of Geotextiles for Testing[2]

D 4439 Terminology for Geotextiles[2]

3. Terminology

3.1 *Definitions*—For definitions of terms relating to soil and rock, refer to Terminology D 653. For definitions of terms relating to geosynthetics, refer to Terminology D 4439.

3.2 *Descriptions of Terms Specific to This Standard:*

3.2.1 *adhesion*, c_a (FL^{-2}), *n*—the shearing resistance between soil and another material under zero externally applied pressure. **(D 653, D-18)**

3.2.2 *angle of friction*, *n*—(angle of friction between solid bodies) (degrees) the angle whose tangent is the ratio between the maximum value of the shear stress that resists slippage between two solid bodies at rest with respect to each other and the normal stress across the contact surface. **(D 653, D-18)**

3.2.3 *atmosphere for testing geosynthetics*, *n*—air maintained at a relative humidity of 65 ± 5 % and temperature of 21 ± 2°C (70 ± 4°F). **(D 4439)**

3.2.4 *coefficient of friction*, *n*—a constant proportionality factor, relating normal stress and the corresponding critical shear stress, at which sliding starts between two surfaces. **(D 653, D-18)**

3.2.5 *direct shear friction test*, *n*—for geosynthetics, a procedure in which the interface between a geosynthetic and any other surface, under a range of normal stresses specified by the user, is stressed to failure by the horizontal movement of one surface against the other.

3.2.6 *geosynthetic*, *n*—a planar synthetic product manufactured from polymeric material used with soil, rock, earth, or other geotechnical engineering-related material as an integral part of a man-made project, structure, or system. **(D 4439)**

4. Summary of Test Method

4.1 The coefficient of friction between a geosynthetic and soil, or between any geosynthetic combination selected by the user, is determined by placing the geosynthetic and one or more contact surfaces, such as soil, within a direct shear box. A constant normal compressive stress is applied to the specimen, and a tangential (shear) force is applied to the apparatus so that one section of the box moves in relation to the other section. The shear force is recorded as a function of the horizontal displacement of the moving section of the shear box. The test is performed for a minimum of three different normal stresses, selected by the user, to model appropriate field conditions. The peak (or alternatively, the residual) shear stresses recorded are plotted against the applied normal compressive stresses used for testing. The test data are generally represented by a best fit straight line whose slope is the coefficient of friction between the two materials where the shearing occurred. The y-intercept of the straight line is the adhesion.

[1] This test method is under the jurisdiction of ASTM Committee D-35 on Geosynthetics and is the direct responsibility of Subcommittee D35.01 on Mechanical Properties.

Current edition approved Oct. 15, 1992. Published December 1992.

[2] *Annual Book of ASTM Standards*, Vol 04.08.

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5. Significance and Use

5.1 The procedure described in this test method for determination of the coefficient of soil and geosynthetic or geosynthetic and geosynthetic friction by the direct shear method is intended as a performance test to provide the user with a set of design values for the test conditions examined. The test specimens and parameters are generally selected by the user.

5.2 This test method may be used for acceptance testing of commercial shipments of geosynthetics, but caution is advised as outlined below.

5.2.1 The coefficient of soil and geosynthetic friction can be expressed only in terms of the soil used in testing (see Notes 1 and 2). The coefficient of friction is a function of the applied normal compressive stress, soil gradation, plasticity, in-place density, moisture content, and other parameters.

NOTE 1—In the case of acceptance testing requiring the use of soil, the user must furnish the soil sample, soil parameters, and direct shear test parameters.

NOTE 2—Soil and geosynthetic friction tests should be performed by laboratories experienced in the friction testing of soils, especially since the test results may be dependent on site-specific soil conditions.

5.2.2 This test method measures the total resistance to sliding of a geosynthetic with a supporting material (substratum) or an overlying material (superstratum). Total sliding resistance may be a combination of sliding, rolling, interlocking of soil particles and geosynthetic surfaces, and shear strain within the geosynthetic specimen.

5.2.3 The test method does not distinguish between individual mechanisms, which may be a function of the soil used, method of soil placement, normal and shear stresses applied, rate of horizontal displacement, and other factors. Every effort should be made to identify, as closely as is practicable, the sheared area and failure mode of the specimen so that comparison tests can be performed. Care should be taken, including close visual inspection of the specimen after testing, to ensure that the testing conditions are representative of those being investigated.

5.2.4 Information on precision between laboratories is incomplete. In cases of dispute, comparative tests to determine whether a statistical bias exists between laboratories may be advisable.

5.3 The test method produces test data that can be used as follows: in the design of geosynthetic-reinforced retaining walls, embankments, and base courses; in applications in which the geosynthetic is placed on a slope; for determination of geosynthetic overlap requirements; or in other applications in which soil/geosynthetic or geosynthetic/geosynthetic friction is critical to design.

6. Apparatus

6.1 *Shear Device*—A rigid device to hold the specimen securely and in such a manner that a uniform force without torque can be applied to the specimen. The device consists of both a stationary and moving container, both of which are capable of containing dry or wet soil and are rigid enough to prevent distortion during shearing of the specimen. The traveling container must be placed on firm bearings and rack to ensure that the movement of the container is only in a direction parallel to that of the applied shear force.

NOTE 3—One container should be adjustable to compensate for deformation of the soil.

6.1.1 Square or rectangular containers are recommended: they should have a minimum dimension that is the greater of 300 mm (12 in.), 15 times the d_{85} of the coarser soil used in the test, or a minimum of five times the maximum opening size (in plan) of the geosynthetic tested. The depth of each container should be 50 mm (2 in.) or six times the maximum particle size of the coarser soil tested, whichever is greater. The minimum specimen to width to thickness ratio is 2:1.

NOTE 4—The minimum container dimensions given in 6.1.1 are guidelines based on requirements for testing most combinations of geosynthetics and soils. Containers smaller than those specified in 6.1.1 can be used if it can be shown that data generated by the smaller devices contain no scale or edge effects bias when compared to the minimum size devices specified in 6.1.1. The user should conduct comparative testing prior to the acceptance of data produced on smaller devices. For direct shear testing involving soils, competent geotechnical review is recommended to evaluate the compatibility of the minimum and smaller direct shear devices.

6.2 *Normal Stress Loading Device*, capable of applying and maintaining a constant uniform normal stress on the specimen for the duration of the test. Careful control and accuracy (±2 %) of the normal stress is important. Normal stress loading devices include, but are not limited to, weights, pneumatic or hydraulic bellows, or piston-applied stresses. For jacking systems, the tilting of loading plates must be limited to 10 mm (0.4 in.) from the center to the edge of the plate during operation of the test device.

6.3 *Shear Force Loading Device*, capable of applying a shearing force to the specimen at a constant rate of displacement (strain controlled) in a direction parallel to the direction of travel of the soil container. The rate of displacement should be controlled to an accuracy of ±10 % over a wide range of displacements. The system must allow constant measurement and readout of the shear force applied. An electronic load cell or proving ring arrangement is generally used. The shear force loading device should be connected to the test apparatus in such a fashion that the point of the load application to the traveling container is in the plane of the shearing interface and remains the same for all tests.

6.4 *Displacement Indicators*, for providing continuous readout of the horizontal shear displacement and, if desired, vertical displacement of the specimen during the consolidation or shear phase. Dial indicators, or linear variable differential transformers (LVDT), capable of measuring a displacement of at least 75 mm (3 in.) for horizontal displacement and 25 mm (1 in.) for vertical displacement are recommended. The sensitivity of displacement indicators should be 0.02 mm (0.001 in.) for measuring horizontal displacement.

6.5 *Geosynthetic Clamping Devices*, required for fixing geosynthetic specimens to the stationary section or container, the traveling container, or both, during shearing of the specimen. Clamps shall not interfere with the shearing surfaces within the shear box and must keep the geosynthetic specimens flat during testing. Flat jaw-like clamping devices are normally sufficient. Gluing of the geosynthetic specimen to a substrate (such as wood), which is placed in either or both of the soil containers, is an acceptable clamping technique, provided that soil is not used along with the

wooden substrate and it does not interfere with the test operation or that the glue does not change the shearing properties of the geosynthetic specimen. If gluing is used, the specimen should be checked carefully to ensure that shearing of the glued surface does not occur. A trial test is recommended to establish the proper type of glue and setting time.

NOTE 5—The selection of specimen substrate may influence the test results. For instance, a test performed using a rigid substrate, such as a wood or metal plate, may not simulate field conditions as accurately as that using a soil substrate. The user should be aware of the influence of substrate on direct shear friction data. Accuracy and reproducibility should be considered when selecting a substrate for testing.

6.6 *Soil Preparation Equipment*, for preparing or compacting bulk soil samples, as outlined in Test Methods D 698 or D 1557 or Method D 3080.

6.7 *Miscellaneous Equipment*, as required for preparing geosynthetic specimens. A timing device and equipment required for maintaining saturation of the geosynthetic or soil samples, if desired.

7. Geosynthetic Sampling

7.1 *Lot Sample*—Divide the product into lots, and for any lot to be tested, take the lot sample as directed in Practice D 4354 (Notes 5 and 6).

7.2 *Laboratory Sample*—Consider the units in the lot sample as the units in the laboratory sample for the lot to be tested. For a laboratory sample, take a sample extending the full width of the geosynthetic production unit and of sufficient length along the selvage or edge from each sample roll so that the requirements of 7.3 can be met. Take a sample that will exclude material from the outer wrap unless the sample is taken at the production site, in which case inner and outer wrap material may be used.

7.3 *Test Specimens*—From each unit in the laboratory sample, remove the required number of specimens as outlined below.

7.3.1 Remove a minimum of three specimens for shearing in a direction parallel to the machine (or roll) direction of the laboratory sample and three specimens for shearing in a direction parallel to the cross-machine (cross-roll) direction, if required (Note 6). The specimens should be slightly larger than the inside dimensions in all directions of the soil container described in 6.1.1, and they should be of sufficient size to facilitate clamping. All specimens should be free of surface defects, etc., that are not typical of the laboratory sample. Space the specimens along a diagonal of the unit of the laboratory sample. Take no specimens nearer the selvage or edge of the geosynthetic production unit than 1/10 the width of the unit.

NOTE 6—Lots for geosynthetics are usually designated by the producer during manufacture. While the test method does not attempt to establish a frequency of testing for the determination of design-oriented data, the lot number of the laboratory sample should be identified. The lot number should be unique to the raw material and manufacturing process for a specific number of units (for example, rolls, panels, etc.) designated by the producer.

NOTE 7—The frictional characteristics of some geosynthetics may depend on the direction tested. In many applications, it is necessary to perform shear test in only one direction. The direction of shear in the geosynthetic specimen(s) must be noted clearly in these cases.

8. Shear Device Calibration

8.1 The direct shear device is calibrated to measure the internal resistance to shear inherent to the device. The inherent shear resistance is a function of the geometry and mass of the traveling container, type and condition of the bearings, and type of shear loading system.

8.2 Assemble the shear device completely without placing a specimen inside it. Do not apply a normal stress. Apply the shear force to the traveling container at a rate of 10 mm/min (0.5 in./min). Record the shear force required to sustain movement of the traveling container for at least 50 mm (2 in.) total horizontal displacement. Record any large variation in applied shear force after movement of the traveling container has been initiated. Any such variations may be indications of damaged or misaligned bearings, or an eccentric application of the shear force.

8.3 The maximum shear force recorded is the internal shear correction to be applied to shear force data after the testing of geosynthetics or soil specimens.

9. Conditioning

9.1 For geosynthetic friction tests without soil, test specimens at the temperature specified in the atmosphere for testing geosynthetics. Humidity control is normally not required for direct shear testing.

9.2 When soil is included in the test specimen, the method of conditioning is selected by the user or mutually agreed upon by the user and the testing agency. In the absence of specified conditioning criteria, the test should be performed at the temperature specified in the standard atmosphere for testing geosynthetics. Relative humidity control should be performed when specified by the user.

9.3 When the geosynthetic is to be tested in the wet condition, soak the specimen in water for a minimum of 24 h prior to testing (Note 8).

NOTE 8—Geosynthetics that do not absorb measurable quantities of water may not require a 24-h soaking period for this test.

10. Procedure A—Geosynthetic and Geosynthetic Friction

10.1 Place the lower geosynthetic specimen flat over a rigid substrate in the lower container of the direct shear apparatus. The substrate may consist of soil, wood, or steel plates or other rigid media. The specimen must cover the entire substrate, and the upper surface of the specimen must extend above the edges of the lower container.

10.1.1 If the test is to be performed using wet specimens, remove the wetted specimen from the conditioning chamber and blot the upper surface of the specimen free of excess surface moisture. Begin the test as soon as possible after removing the specimen from the conditioning chamber.

10.2 Slide the two containers together and fix them in the start position. Place the upper geosynthetic specimen over the previously placed lower specimen so that both specimens are flat, free of folds, wrinkles, etc., and in complete contact within the test area. The specimen must protrude below the lower surface of the upper container. Only the two specimens are to be in contact within the test area.

10.3 Place a rigid superstratum over the upper specimen so that a uniform stress may be applied over the entire specimen within the test area. Fix the loading plate and apply the normal compressive stress to the specimen.

10.4 As required, clamp the specimen to constrain failure to the interface between the upper and lower geosynthetic

specimens.

10.4.1 One or both of the specimens may be glued or epoxied to the rigid superstrate or substrate, subject to the limitations described in 6.5. This may be a substitute for clamping.

10.5 Place and zero the displacement indicators onto the traveling container. Assemble the shear force loading device such that the loading ram is in contact with the traveling container, but no shear force is applied.

10.6 Apply the shear force using a constant rate of displacement. In the absence of any material specifications, use a maximum displacement rate of 5 mm/min (0.2 in./min).

10.7 Record the shear force as a function of displacement. If the data are not recorded continuously, a minimum of 20 data points should be obtained per test.

10.8 Run the test until the applied shear force remains constant with increasing displacement. Displacements ranging from 25 to 75 mm (1 to 3 in.) are generally required to generate this residual shear force.

10.9 At the end of the test, remove the normal stress from the specimen and disassemble the device carefully. Inspect the failure surface and clamp area carefully in order to identify the failure mechanisms involved. Note evidence of shear strains within the specimen or at the clamps.

10.9.1 Evidence of shear strains from testing of a specimen that is not typical of other specimens tested may result in discarding of the specimen and retesting. If excessive strains in the specimen or slipping occur, the test may have to be rerun at a lower normal compressive stress.

10.10 Repeat the test at a new normal compressive stress under new geosynthetic specimens. Test a minimum of three specimens, each at a different normal stress selected by the user.

10.11 Plot the test data as directed in 11.11 and 11.12.

11. Procedure B—Soil and Geosynthetic Friction

11.1 Place soil or rigid substrate in the lower container, as required. Compact the soil at the specific moisture content to the density desired. Fill the lower container with soil so that the surface of the soil specimen protrudes a distance equal to one-half of the d_{85} of the soil, as described in Method D 3080. A protrusion of 1 mm is sufficient for fine-grained soils. Level the soil surface carefully.

11.2 Place the lower geosynthetic specimen loosely over the substrate. Clamp or otherwise fix the end of the specimen temporarily, and reset it to ensure that the geosynthetic specimen is in complete contact with the soil. Remove all folds or wrinkles and verify that the protrusion of the soil substrate is suitable as outlined in 11.1.

11.2.1 For specimens tested in the saturated state, blot the upper surface of the specimen to remove excess moisture.

11.3 Fix the two soil containers in the start position, and place the upper geosynthetic specimen, if used, as directed in 10.2.

11.3.1 Clamp or fix the upper geosynthetic specimen temporarily before placing the upper soil, if used, and adjust the distance between the soil containers so that the distance between the upper surface of the geosynthetic specimen and the lower surface of the upper soil container is at least equal to the d_{85} of the upper soil. Alternatively, the upper container can be raised after placement and compaction of the upper soil layer.

11.4 Place the upper soil at the desired density and moisture content in a manner that minimizes damage to the geosynthetic specimen. Unclamp the geosynthetic specimen and apply the normal compressive stress.

11.4.1 If required, consolidate the soil specimens to eliminate excess soil pore pressures or to model field conditions. Required consolidation times are calculated as outlined in Method D 3080 (Note 9).

11.4.2 After the consolidation period, reclamp the geosynthetic specimen to the upper or lower container, as required. If the failure surface is not to be constrained to any particular surface, the specimen may remain unclamped.

11.5 Place the displacement indicators and assemble the shear loading device as described in 10.5.

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).

NOTE 9—For the large-soil specimens typically used for this test, excess pore pressures may not be dissipated using the guidelines in Method D 3080. True drained conditions may not exist if this is the case, and the test should not be considered drained. Thinner soil specimens or very slow deformation rates, or both, should be considered if drained conditions are desired.

11.7 Record the shear force as described in 10.7, and run the test until a residual shear force is attained as determined in 10.8.

11.8 Remove the normal stress and disassemble the device at the end of the test. Carefully inspect and identify the failure surface of the specimen and the area of the specimen clamp. Specimen failures should be consistent for all tests in order for the test data to be comparable.

11.9 At the end of the test, remove the soil specimen to determine the density and moisture content, if required.

11.10 Repeat the procedure for a minimum of two additional normal compressive stresses.

11.11 Plot the test data as a graph of applied shear force versus container displacement. For this plot, identify the peak shear force or residual shear force, if required. Determine the horizontal displacements for these shear forces.

11.12 Calculate the peak shear stress (or, alternatively, the residual stress, if required), as directed in Section 12. Subtract the internal shear correction (determined in 9.3) from the shear stress. The difference between the recorded shear stress and the internal shear correction is the actual shear stress applied to the specimen.

12. Calculation

12.1 For tests using soil, calculate the initial and final water content, unit weight, and degree of saturation, if required.

12.2 Calculate the apparent shear stress applied to the specimen for each recorded shear force as follows:

$$T = F_s/A_c$$

where:
T = shear stress (kPa),
τ_s = shear force (kN), and
A_c = corrected area (m^2).

12.2.1 For tests in which the area of specimen contact decreases with increased displacement, a corrected area must be calculated. This will occur in test devices in which the stationary and traveling containers have the same overall plan dimensions. In this case, the actual contact area will decrease as a function of horizontal displacement of the traveling container. For square or rectangular containers, the corrected area is calculated for each displacement reading using the following equation:

$$A_c = A_o - (d\ W)$$

where:
A_c = corrected area (m^2),
A_o = initial specimen contact area (m^2),
d = horizontal displacement of the traveling container (m), and
W = specimen contact width in a direction perpendicular to that of shear force application (m).

12.2.2 No area correction may be required for tests in which the stationary container is larger than the traveling container, provided that the horizontal displacement of the traveling container does not result in a decrease in specimen contact area.

12.3 Plot each shear stress, as determined in 11.11 and 11.12, versus applied normal compressive stress for each test conducted. The shear stress and normal stress axes must be drawn to the same scale.

12.4 Connect the data points with a best fit straight line. Some judgment and experience may be required to construct this line, which is referred to as the failure envelope. The slope of the failure envelope is the coefficient of friction. The angle of friction is determined using the following equations:

$$\delta_p = \tan^{-1}(\omega_p)$$

where:
δ_p = angle of friction corresponding to the peak shear stress (degrees), and
ω_p = the coefficient of friction corresponding to the peak shear stress.

12.4.1 Alternatively, the coefficient of friction may be calculated based on residual shear stresses recorded during testing using the following equation:

$$\delta_r = \tan^{-1}(\omega_r)$$

where:
δ_r = angle of friction corresponding to the residual shear stress (degrees), and
ω_r = the coefficient of friction corresponding to the residual shear stress.

12.5 The y-intercept of the shear stress versus normal stress plot is the adhesion.

13. Report

13.1 In the report of the coefficient of geosynthetic/geosynthetic or soil/geosynthetic friction by the direct shear method, include the following information:

13.1.1 Project, type(s), and description of geosynthetic specimens tested and direction tested.

13.1.2 Complete information on any soils used in testing, including soil preparation, compaction, moisture, gradation, classification, etc., and the methods used.

13.1.3 Description of the test apparatus, including container dimensions, loading apparatus, and recording devices used.

13.1.4 All test conditions, including normal compressive pressures selected, rate of horizontal displacement, specimen (including soil) construction, and clamping methods used. A sketch of the test specimen used is recommended.

13.1.5 Statement of any departures from the suggested test procedure, as required for special studies, so that the results can be evaluated and used.

13.2 Complete test data, including plots of shear force versus horizontal displacement and a plot of shear stress versus normal compressive stress for the tests conducted. Clearly mark all data points, the failure envelope, and the adhesion and coefficient of friction values.

14. Precision and Bias

14.1 The precision of this test method is being established.

14.2 *Bias*—The value of the coefficient of soil and geosynthetic friction can be defined only in terms of the soil and conditions used during testing. Because of the many variables involved and the lack of a superior standard or referee method, there are no direct data to determine bias.

14.2.1 The value of the coefficient of geosynthetic and geosynthetic friction can be defined only in terms of a test method. When this test method is the determining test method, measurements of the coefficient of geosynthetic/soil and geosynthetic/geosynthetic friction have no bias.

15. Keywords

15.1 coefficient of friction; direct shear; geosynthetics; interface shearing resistance; performance test

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This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, PA 19103.

APPENDIX B

APPENDIX B

DATA QUALITY OBJECTIVE (DQO) SUMMARY

DATA QUALITY OBJECTIVE LOGIC FLOW
SOIL-GEOSYNTHETIC INTERFACE DIRECT SHEAR TESTING
ON-SITE DISPOSAL FACILITY

1. Problem Statement

The preferred remedial alternative for Operable Units 1 through 5 includes the on-site disposal of impacted material meeting waste acceptance criteria for the On-Site Disposal Facility (OSDF). The design and construction of an on-site disposal facility is required as a part of the Operable Unit remediation action plans and the Records of Decision. A critical part of the disposal facility design and construction is a low-permeability liner and final cover system consisting of compacted low-permeability clay layers constructed from on-site borrow sources and geosynthetic materials.

In support of the design and construction of the OSDF, laboratory interface and internal direct shear testing for components of the liner and final cover systems will be performed. Details for performing the laboratory testing program are provided in the project specific plan (PSP) Soil-Geosynthetic Interface Direct Shear Testing.

2. Identification of a Decision that Addresses the Problem

The information generated by the soil-geosynthetic interface direct shear testing is essential in establishing the requirements of OSDF technical specifications for design and construction of the liner and final cover systems. The data obtained through this geotechnical testing program will be used to verify assumptions for the soil-geosynthetic material interface strength characteristics used in the preparation of the OSDF preliminary design. The testing will be conducted in support of the slope stability evaluations of the liner and cover systems prepared as a part of the OSDF design packages. Additional testing will be required as part of the construction quality assurance (CQA) program that will be implemented during OSDF construction.

If the laboratory direct shear testing results indicate that Design Criteria Package (DCP) requirements for slope stability will not be satisfied, then alternate soil or geosynthetic materials will be tested to develop a suitable combination of components that meet design performance criteria.

3. Identification of Inputs that Affect the Decision

The design and construction parameters needed to establish the requirements of the OSDF technical specifications will be measured through geotechnical laboratory testing. The testing will be used to evaluate the shear resistance of interfaces between geosynthetic materials and clay soil layers in the liner and final cover systems. The performance of selected geosynthetic materials will also be assessed.

Geotechnical laboratory testing will include:

Test Description	Standard
Atterberg Limits	ASTM D 4318
Compaction	ASTM D 698
Soil-Geosynthetic Friction by Direct Shear	ASTM D 5321

4. Specification of the Domain of the Decision

The samples of clay soil used in the geotechnical testing will be collected by FERMCO from potential borrow areas at the project site. Clay soils samples will be chosen to be representative of the higher plasticity materials to be used for the construction of the low-permeability clay liner and cover components in the OSDF. Sample locations are described in the PSP.

5. Development of Logic Statement

The data generated through the interface and internal direct shear testing is a critical element in the verification of the OSDF design. The geotechnical testing program is designed to evaluate select components of the proposed liner and final cover systems for the OSDF. The results will be used to verify assumptions in the DCP and will be incorporated into the OSDF technical specifications. If the testing program does not verify the suitability of on-site clay and selected geosynthetic materials for use in construction of the OSDF clay liner and cap components, then additional testing will be required prior to design completion.

6. Establish Constraints on Uncertainty

The probability of making an incorrect decision based on the study findings is considered to be low. The tests will be conducted in accordance with procedures set forth in ASTM standards, with the applicable ASTM precision and bias statements considered in interpreting the results. Potential uncertainty exists in the representativenes of the clay soil used in testing of the entire material to be used in construction of the OSDF. This uncertainty is addressed, as described in the PSP, by a procedure for forming the composite clay sample for testing to maximize the likelihood of measuring lower-bound (i.e., conservative) shear strengths.

7. Optimizing

The geotechnical testing program will be performed and reported in accordance with all applicable ASTM and project standards.

8. Summary

The objective of the interface and internal direct shear testing is to evaluate the shear strength of select components of the proposed liner and final cover systems for the OSDF. The geotechnical tests will be conducted in accordance with applicable ASTM standards as described in the project specific plan. The results will be used to verify the assumptions used in the OSDF preliminary design.

FEMP DIRECT SHEAR TESTING
DQO SUMMARY FORM

1.A. Task/Description:
Soil-Geosynthetic Interface Direct Shear Testing

CRU #: 2

1.B. Project Phase: (Place an "x" in the appropriate selection.)

☐ RI ☐ FS ☑ RD ☐ RA ☐ R,A ☐ Other (specify): _____

1.C. DQO No.: _____ **DQO Reference No.:** _____

2. Media Characterization: (Place an "x" in the appropriate selection.)

☐ Air ☐ Biological ☐ Groundwater ☐ Sediment ☑ Soil
☐ Waste ☐ Wastewater ☐ Surface water ☑ Other (specify): GeoSynthetic Materials

3. Data Use with Analytical Support Level (A-E):
(Check the appropriate Analytical Support Level selection(s) beside each applicable Data Use.)

Site Characterization
☐ A ☐ B ☐ C ☐ D ☐ E

Risk Assessment
☐ A ☐ B ☐ C ☐ D ☐ E

Evaluation of Alternatives
☐ A ☐ B ☐ C ☐ D ☐ E

Engineering Design
☐ A ☐ B ☐ C ☐ D ☑ E

Monitoring During Remediation Activities
☐ A ☐ B ☐ C ☐ D ☐ E

Other (explain): _____
☐ A ☐ B ☐ C ☐ D ☐ E

4.A. Drivers: Draft Remedial Design Work Plan for Remedial Actions at Operable Unit 2 [DOE, 1995d]; Design Criteria Package, On-Site Disposal Facility [GeoSyntec, 1995].

4.B. Objective: The objective of the testing program is to evaluate the shear strength of select components of the proposed liner and final cover systems for the OSDF. Testing will include: (i) nine site-specific clay soil-geosynthetic clay liner (GCL) interface direct shear test series; (ii) six GCL-geomembrane interface direct shear test series; and (iii) three GCL internal strength direct shear test series. These interface and internal direct shear test conditions have been identified as requiring testing because they involve the use of site-specific clay soils for which site-specific testing is required, or they involve GCLs for which insufficient information exists in the technical literature. The proposed tests are designed to provide the information necessary to complete the design of the OSDF. Additional interface testing to confirm design assumptions will be required as part of the construction quality assurance (CQA) program that will be implemented during OSDF construction.

FEMP DIRECT SHEAR TESTING
DQO SUMMARY FORM

DQO Number: [redacted]

5. Site Information (Description):

Bulk samples of brown clay will be collected from areas described in the work plan. A composite sample of the clay to be used for testing will be formed from the bulk samples as described in the work plan. Geotechnical testing will be performed at GeoSyntec Consultants Soil-Geosynthetic Interaction Testing Laboratory and Geomechanics and Environmental Laboratory, both located in Atlanta, Georgia.

6.A. Data Types with appropriate Analytical Support Level Equipment Selection and SCQ Reference:
(Place an "x" inside the appropriate box or boxes to select the type of analysis or analyses required. Then select the type of equipment to perform the analysis, if appropriate. Please include a reference to the SCQ Section.)

1. ☐ pH
   ☐ Temperature
   ☐ Specific Conductance
   ☐ Dissolved Oxygen
2. ☐ Uranium
   ☐ Full Radiologic
   ☐ Metals
   ☐ Cyanide
   ☐ Silica
3. ☐ BTX
   ☐ TPH
   ☐ Oil/Grease
4. ☐ Cations
   ☐ TOC
   ☐ TCLP
   ☐ CEC
   ☐ COD
5. ☐ VOA
   ☐ ABN
   ☐ Pesticides
   ☐ PCB
6. Other (specify)
   ☑ Geotechnical (see Direct Shear Testing Work Plan)

6.B. Equipment Selection and SCQ Reference:

Equipment Selection	Refer to SCQ Section
ASL A _____	SCQ Section: _____
ASL B _____	SCQ Section: _____
ASL C _____	SCQ Section: _____
ASL D _____	SCQ Section: _____
ASL E See Direct Shear Testing Work Plan	SCQ Section: 5.3.3

FEMP DIRECT SHEAR TESTING
DQO SUMMARY FORM

DQO Number: ____

7.A. Sampling Methods: (Place an "x" in the appropriate selection box.)

☐ Biased ☐ Composite ☐ Environmental ☑ Grab (for soil samples) ☐ Grid
☑ Intrusive ☐ Non-Intrusive ☐ Phased ☐ Source

Other (specify): ☑ Geosynthetic samples obtained from manufacturers

7.B. Sample Work Plan Reference: (List the samples required. Reference the work plan or sampling plan guiding the sampling activity, as appropriate.)

The Direct Shear Testing Work Plan lists the geosynthetic and soil samples required and describes the sampling activity.

Background Samples: Soil samples have previously been collected from the area.

7.C. Sample Collection Reference: (Please provide a specific reference to the SCQ Section and subsection guiding sampling collection procedures.)

Background Samples: Appendix K

8.0 Quality Control Samples: (Place an "x" in the appropriate selection box.)

8.A. Field Quality Control Samples:

☐ Trip Blanks ☐ Container Blanks ☐ Field Blanks
☐ Duplicate Samples ☐ Equipment Rinsate Samples ☐ Split Samples
☐ Preservation Blanks ☐ Performance Evaluation Samples ☐ Other (specify): ____

8.B. Laboratory Quality Control Samples:

☐ Method Blank ☐ Matrix/Duplicate/Replicate ☐ Matrix Spike ☐ Surrogate Spikes

Other (specify): ____

9. Other: Please provide any other germane information that may impact the data quality or gathering of this particular objective, task, or data use.

See Direct Shear Testing Work Plan.