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TRANSMITTAL OF FINAL SOIL-GEOSYNTHETIC INTERFACE DIRECT TESTING REPORT FOR THE ON-SITE DISPOSAL FACILITY

03/27/97

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175
REPORT

Department of Energy
Ohio Field Office
Fernald Area Office
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MAR 27 1997

DOE-0732-97

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

Mr. Thomas Schneider, Project Manager
Ohio Environmental Protection Agency
401 East Fifth Street
Dayton, Ohio 45402-2911

Dear Mr. Saric and Mr. Schneider:

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

The U.S. Department of Energy is pleased to transmit the *Final Soil-Geosynthetic Interface Direct Shear Testing Report*. The report discusses methods and results of shear testing performed to support slope stability evaluations of the on-site disposal facility liner and cap systems. This document was approved by U.S. Environmental Protection Agency (U.S. EPA) on January 17, 1997 and by Ohio Environmental Protection Agency (OEPA) on March 4, 1997. There were no changes to the document as a result of comments from U.S. EPA or OEPA.

Please contact Rod Warner at (513) 648-3156 if there are any questions regarding this transmittal.

Sincerely,

Susan M Peterson for

Johnny W. Reising
Fernald Remedial Action
Project Manager

FEMP:Warner

Enclosure: As Stated

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SOIL- GEOSYNTHETIC INTERFACE DIRECT SHEAR TESTING FINAL REPORT

ON-SITE DISPOSAL FACILITY

REVISION 0
MARCH 1997

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

prepared by

GeoSyntec Consultants
1100 Lake Hearn Drive, NE, Suite 200
Atlanta, Georgia 30342

under

Fluor Daniel Fernald
Subcontract 95PS005028

FINAL REPORT
SOIL-GEOSYNTHETIC INTERFACE DIRECT SHEAR TESTING

On-Site Disposal Facility

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ACRONYM LIST

ASTM	American Society of Testing and Materials
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CETCO	Colloid Environmental Technologies Company
DOE	United States Department of Energy
FEMP	Fernald Environmental Management Project
FDF	Fluor Daniel Fernald
FS	Feasibility Study
GCL	Geosynthetic Clay Liner
GEL	Geomechanics and Environmental Laboratory
GELOPM	GEL Operations and Procedures Manual
GUNDLE	Gundle Lining Systems, Inc.
GSE	GSE Lining Technology, Inc.
LL	Liquid Limit
NSC	National Seal Company
OMC	Optimum Moisture Content
OSDF	On-Site Disposal Facility
OU	Operable Unit
OU2	Operable Unit 2
PI	Plasticity Index
PL	Plastic Limit
QAPP	Quality Assurance Project Plan
ROD	Record of Decision
SCQ	Sitewide CERCLA Quality Assurance Plan
SGI	Soil-Geosynthetic Interaction Testing Laboratory
SGIOPM	SGI Operations and Procedures Manual
SGIFR	Soil-Geosynthetic Interface Direct Shear Testing Final Report
SGIWP	Soil-Geosynthetic Interface Direct Shear Testing Work Plan
SLT	SLT North America, Inc.
USCS	Unified Soil Classification System
WAC	Waste Acceptance Criteria

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SECTION 1

1. INTRODUCTION

1.1 Overview

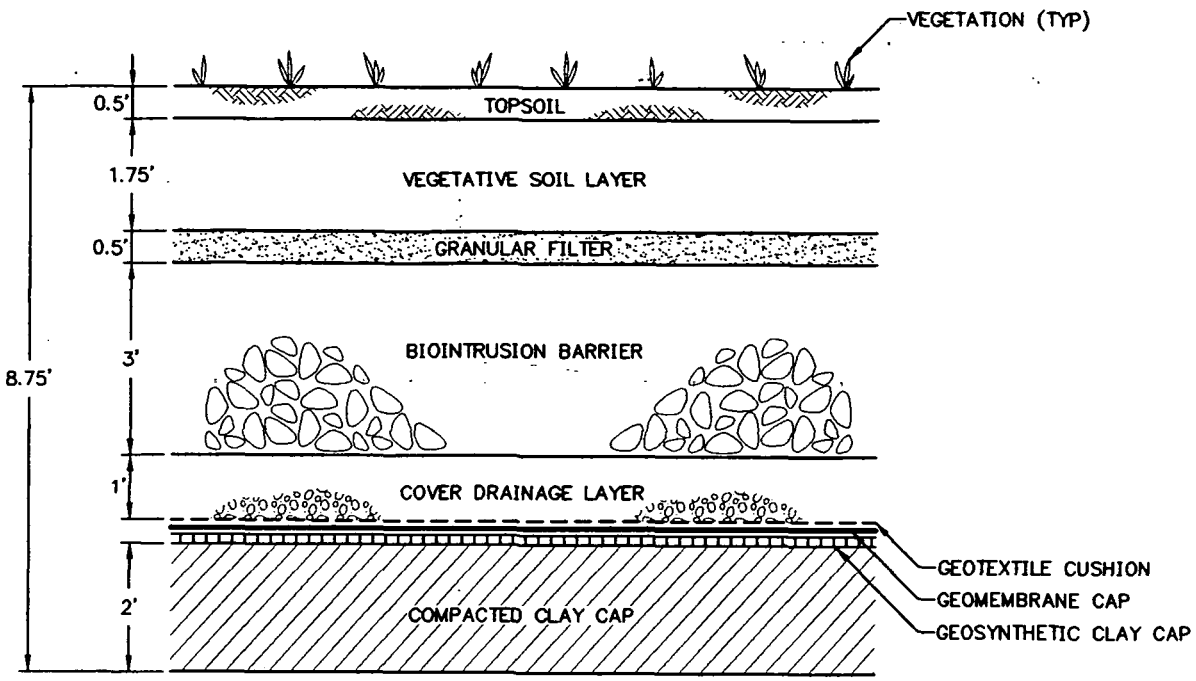
The Fernald Environmental Management Project (FEMP), located in Fernald, Ohio, will include construction of an on-site disposal facility (OSDF) for permanent disposal of impacted material. The conceptual design for a FEMP OSDF was developed as an alternative in the Operable Unit 2 (OU2) feasibility study (FS) and identified as the selected remedial alternative in the OU2 Record of Decision (ROD). On-site disposal of impacted material is also the preferred alternative for Operable Unit 3 and Operable Unit 5 at the FEMP. In addition, the material sent to the OSDF by OU3 may include contributions from OU1 and OU4. All material destined for OSDF disposal must meet the OSDF waste acceptance criteria (WAC).

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 prefinal OSDF design are shown in Figure 1-1.

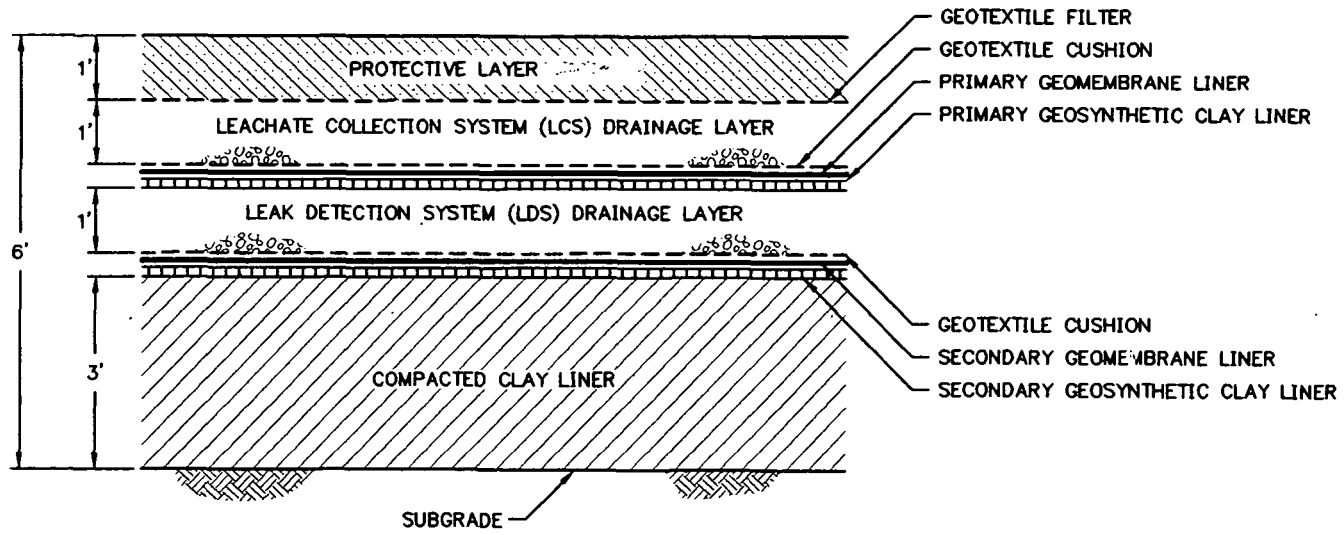
The laboratory testing program described in this report was performed by GeoSyntec Consultants (GeoSyntec) as part of its scope of services under the Fluor Daniel Fernald (FDF) Subcontract 95PS005028. FDF authorized GeoSyntec to conduct a laboratory testing program to evaluate the internal and interface shear strengths of various components of the liner and final cover systems for the OSDF. Representative samples of the on-site soil material used in the testing program were obtained from the project site and provided to GeoSyntec by FDF. Samples of each geosynthetic material used in the testing program were obtained by GeoSyntec from the appropriate geosynthetic manufacturer.

This document presents the final report for the laboratory interface and internal direct shear testing program conducted on components of the liner and final cover systems of the OSDF. The testing was conducted in support of slope stability evaluations of the OSDF liner and final cover systems and will be used to support preparation of the OSDF design packages.

PREFINAL LINER AND COVER SYSTEM DESIGN
ON-SITE DISPOSAL FACILITY



FINAL COVER SYSTEM



LINER SYSTEM

GeoSyntec Consultants
ATLANTA, GEORGIA

FIGURE NO.	1-1
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	3900F904

The laboratory interface and internal direct shear testing program was conducted in accordance with the following GeoSyntec documents: (i) *Soil-Geosynthetic Interface Direct Shear Testing Work Plan* (SGIWP); (ii) *Soil-Geosynthetic Interaction Testing Laboratory Operations and Procedures Manual* (SGIOPM); (iii) *Geomechanics and Environmental Laboratory Operation and Procedures Manual* (GELOPM); and (vi) Quality Assurance Project Plan (QAPP). The testing program was also performed in accordance with applicable requirements of the FDF Sitewide CERCLA Quality Assurance Plan (SCQ).

Soil property and compaction testing associated with the testing program described in this report was conducted at GeoSyntec's Geomechanics and Environmental Laboratory (GEL) located in Alpharetta, Georgia. Direct shear testing associated with the program was conducted at GeoSyntec's Soil-Geosynthetic Interaction Testing Laboratory (SGI), located in Atlanta, Georgia.

1.2 Organization

The remainder of the report is organized as follows:

- background information regarding the laboratory testing program is presented in Section 2;
- details of the laboratory testing program are described in Section 3;
- results of the laboratory testing program are presented in Section 4;
- discussion of the results and their significance with respect to slope stability analyses for the OSDF design packages is presented in Section 5; and
- limitations applicable to this report are presented in Section 6.

SECTION 2

2. BACKGROUND

2.1 Overview

The laboratory testing program consisted of a variety of individual soil property and compaction tests and 27 direct shear test series. Each direct shear test series consisted of one or three individual tests with each test conducted at a different level of normal stress ranging from 5 to 45 psi (35 to 315 kPa). A description of each test method used during this testing program is given in following two subsections of this report.

2.2 Soil Property Tests

Five types of soil property tests (i.e., as-received moisture content, particle-size analysis, Atterberg limits, soil classification, and compaction) were conducted in this testing program. Each test was conducted in accordance with a specific American Society for Testing and Materials (ASTM) Standard Test Method, as indicated below. Details of each testing procedure are given in the GELOPM and in the referenced ASTM standards.

- *As-received Moisture Content:* conducted in accordance with the ASTM Standard Test Method D 2216, "*Laboratory Determination of Water (Moisture) Content of Soil and Rock*";

- *Particle-Size Analysis:* conducted in accordance with the ASTM Standard Test Method D 422, "*Particle-Size Analysis of Soils*";

- *Atterberg Limits:* conducted in accordance with the ASTM Standard Test Method D 4318, "*Liquid Limit, Plastic Limit, and Plasticity Index of Soils*";

- *Soil Classification:* conducted in accordance with the ASTM Standard Test Method D 2487, "*Classification of Soils for Engineering Purposes*"; and

- *Standard Proctor Compaction Testing:* conducted in accordance with the ASTM Standard Test Method D 698, *"Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lb/ft^3 (600 kN-m/m^3))"*.

2.3 Direct Shear Tests

Direct shear tests performed as part of this testing program were carried out in accordance with the 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. The tests were conducted in a large direct shear device containing an upper and lower shear box. The upper shear box measures 12 in. by 12 in. (300 mm by 300 mm) in plan and 3 in. (75 mm) in depth. The lower shear box measured 12 in. by 14 in. (300 mm by 360 mm) in plan and 3 in. (75 mm) in depth.

SECTION 3

3. TESTING PROGRAM

3.1 Overview

As noted at the start of Section 2 of this report, the laboratory testing program consisted of soil property and compaction testing and direct shear testing. The materials used in the testing program are summarized in Section 3.2. Details of the tests and specific testing procedures are presented in Section 3.3 and Section 3.4.

3.2 Geosynthetic and Soil Materials

3.2.1 Geosynthetic Materials

Six geosynthetic materials were used in the testing program. The materials are referenced by name in this report, and include:

- 80-mil (2.0-mm) thick GSE Lining Technology, Inc. (GSE) Hyperflex Frictionflex geomembrane, referred to as 80-mil GSE Hyperflex Frictionflex geomembrane; this geomembrane is manufactured from high density polyethylene (HDPE) and has a textured surface produced through a spray-application process;

- 80-mil (2.0-mm) thick GSE HDPE textured geomembrane, referred to as 80-mil GSE HD textured geomembrane; this geomembrane is manufactured from HDPE and has a textured surface produced through a blown-film process;

- GSE Gundseal geosynthetic clay liner (GCL) consisting of a bentonite component adhesive-bonded to one side of a 40-mil (1.0-mm) thick GSE HD textured geomembrane, referred to as 40-mil GSE HD textured Gundseal GCL;

- Colloid Environmental Technologies Company (CETCO) Bentomat ST GCL consisting of a woven geotextile on one side of a bentonite core and a nonwoven geotextile on the other side of the core, needle-punched together to form the finished product, referred to as Bentomat ST GCL; two samples from a manufacturing lot of this GCL were evaluated during the testing program; GeoSyntec understands that the first sample was taken by the manufacturer near the beginning of the production of a lot of material and the second sample was taken near the end of the production lot;

- CETCO Claymax 500SP GCL consisting of a woven geotextile on each side of a bentonite core, stitch-bonded together with lines of stitches on 4-in. (100-mm) centers to form the finished product, referred to as Claymax 500SP GCL; and

- National Seal Company (NSC) Bentofix NS GCL consisting of a woven geotextile on one side of a bentonite core and a nonwoven geotextile on the other side of the core, needle-punched and thermally-locked together to form the finished product, referred to as Bentofix NS GCL.

At the request of FDF, bulk samples of the six types of the geosynthetic materials used in the testing program were obtained by GeoSyntec from each geosynthetic manufacturer. Upon receipt of the bulk samples at SGI, each material was examined for visible manufacturing or material defects. In accordance with the SGIOPM, a laboratory sample number assigned by SGI for tracking purposes to each bulk geosynthetic sample. The SGI laboratory sample number was cross-referenced to the roll number assigned by the manufacturer. The sample and roll numbers for each bulk sample of geosynthetic material are summarized in Table 3-1.

3.2.2 Soil Materials

Two types of site soil materials (i.e., "clay soil" and "supplemental clay soil") were used in the testing program. GeoSyntec understands that bulk samples of the clay soil were obtained by FDF from a depth of 2.5 to 7.5 ft (0.8 to 2.4 m) at locations identified as G2-SB-48 and G2-SB-49 at the project site, and that bulk samples of the

TABLE 3-1
SUMMARY OF GEOSYNTHETIC MATERIAL SAMPLE NUMBERS
SOIL-GEOSYNTHETIC INTERFACE DIRECT SHEAR TESTING PROGRAM
FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY

Geosynthetic Material	Manufacturer Roll Number	SGI Sample Number
Bentomat ST GCL (Beginning of Production Lot)	33995A29	AL5318
Claymax 500SP GCL	192450	AL5319
80-mil GSE HD Textured Geomembrane	03037093	AL5340
80-mil GSE Hyperflex Frictionflex Geomembrane	AF5758	AL5341
Bentofix NS GCL	48066	AL5393
40-mil HD Textured Gundseal GCL	04021531	AL5438
Bentomat ST GCL (End of Production Lot)	03896A59	AL5483

supplemental clay soil were obtained by FDF from a depth of 0 to 5 ft (0 to 1.6 m) in the vicinity of soil borings G2-SB-05 and G2-SB-12 at the project site (Figure 3-1). Eight buckets of each type of site soil material, each weighing approximately 50 lbs (23 kg), were shipped directly to SGI for testing.

Upon receipt at SGI, a laboratory sample number was assigned to each sample bucket for tracking purposes. The SGI laboratory sample number was crossed-referenced to the field sample number assigned by FDF. The SGI sample numbers and field sample numbers for the clay soil and supplemental clay soil are summarized in Tables 3-2 and 3-3, respectively.

A concrete sand was provided by GeoSyntec to fill the lower shear box and serve as a bedding layer below each test interface in all of the interface direct shear tests. The concrete sand is classified as a SP material by the unified Soil Classification System (USCS) and has the following characteristics: (i) maximum particle size of 0.2 in. (5 mm); (ii) approximately three percent by weight finer than the No. 200 U.S. standard sieve; (iii) a coefficient of uniformity of 6.4; and (iv) a coefficient of curvature of 0.85.

3.3 Soil Characterization Tests

Soil property tests were conducted on the clay soil and supplemental clay soil in accordance with the test procedures described in Section 2.2. As outlined in the SGIWP, each sample bucket was mixed to establish relatively uniform soil composition within the bucket and then tested for Atterberg limits. For the clay soil, five of the eight sample buckets were identified to have a plasticity index (PI) exceeding 17, and these five sample buckets were then mixed by GeoSyntec by equal moist weight to form a composite sample (see Table 3-2). This composite sample, referred to as the clay soil, was used in the direct shear testing program. For the supplemental clay soil, four of the eight sample buckets were identified to have a PI exceeding 30, and these four sample buckets were mixed by GeoSyntec by equal moist weight to form a composite sample (see Table 3-3). This composite sample, referred to as the supplemental clay soil, was used in the direct shear testing program.

LOCATION OF SOIL SAMPLES FOR INTERFACE DIRECT SHEAR TESTING

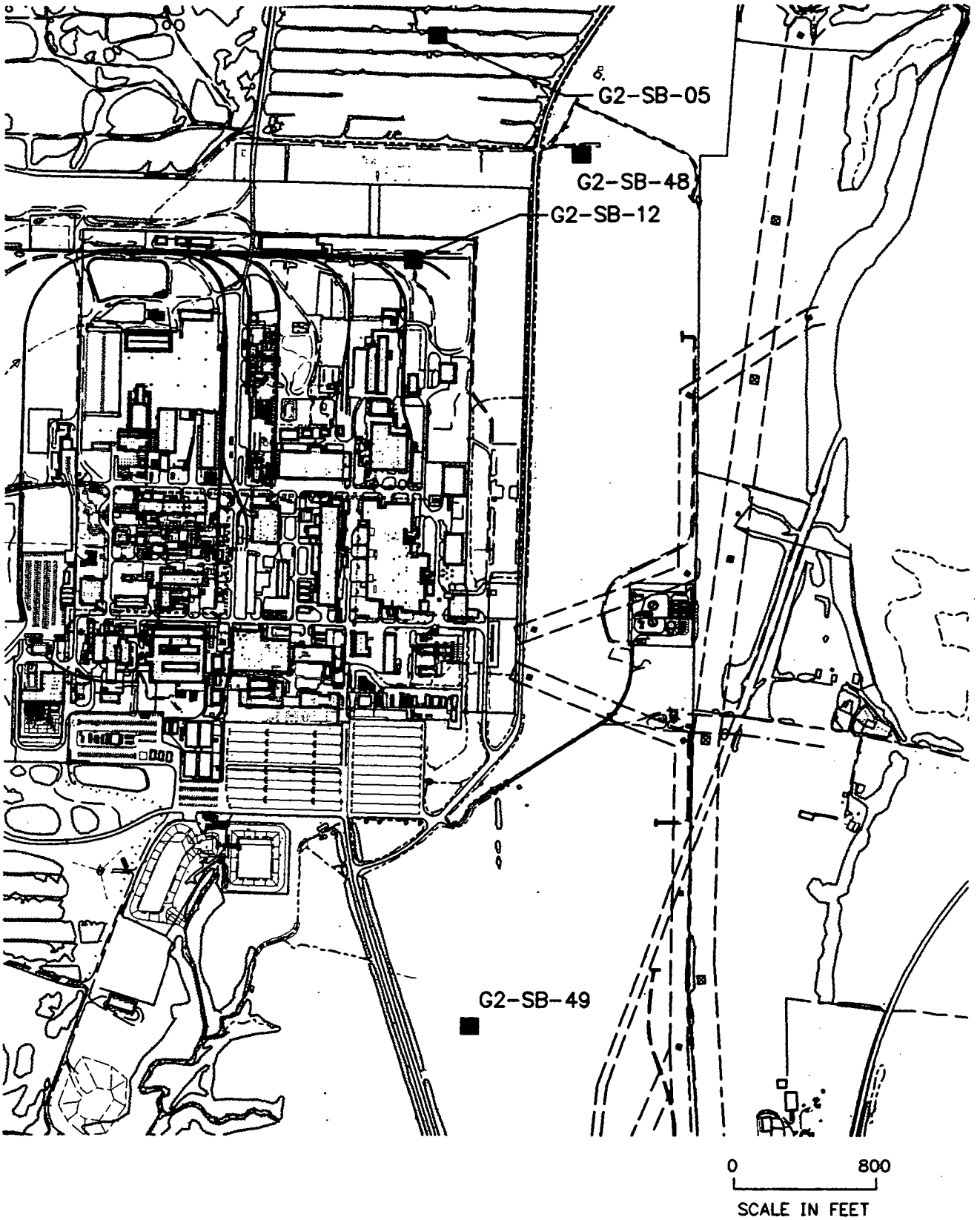


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FIGURE NO.	3-1
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006.PM4
FILE NO.	F95A002.DGN

TABLE 3-2
SUMMARY OF CLAY SOIL SAMPLE NUMBERS
SOIL-GEOSYNTHETIC INTERFACE DIRECT SHEAR TESTING PROGRAM
FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY

Soil Material	FDF Sample Number	SGI Sample Number
Clay Soil	411044-1	AL5211-1
Clay Soil	411044-2	AL5211-2
Clay Soil	411044-3	AL5211-3
Clay Soil	411044-4	AL5211-4
Clay Soil	411045-5	AL5212-5
Clay Soil	411045-6	AL5212-6
Clay Soil	411045-7	AL5212-7
Clay Soil	411045-8	AL5212-8
Clay Soil[1] (Composite Sample)	411044-3,411044-4, 411045-5,411045-6, and 411045-8	AL5291

Note: (1) The composite sample was formed by GeoSyntec by mixing together five selected field samples (i.e., field sample Nos. 411044-3,411044-4, 411045-5, 411045-6, and 411045-8) by equal moist weight. As described in the SGIWP, the selected samples were those with a plasticity index exceeding 17.

TABLE 3-3
SUMMARY OF SUPPLEMENTAL CLAY SOIL SAMPLE NUMBERS SOIL-GEOSYNTHETIC INTERFACE DIRECT SHEAR TESTING PROGRAM FERNALD ENVIRONMENTAL MANAGEMENT PROJECT ON-SITE DISPOSAL FACILITY

Soil Material	FDF Sample Number	SGI Sample Number
Supplemental Clay Soil	411965	AL5454
Supplemental Clay Soil	411968	AL5457
Supplemental Clay Soil	411969	AL5458
Supplemental Clay Soil	411970	AL5459
Supplemental Clay Soil	411976	AL5465
Supplemental Clay Soil	411977	AL5466
Supplemental Clay Soil	411978	AL5467
Supplemental Clay Soil	411979	AL5468
Supplemental Clay Soil[1] (Composite Sample)	411965, 411968, 411969, and 411970	AL5493

Note: (1) The composite sample was formed by GeoSyntec by mixing together four selected field samples (i.e., field sample Nos. 411965, 411968, 411969, and 411970) by equal moist weight. As described in the SGIWP, the selected samples were those with a plasticity index exceeding 30.

Atterberg limits, particle-size analyses, soil classification, and soil compaction testing were conducted on each of the composite samples of clay soil and supplemental clay soil in accordance with the SGIWP.

3.4 Direct Shear Tests

3.4.1 Configuration of Test Specimens

Three types of test specimen configurations were used in the 27 direct shear test series. Each of these configurations is described below.

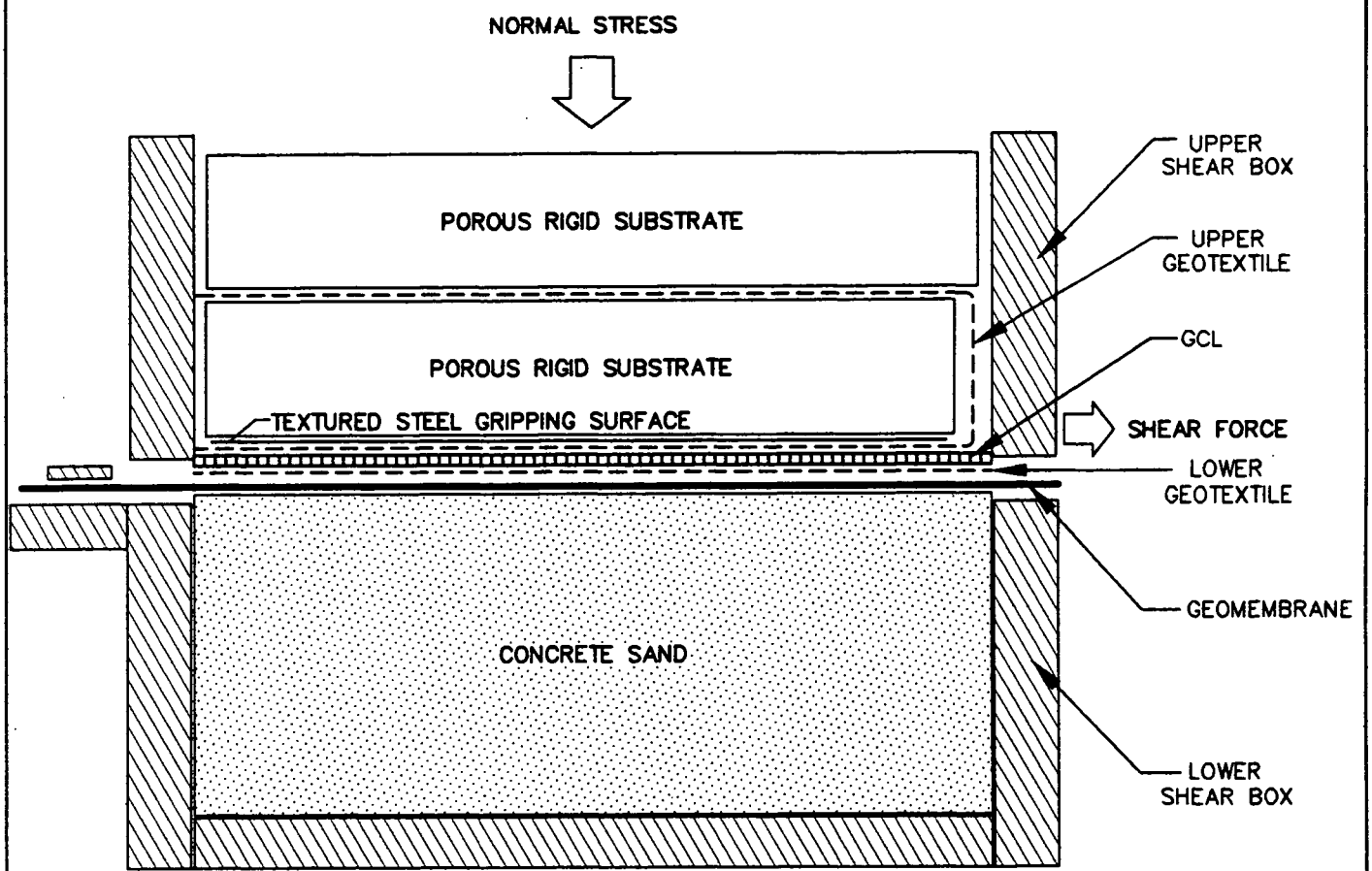
- *Test Series 1 through 4, 9, and 10*: interface between GCL and geomembrane under soaked and consolidated conditions. From top to bottom, each test specimen consisted of:
  - rigid substrate with textured gripping surface;
  - GCL (Bentomat ST, Claymax 500SP, or Bentofix NS GCL) with woven geotextile facing down (i.e., in contact with geomembrane);
  - geomembrane (80-mil GSE Hyperflex Frictionflex or 80-mil GSE HD textured geomembrane); and
  - concrete sand.

  This test specimen configuration is illustrated in Figure 3-2.

- *Test Series Numbers 5, 5X, 6, and 11*: internal shear strength of GCL under soaked and consolidated conditions. From top to bottom, each test specimen consisted of:
  - rigid substrate with textured gripping surface;
  - GCL (Bentomat ST, Claymax 500SP, or Bentofix NS GCL); and
  - rigid substrate with textured gripping surface;

  This test specimen configuration is illustrated in Figure 3-3.

CONFIGURATION OF GCL/GEOMEMBRANE TEST SPECIMEN

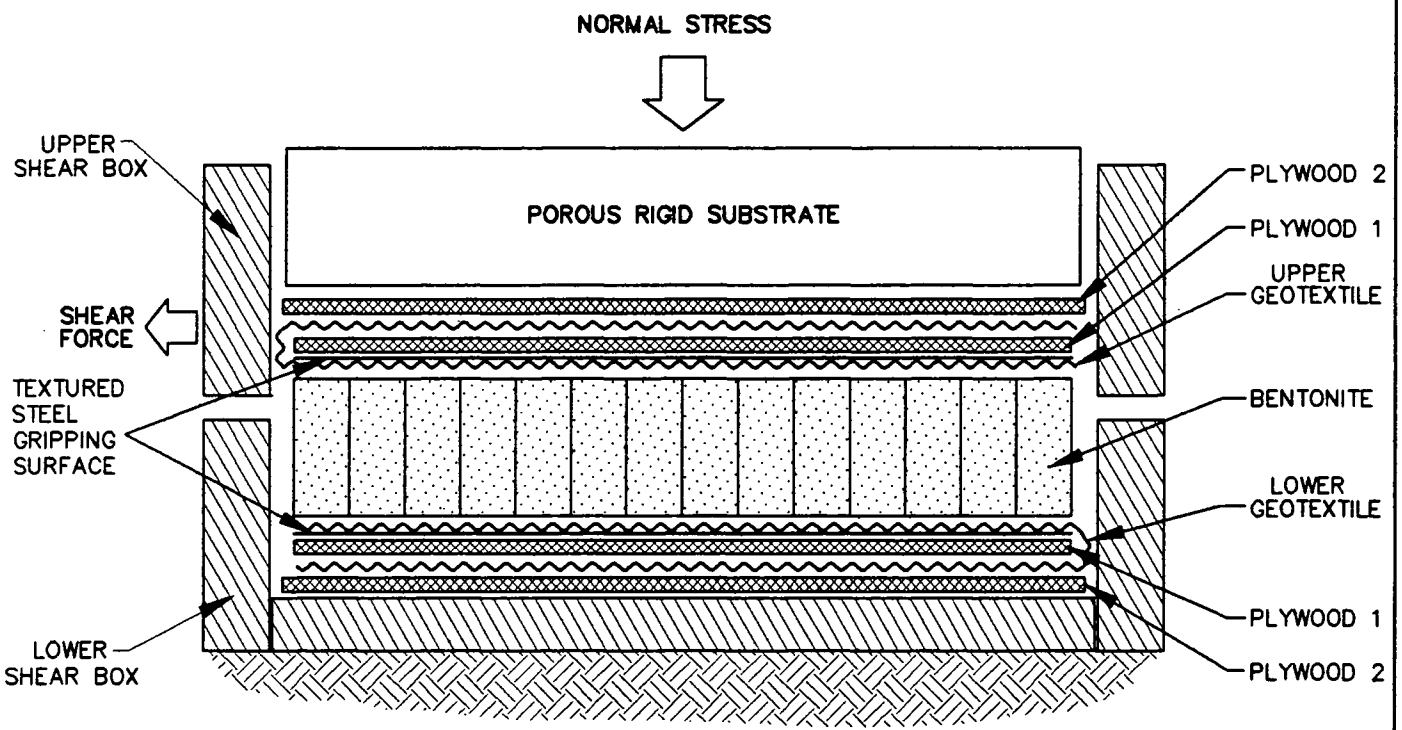


NOTE: NOT TO SCALE

GeoSyntec Consultants
SOIL–GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	3–2
PROJECT NO.	GE3900–9.3
DOCUMENT NO.	F964S006
FILE NO.	3900F901.DWG

CONFIGURATION OF GCL TEST SPECIMEN



NOTE: 1. GCL THICKNESS EXAGGERATED FOR CLARITY.
2. NOT TO SCALE.

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GEOSYNTEC CONSULTANTS
SOIL–GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	3–3
PROJECT NO.	GE3900–9.3
DOCUMENT NO.	F964S006
FILE NO.	3900F902.DWG

- *Test Series Numbers 7, 8, and 12 through 22B*: interface between soil and GCL under soaked and consolidated conditions. From top to bottom, each test specimen consisted of:
  - site soil (clay soil or supplemental clay soil), compacted by hand tamping to specific target placement conditions (i.e., dry unit weight and moisture content);
  - GCL (Bentomat ST, Bentofix NS, Claymax 500SP, or 40-mil GSE MD textured Gundseal GCL); for the Bentomat ST and Bentofix NS materials the nonwoven geotextile was placed in contact with the site soil; for the Claymax 500SP the woven geotextile was placed in contact with the site soil; for the 40-mil GSE HD textured Gundseal material the textured geomembrane side was placed in contact with the site soil; and
  - concrete sand.

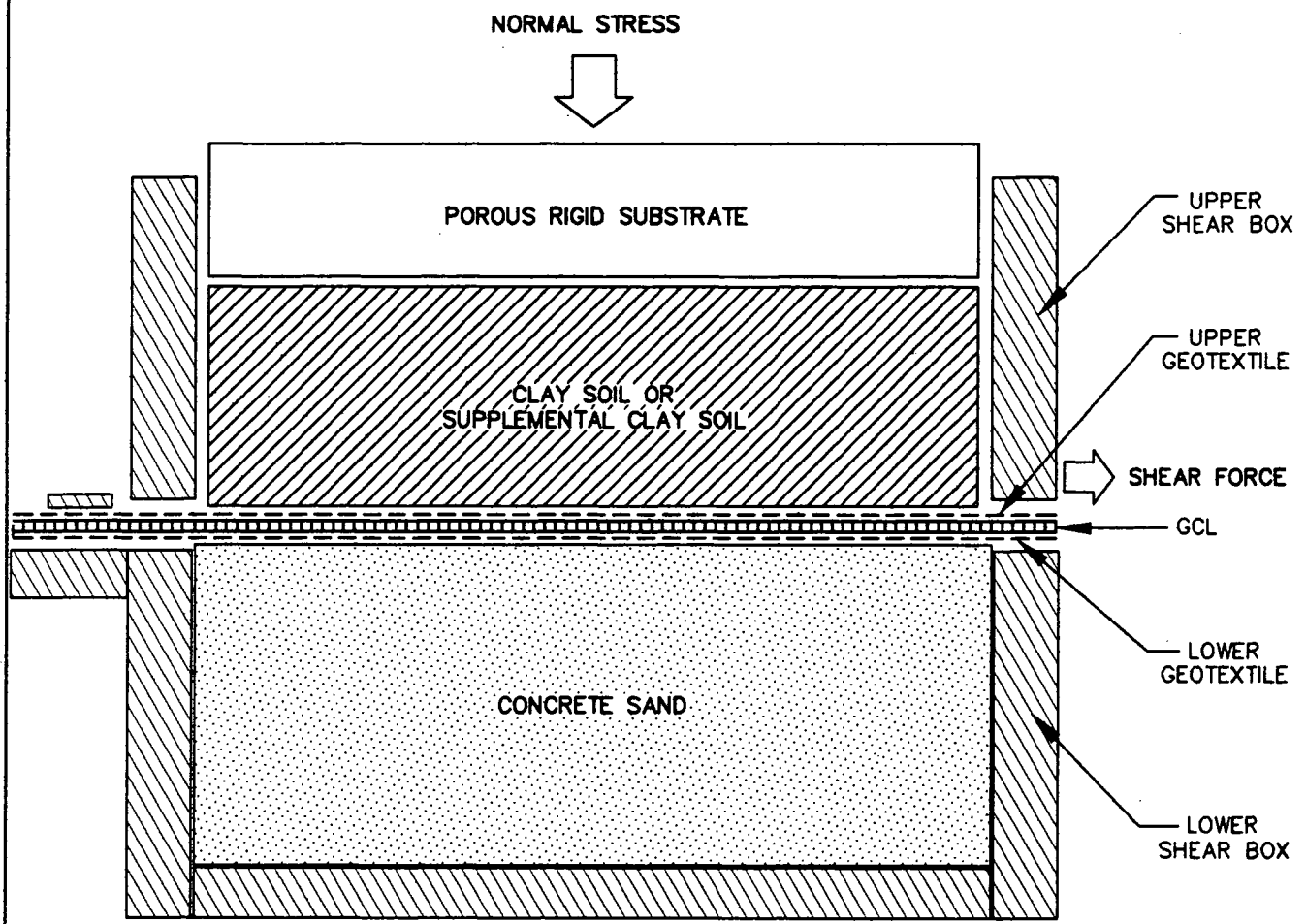
  The test specimen configuration is illustrated in Figure 3-4.

The specific soil and geosynthetic materials used in each direct shear test series are identified by their SGI sample numbers and are summarized in Table 3-4. It is noted that the reported test series numbers are not the same as those presented in the SGIWP. For reference, the test series numbers presented in the SGIWP are cross-referenced to the reported test series numbers in Table 3-4.

3.4.2 Testing Procedures

A summary of the test equipment and conditions used to conduct the interface direct shear tests is presented in Table 3-5. This table indicates the size of the shear box, the initial dry unit weight for the soil component, the initial moisture content of the soil and GCL specimens, normal stress applied during soaking, time for soaking, normal stress applied during consolidation, time for consolidation, moisture content of the soil and GCL specimens at the shearing interface at the completion of testing, normal stress applied to the soil or rigid substrate in the upper shear box during shearing, and horizontal displacement rate for each test.

CONFIGURATION OF SOIL/GCL TEST SPECIMEN



NOTE: 1. GCL IN TEST SERIES NOS. 16A, 16B, 22A, AND 22B WAS GUNDSEAL PRODUCT ORIENTED WITH GEOMEMBRANE BACKING AGAINST CLAY SOIL AND BENTONITE CORE AGAINST CONCRETE SAND

2. NOT TO SCALE.

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GeoSyntec Consultants
SOIL–GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	3–4
PROJECT NO.	GE3900–9.3
DOCUMENT NO.	F964S006
FILE NO.	3900F903.DWG

TABLE 3-4
SUMMARY OF TEST SERIES NUMBERS AND TESTING MATERIALS SOIL-GEOSYNTHETIC INTERFACE DIRECT SHEAR TESTING PROGRAM FERNALD ENVIRONMENTAL MANAGEMENT PROJECT ON-SITE DISPOSAL FACILITY

Reported Test Series Number	Test Series Number in SGIWP[1]	SGI Geomembrane Sample Number[2]	SGI GCL Sample Number	SGI Soil Sample Number[2]
1	14	AL5341	AL5318	N/A
1X	14	AL5341	AL5483	N/A
2	15	AL5340	AL5318	N/A
3	18	AL5341	AL5319	N/A
4	19	AL5340	AL5319	N/A
5	20	N/A	AL5318	N/A
5X	20	N/A	AL5483	N/A
6	22	N/A	AL5319	N/A
7	4	N/A	AL5318	AL5291
8	6	N/A	AL5319	AL5291
9	16	AL5341	AL5393	N/A
10	17	AL5340	AL5393	N/A
11	21	N/A	AL5393	N/A
12	5	N/A	AL5393	AL5291

Notes: (1) The test series number in the SGIWP is cross-referenced to the reported test series number as indicated in Column 1 of the Table.

(2) N/A refers to the fact that this type of material was not used in the test series.

TABLE 3-4 (continued)

Test Series Number	Test Series Number in SGIWP[1]	SGI Geomembrane Sample Number[2]	SGI GCL Sample Number	SGI Soil Sample Number[2]
13	1	N/A	AL5318	AL5291
14	7	N/A	AL5318	AL5291
15A	10	N/A	AL5318	AL5291
15B	10	N/A	AL5318	AL5291
16A	12	N/A	AL5438	AL5291
16B	12	N/A	AL5438	AL5291
17	2	N/A	AL5393	AL5291
18	3	N/A	AL5319	AL5291
19	8	N/A	AL5393	AL5291
20	9	N/A	AL5319	AL5291
21	11	N/A	AL5318	AL5493
22A	13	N/A	AL5438	AL5493
22B	13	N/A	AL5438	AL5493

Notes: (1) The test series number in the SGIWP is cross-referenced to the reported test series number as indicated in Column 1 of the Table.
(2) N/A refers to the fact that this type of material was not used in the test series.

TABLE 3-5

SUMMARY OF DIRECT SHEAR TEST EQUIPMENT AND CONDITIONS
SOIL-GEOSYNTHETIC INTERFACE DIRECT SHEAR TESTING PROGRAM
FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY

Test Series Number	Shear Box Size	TEST CONDITIONS[1]									Normal Stress During Shearing (psi)	Displacement Rate (in./min)
		γ_{di} (pcf)	ω_{ci} (%)		Soaking		Consolidation		ω_{cf} (%)			
			Soil	GCL	Stress (psi)	Time (Hours)	Stress (psi)	Time (Hours)	Soil	GCL		
1	12" x 12"	N/A	N/A	14.8	3	168	5	48	N/A	87.0	5	0.004
				14.8	3	168	20	48		72.3	20	0.004
				14.8	3	168	45	48		67.4	45	0.004
1X	12" x 12"	N/A	N/A	22.2	3	168	5	48	N/A	89.7	5	0.004
				22.2	3	168	20	48		70.3	20	0.004
				22.2	3	168	45	48		51.7	45	0.004
2	12" x 12"	N/A	N/A	14.2	3	168	5	48	N/A	84.6	5	0.004
				14.2	3	168	20	48		64.2	20	0.004
				14.2	3	168	45	48		63.8	45	0.004
3	12" x 12"	N/A	N/A	27.3	3	168	5	48	N/A	103.3	5	0.004
				27.3	3	168	20	48		64.1	20	0.004
				27.3	3	168	45	48		63.5	45	0.004
4	12" x 12"	N/A	N/A	23.7	3	168	5	48	N/A	106.0	5	0.004
				23.7	3	168	20	48		77.1	20	0.004
				23.7	3	168	45	48		76.9	45	0.004
5	12" x 12"	N/A	N/A	16.7	3	168	5	48	N/A	91.9	5	0.004
				16.7	3	168	20	48		65.6	20	0.004
				16.7	3	168	45	48		58.7	45	0.004
5X	12" x 12"	N/A	N/A	22.2	3	168	5	48	N/A	107.8	5	0.004
				22.2	3	168	20	48		94.5	20	0.004
				22.2	3	168	45	48		59.0	45	0.004

Notes: (1) γ_{di} refers to initial dry unit weight of soil specimen.
ω_{ci} refers to initial moisture content of soil or GCL specimen.
ω_{cf} refers to final moisture content of soil of GCL specimen.
N/A refers to data which is not applicable to test.

TABLE 3-5 (continued)

Test Series Number	Shear Box Size	TEST CONDITIONS[1]									Normal Stress During Shearing (psi)	Displacement Rate (in./min)
		γ_{di} (pcf)	ω_{ci} (%)		Soaking		Consolidation		ω_{cf} (%)			
			Soil	GCL	Stress (psi)	Time (Hours)	Stress (psi)	Time (Hours)	Soil	GCL		
6	12" x 12"	N/A	N/A	37.1	3	168	5	48	N/A	109.6	5	0.004
				37.1	3	168	20	48		98.2	20	0.004
				37.1	3	168	45	48		61.4	45	0.004
7	12" x 12"	112.0	17.6	13.8	3	168	5	48	19.1	84.6	5	0.004
		112.0	17.6	13.8	3	168	20	48	18.6	55.1	20	0.004
		112.3	17.3	13.8	3	168	45	48	15.9	46.4	45	0.004
8	12" x 12"	112.4	17.2	21.4	3	168	5	48	20.2	94.5	5	0.004
		111.6	18.0	21.4	3	168	20	48	18.2	54.3	20	0.004
		112.2	17.4	21.4	3	168	45	48	15.0	51.6	45	0.004
9	12" x 12"	N/A	N/A	7.0	3	168	5	48	N/A	101.3	5	0.004
				7.0	3	168	20	48		93.8	20	0.004
				7.0	3	168	45	48		82.0	45	0.004
10	12" x 12"	N/A	N/A	6.9	3	168	5	48	N/A	101.1	5	0.004
				6.9	3	168	20	48		74.2	20	0.004
				6.9	3	168	45	48		66.8	45	0.004
11	12" x 12"	N/A	N/A	7.3	3	168	5	48	N/A	84.4	5	0.004
				7.3	3	168	20	48		77.8	20	0.004
				7.3	3	168	45	48		64.0	45	0.004
12	12" x 12"	111.9	17.6	7.1	3	168	5	48	17.6	87.1	5	0.004
		111.2	18.3	7.1	3	168	20	48	16.6	64.5	20	0.004
		111.5	18.0	7.1	3	168	45	48	15.6	57.1	45	0.004
13	12" x 12"	111.6	17.9	17.2	3	168	5	48	17.8	74.8	5	0.04
		112.2	17.3	17.2	3	168	20	48	16.2	59.0	20	0.04
		112.5	17.0	17.2	3	168	45	48	15.7	53.3	45	0.04
14	12" x 12"	114.5	17.2	17.3	3	168	5	48	18.5	71.6	5	0.04
		114.1	17.6	17.3	3	168	20	48	17.2	53.5	20	0.04
		115.7	16.0	17.3	3	168	45	48	15.7	41.9	45	0.04
15A	12" x 12"	111.4	16.7	15.7	3	168	20	48	17.9	53.0	20	0.004
15B	12" x 12"	115.5	14.2	15.2	3	168	20	48	19.3	62.3	20	0.004

Notes: (1) γ_{di} refers to initial dry unit weight of soil specimen.
ω_{ci} refers to initial moisture content of soil or GCL specimen (ASTM D 2216).
ω_{cf} refers to final moisture content of soil or GCL specimen at the shearing interface (ASTM D 2216).
N/A refers to data which is not applicable to test.

TABLE 3-5 (continued)

Test Series Number	Shear Box Size	TEST CONDITIONS[1]									Normal Stress During Shearing (psi)	Displacement Rate (in./min)
		γ_{di} (pcf)	ϖ_{ci} (%)		Soaking		Consolidation		ϖ_{cf} (%)			
			Soil	GCL	Stress (psi)	Time (Hours)	Stress (psi)	Time (Hours)	Soil	GCL		
16A	12" x 12"	111.4	18.7	11.3	3	168	5	48	35.8	137.8	5	0.004
16B	12" x 12"	115.6	16.8	11.4	3	168	5	48	31.7	118.0	5	0.004
17	12" x 12"	112.2	17.5	6.8	3	168	5	48	17.7	85.2	5	0.04
		111.7	18.3	6.8	3	168	20	48	16.7	77.7	20	0.04
		112.0	17.3	6.8	3	168	45	48	16.1	65.3	45	0.04
18	12" x 12"	112.0	17.5	27.2	3	168	5	48	16.8	73.8	5	0.04
		112.8	17.8	27.2	3	168	20	48	16.3	55.4	20	0.04
		112.2	17.4	27.2	3	168	45	48	15.1	53.8	45	0.04
19	12" x 12"	114.5	16.8	7.3	3	168	5	48	19.0	80.7	5	0.04
		114.6	16.7	7.3	3	168	20	48	16.7	68.5	20	0.04
		115.4	16.3	7.3	3	168	45	48	15.7	67.8	45	0.04
20	12" x 12"	115.5	16.2	26.4	3	168	5	48	18.5	76.3	5	0.04
		114.5	17.2	26.4	3	168	20	48	16.1	58.8	20	0.04
		115.2	16.5	26.4	3	168	45	48	15.2	57.1	45	0.04
21	12" x 12"	95.7	25.6	19.1	3	168	5	48	28.8	76.2	5	0.004
		95.5	25.8	19.1	3	168	20	48	26.7	54.9	20	0.004
		95.4	25.0	19.1	3	168	45	48	24.3	46.4	45	0.004
22A	12" x 12"	95.9	25.3	9.3	3	168	5	48	27.6	115.5	5	0.004
22B	12" x 12"	99.4	23.3	8.9	3	168	5	48	26.9	113.3	5	0.004

Notes: (1) γ_{di} refers to initial dry unit weight of soil specimen.
ω_{ci} refers to initial moisture content of soil or GCL specimen.
ω_{cf} refers to final moisture content of soil of GCL specimen.
N/A refers to data which is not applicable to test.

For all of the direct shear test series, a fresh test specimen was prepared for each normal stress condition. For each test series, the test specimens were set up and tested as described below to achieve the desired moisture condition for the soil and to cause shear failure to occur at the desired interface.

- *Test Series Numbers 1 through 4, 9, and 10:* A fresh geomembrane specimen (i.e., 80-mil GSE Hyperflex Frictionflex or 80-mil GSE HD textured geomembrane) was trimmed from the bulk sample and attached to the lower shear box with mechanical compression clamps. A fresh GCL specimen (i.e., Bentomat ST, Claymax 500SP, or Bentofix NS GCL) was trimmed from the bulk sample and attached to the upper shear box. The GCL specimen was oriented so that the woven geotextile component of the GCL was in contact with the geomembrane (Figure 3-2). This set-up caused shearing to occur at the interface between the GCL woven geotextile and the geomembrane. A rigid substrate with a textured steel gripping surface was placed on top of the GCL. The textured steel gripping surface was used to minimize slippage between the upper geotextile component of the GCL and rigid wooden substrate, thereby promoting a uniform transfer of shear load onto the test interface.

  For each test, the GCL and geomembrane specimens were immersed together in tap water for 168 hours under a normal stress of 3 psi (21 kPa). The normal stress during soaking was applied to the test specimen prior to immersion. After the 168-hour immersion period, the soaking water was drained and the test specimen was then consolidated for 48 hours under an applied normal stress of 5, 20, or 45 psi (35, 140, or 315 kPa). After the 48-hour consolidation period, the consolidation stress was removed and the test specimen was placed and secured in the shear box for testing. The normal stress used for shearing was then applied to the test specimen within approximately five minutes of the removal of the consolidation normal stress, and shearing commenced at the specified rate immediately thereafter.

- *Test Series Numbers 5, 5X, 6, and 11*: A fresh GCL specimen (i.e., Bentomat ST, Claymax 500SP, or Bentofix NS GCL) was trimmed from the bulk sample. The GCL specimen was constrained between two rigid wooden

substrates with the use of textured steel gripping surfaces. The ends of each geotextile were then sandwiched between a second rigid wooden substrate prior to testing as shown in Figure 3-3. The entire test specimen was then placed in the shear box. This set-up caused shearing to occur within the GCL. The textured gripping surfaces were employed to minimize slippage between the geotextile components of the GCL specimen and rigid wooden substrates, thereby promoting a uniform transfer of shear load to the GCL specimen.

For each test, the entire test specimen was immersed in tap water for 168 hours under a normal stress of 3 psi (21 kPa). The normal stress during soaking was applied to the test specimen prior to immersion. After the 168-hour immersion period, the soaking water was drained and the test specimen was then consolidated for 48 hours under an applied normal stress of 5, 20, or 45 psi (35, 140, or 315 kPa). After the 48-hour consolidation period, the consolidation stress was removed and the test specimen was placed and secured in the shear box for testing. The normal stress used for shearing was then applied to the test specimen within approximately five minutes of the removal of the consolidation normal stress, and shearing commenced at the specified rate immediately thereafter.

- *Test Series Numbers 7, 8, and 12 through 22B:* A fresh GCL specimen (i.e., Bentomat ST, Claymax 500SP, Bentofix NS, or 40-mil GSE HD textured Gundseal GCL) was trimmed from the bulk sample and attached to the lower shear box with mechanical compression clamps. The GCL specimen was oriented so that a specific component of the GCL faced upward (i.e., nonwoven geotextile component of Bentomat ST and Bentofix NS GCLs, woven geotextile component of Claymax 500SP GCL, or HD textured geomembrane side of 40-mil GSE HD textured Gundseal GCL). Fresh specimens of the upper soil (i.e. clay soil (AL5291) or supplemental clay soil (AL5493)) were moisture-conditioned using tap water and compacted away from the GCL specimen by hand tamping to the reported dry unit weight for each normal stress condition, and then placed on top of the GCL for testing (Figure 3-4). The target compaction conditions for the upper soil varied from 95 to 98 percent of maximum dry density and from 0 to 3.5 percent wet of

optimum moisture content based on the standard Proctor compaction test results. The total thickness of the compacted upper soil layer was 1.5 in. (38 mm). This set-up would cause shearing to occur at the interface between the upper soil and the specific component of the GCL.

For each test, the entire test specimen was immersed in tap water for 168 hours under a normal stress of 3 psi (21 kPa). The normal stress during soaking was applied to the test specimen prior to immersion. After the 168-hour immersion period, the test specimen was then consolidated in the tap water for 48 hours under an applied normal stress of 5, 20, or 45 psi (35, 140, or 315 kPa). After the 48-hour consolidation period, the consolidation stress was removed and the test specimen was placed and secured in the shear box for testing. The normal stress used for shearing was then applied to the test specimen within approximately five minutes of the removal of the consolidation normal stress, and shearing commenced at the specified rate immediately thereafter.

Other features of the testing procedure included the following:

- a freshly remolded 3-in. (75-mm) thick layer of concrete sand was used as the bedding layer below each test specimen; the concrete sand was compacted by hand tamping to a relatively dense state under dry conditions;

- each test specimen was sheared at a constant displacement rate immediately after application of the normal stress used for shearing;

- the direction of shear for each direct shear test was in the direction of manufacture (machine direction) of the geosynthetic samples; and

- each test specimen was sheared to an approximate minimum shear displacement of 2 in. (50 mm).

4. TEST RESULTS

4.1 Overview

The data reduction procedures for, and test results from, the testing program are summarized below. The results of the soil property tests performed as part of the testing program are presented in Appendix A to this report. The results of the direct shear tests performed as part of the testing program are presented in Appendix B.

4.2 Soil Property Tests

The results of the soil property tests on the clay soil and supplemental clay soil are summarized in Table 4-1. The particle-size distribution and compaction curves for the two soil materials are presented in Appendix A.

4.3 Direct Shear Tests

Sliding (i.e., shear failure) was observed to occur at the intended interface in all tests except the following: (i) Test Series 5, separation between the geotextile and the bentonite core (i.e., internal shear failure) was not achieved in any of the tests due to rupture of the geotextile; (ii) Test Series Numbers 12 and 19, shear failure was observed to occur at the intended interface between the upper soil and the nonwoven geotextile core of the GCL in contact with the upper soil for the test conducted at a normal stress of 5 psi (35 kPa) and within the GCL for tests conducted at normal stresses of 20 and 45 psi (140 and 315 kPa); and (iii) Test Series Number 17, shear failure was observed to occur at the intended interface between the upper soil and the nonwoven geotextile component of the GCL in contact with the upper soil for tests conducted at normal stresses of 5 and 20 psi (35 and 140 kPa) and within the GCL for the test conducted at a normal stress of 45 psi (315 kPa).

For each of the direct shear test series, the total-stress shearing resistance was evaluated for each applied normal stress. The test data were plotted on a graph of

TABLE 4-1

SOIL PROPERTY AND COMPACTION TEST RESULTS
SOIL-GEOSYNTHETIC INTERFACE DIRECT SHEAR TESTING PROGRAM
FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY

Soil Sample Tested	As-Received Moisture Content ASTM D 2216	Atterberg Limits ASTM D 4318			Soil Classification[1] ASTM D 2487	Particle Size[1] ASTM D 422	Compaction Characteristics[1] ASTM D 698	
		LL (%)	PL (%)	PI (%)			Maximum Dry Unit Weight (pcf)	Optimum Water Content (%)
Clay Soil (AL5211-1)	14.6	35	18	17	N/A	N/A	N/A	N/A
Clay Soil (AL5211-2)	13.4	35	18	17	N/A	N/A	N/A	N/A
Clay Soil (AL5211-3)	14.6	35	17	18	N/A	N/A	N/A	N/A
Clay Soil (AL5211-4)	15.3	38	18	20	N/A	N/A	N/A	N/A
Clay Soil (AL5212-5)	16.1	42	19	23	N/A	N/A	N/A	N/A
Clay Soil (AL5212-6)	15.8	39	18	21	N/A	N/A	N/A	N/A
Clay Soil (AL5212-7)	14.7	34	17	17	N/A	N/A	N/A	N/A
Clay Soil (AL5212-8)	13.8	36	18	18	N/A	N/A	N/A	N/A
Clay Soil (Composite Sample) (AL5291)	N/A	36	16	20	CL (Sandy Lean Clay)	9% Gravel 21% Sand 49% Silt 20% Clay	117.5	14.5

Note: (1) N/A refers to the fact that the test was not conducted for the soil specimen.

TABLE 4-1 (continued)

Soil Sample Tested	As-Received Moisture Content ASTM D 2216	Atterberg Limits ASTM D 4318			Soil Classification[1] ASTM D 2487	Particle Size[1] ASTM D 422	Compaction Characteristics[1] ASTM D 698	
		LL (%)	PL (%)	PI (%)			Maximum Dry Unit Weight (pcf)	Optimum Water Content (%)
Supplemental Clay Soil (AL5454)	28.0	65	21	44	N/A	N/A	N/A	N/A
Supplemental Clay Soil (AL5457)	25.5	59	19	40	N/A	N/A	N/A	N/A
Supplemental Clay Soil (AL5458)	25.4	63	21	42	N/A	N/A	N/A	N/A
Supplemental Clay Soil (AL5459)	25.8	64	20	44	N/A	N/A	N/A	N/A
Supplemental Clay Soil (AL5465)	15.1	35	18	17	N/A	N/A	N/A	N/A
Supplemental Clay Soil (AL5466)	19.3	38	19	19	N/A	N/A	N/A	N/A
Supplemental Clay Soil (AL5467)	18.5	34	20	14	N/A	N/A	N/A	N/A
Supplemental Clay Soil (AL5468)	16.8	32	18	14	N/A	N/A	N/A	N/A
Supplemental Clay Soil (Composite Sample) (AL5493)	N/A	63	23	40	CH (Fat Clay)	0% Gravel 2% Sand 64% Silt 34% Clay	101.0	21.7

Note: (1) N/A refers to the fact that the test was not conducted for the soil specimen.

shear force versus horizontal displacement. The resulting plots are presented in Appendix B. The peak value of shear force was used to calculate the peak shear strength. For this report, the large-displacement shear strength was calculated using the post-peak shear force measured at the end of each test (which typically occurred at a shear displacement of approximately 2 in. (50 mm)). For the interface direct shear tests, no area correction was used when computing normal and shear stresses because each test was performed using a constant effective sample area (i.e., the area of each geosynthetic specimen was larger than that of the upper shear box). For the internal GCL direct shear tests, a constant area of 1 ft^2 (0.1 m^2) was assumed when computing normal and shear stresses.

The calculated shear strengths were plotted on a graph of shear stress versus normal stress and the results were used to evaluate total-stress peak and large-displacement shear strength envelopes. For the test series consisting of three tests, a best-fit straight line was drawn through the data points from each test series to obtain the corresponding total-stress peak and large-displacement shear strength friction angles and adhesions. The coefficient of correlation (R^2), a standard statistical indicator of how well the best-fit line matches the test data, was obtained for each best-fit line. For the test series consisting of one test, a straight line was drawn from the origin through the test data point from each test series to obtain total-stress peak and large-displacement shear strength friction angles. The summary plots of shear stress versus normal stress for each test series are also presented in Appendix B. The friction angles, adhesions, and R^2 values derived from the plotted test results are presented in Table 4-2.

For all of the three-point test series, it is noted that the reported total-stress shear strength parameters of friction angle and adhesion are based on the best-fit straight line drawn through the test data on a plot of shear stress versus normal stress. These values may not reflect the true shear strength of the interface and/or GCL and caution should be exercised in using these shear strength parameters for applications involving normal stresses outside the range of stresses covered by the test series.

TABLE 4-2

RESULTS FROM SOIL-GEOSYNTHETIC INTERACTION DIRECT SHEAR TESTING PROGRAM MEASURED TOTAL STRESS SHEAR STRENGTH PARAMETERS FERNALD ENVIRONMENTAL MANAGEMENT PROJECT ON-SITE DISPOSAL FACILITY

Test Series Number	Interfaces or GCL Specimens Tested[1]	Normal Stress (psi)	Peak Shear Strength[2]			Large-Displacement Shear Strength[2,3]			Reference Appendix Figure Numbers
			Friction Angle	Adhesion (psf)	R^2	Friction Angle	Adhesion (psf)	R^2	
1	Bentomat ST GCL (AL5318) With Woven Geotextile Against Geomembrane/80-mil GSE Hyperflex Frictionflex Geomembrane (AL5341) Under Soaked And Consolidated Conditions	5 to 45	22°	115	0.987	10°	140	1.000	B-1 and B-2
1X	Bentomat ST GCL (AL5483) With Woven Geotextile Against Geomembrane/80-mil GSE Hyperflex Frictionflex Geomembrane (AL5341) Under Soaked And Consolidated Conditions	5 to 45	20°	40	0.988	10°	85	0.989	B-3 and B-4
2	Bentomat ST GCL (AL5318) With Woven Geotextile Against Geomembrane/80-mil GSE HD Textured Geomembrane (AL5340) Under Soaked And Consolidated Conditions	5 to 45	16°	260	0.979	10°	215	0.989	B-5 and B-6
3	Claymax 500SP GCL (AL5319) With Woven Geotextile Against Geomembrane/80-mil GSE Hyperflex Frictionflex Geomembrane (AL5341) Under Soaked And Consolidated Conditions	5 to 45	9°	190	0.985	7°	180	0.981	B-7 and B-8
4	Claymax 500SP GCL (AL5319) With Woven Geotextile Against Geomembrane/80-mil GSE HD Textured Geomembrane (AL5340) Under Soaked And Consolidated Conditions	5 to 45	10°	195	0.953	7°	185	0.952	B-9 and B-10
5	Internal Strength of Bentomat ST GCL (AL5318) Under Soaked And Consolidated Conditions	5 to 45	34°	780	0.995	N/A	N/A	N/A	B-11 and B-12
5X	Internal Strength of Bentomat ST GCL (AL5483) Under Soaked And Consolidated Conditions	5 to 45	21°	760	1.000	7°	30	0.957	B-13 and B-14

Notes: (1) See Appendix B for detailed test conditions and procedures.

(2 The reported total-stress shear strength parameters of friction angle and adhesion for each test series may not reflect the true shear strength of the interface and/or GCL and caution should be exercised in using these shear strength parameters for applications involving normal stresses outside the range of stresses covered by the test series. The value of R^2, the coefficient of correlation, provides an indication of how well the best-fit shear strength parameters match the test data. N/A refers to the fact that the value of R^2 was not calculated for the single-point test series.

(3) The large displacement shear strength was calculated using the post-peak shear force measured at the end of each test. N/A refers to the fact that the test data was not measured during the test.

(4) Large-displacement shear strengths were not measured for all tests in the series.

TABLE 4-2 (continued)

Test Series Number	Interfaces or GCL Specimens Tested[1]	Normal Stress (psi)	Peak Shear Strength[2]			Large-Displacement Shear Strength[2,3]			Reference Appendix Figure Numbers
			Friction Angle	Adhesion (psf)	R^2	Friction Angle	Adhesion (psf)	R^2	
6	Internal Strength Of Claymax 500SP GCL (AL5319) Under Soaked And Consolidated Conditions	5 to 45	7°	680	0.995	7°	680	0.995	B-15 and B-16
7	Clay Soil (AL5291) At 95% Of Maximum Dry Unit Weight And 3.5% Wet Of Optimum Moisture Content/Bentomat ST GCL (AL5318) With Nonwoven Geotextile In Contact With Clay Soil Under Soaked And Consolidated Conditions	5 to 45	20°	280	0.976	20°	280	0.976	B-17 and B-18
8	Clay Soil (AL5291) At 95% Of Maximum Dry Unit Weight And 3.5% Wet Of Optimum Moisture Content/Claymax 500SP GCL (AL5319) With Woven Geotextile In Contact With Clay Soil Under Soaked And Consolidated Conditions	5 to 45	16°	105	0.999	16°	105	0.999	B-19 and B-20
9	Bentofix NS GCL (AL5393) With Woven Geotextile Against Geomembrane/80-mil GSE Hyperflex Frictionflex Geomembrane (AL5341) Under Soaked And Consolidated Conditions	5 to 45	18°	55	0.997	11°	10	0.985	B-21 and B-22
10	Bentofix NS GCL (AL5393) With Woven Geotextile Against Geomembrane/80-mil GSE HD Textured Geomembrane (AL5340) Under Soaked And Consolidated Conditions	5 to 45	17°	110	0.992	10°	115	0.986	B-23 and B-24
11	Internal Strength Of Bentofix NS GCL (AL5393) Under Soaked And Consolidated Conditions	5 to 45	17°	465	1.000	8°	20	0.976	B-25 and B-26
12	Clay Soil (AL5291) At 95% Of Maximum Dry Unit Weight And 3.5% Wet Of Optimum Moisture Content/Bentofix NS GCL (AL5393) With Nonwoven Geotextile In Contact With Clay Soil Under Soaked And Consolidated Conditions	5 to 45	16°	365	0.992	8°[4]	430[4]	0.997	B-27 and B-28

Notes: (1) See Appendix B for detailed test conditions and procedures.

(2) The reported total-stress shear strength parameters of friction angle and adhesion for each test series may not reflect the true shear strength of the interface and/or GCL and caution should be exercised in using these shear strength parameters for applications involving normal stresses outside the range of stresses covered by the test series. The value of R^2, the coefficient of correlation, provides an indication of how well the best-fit shear strength parameters match the test data. N/A refers to the fact that the value of R^2 was not calculated for the single-point test series.

(3) The large displacement shear strength was calculated using the post-peak shear force measured at the end of each test. N/A refers to the fact that the test data was not measured during the test.

(4) Large-displacement shear strengths were not measured for all tests in the series.

TABLE 4-2 (continued)

Test Series Number	Interfaces Tested[1]	Normal Stress (psi)	Peak Shear Strength[2]			Large-Displacement Shear Strength[2,3]			Reference Appendix Figure Numbers
			Friction Angle	Adhesion (psf)	R^2	Friction Angle	Adhesion (psf)	R^2	
13	Clay Soil (AL5291) At 95% Of Maximum Dry Unit Weight And 3.5% Wet Of Optimum Moisture Content/Bentomat ST GCL (AL5318) With Nonwoven Geotextile In Contact With Clay Soil Under Soaked And Consolidated Conditions	5 to 45	20°	105	0.999	19°	100	1.000	B-29 and B-30
14	Clay Soil (AL5291) At 98% Of Maximum Dry Unit Weight And 2.0% Wet Of Optimum Moisture Content/Bentomat ST GCL (AL5318) With Nonwoven Geotextile In Contact With Clay Soil Under Soaked And Consolidated Conditions	5 to 45	21°	140	0.999	21°	140	0.999	B-31 and B-32
15A	Clay Soil (AL5291) At 95% Of Maximum Dry Unit Weight And 2.0% Wet Of Optimum Moisture Content/Bentomat ST GCL (AL5318) With Nonwoven Geotextile In Contact With Clay Soil Under Soaked And Consolidated Conditions	20	27°	0	N/A	27°	0	N/A	B-33 and B-34
15B	Clay Soil (AL5291) At 98% Of Maximum Dry Unit Weight And Optimum Moisture Content/Bentomat ST GCL (AL5318) With Nonwoven Geotextile In Contact With Clay Soil Under Soaked And Consolidated Conditions	20	25°	0	N/A	25°	0	N/A	B-35 and B-36
16A	Clay Soil (AL5291) At 95% Of Maximum Dry Unit Weight And 3.5% Wet Of Optimum Moisture Content/40-mil GSE HD Textured Gundseal GCL (AL5438) With Textured Side In Contact With Clay Soil Under Soaked And Consolidated Conditions	5	38°	0	N/A	38°	0	N/A	B-37 and B-38
16B	Clay Soil (AL5291) At 98% Of Maximum Dry Unit Weight And 2.0% Wet Of Optimum Moisture Content/40-mil GSE HD Textured Gundseal GCL (AL5438) With Textured Side In Contact With Clay Soil Under Soaked And Consolidated Conditions	5	41°	0	N/A	41°	0	N/A	B-39 and B-40
17	Clay Soil (AL5291) At 95% Of Maximum Dry Unit Weight And 3.5% Wet Of Optimum Moisture Content/Bentofix NS GCL (AL5393) With Nonwoven Geotextile In Contact With Clay Soil Under Soaked And Consolidated Conditions	5 to 45	19°	355	0.973	12°[4]	570[4]	0.772	B-41 and B-42

Notes: (1) See Appendix B for detailed test conditions and procedures.

(2) The reported total-stress shear strength parameters of friction angle and adhesion for each test series may not reflect the true shear strength of the interface and/or GCL and caution should be exercised in using these shear strength parameters for applications involving normal stresses outside the range of stresses covered by the test series. The value of R^2, the coefficient of correlation, provides an indication of how well the best-fit shear strength parameters match the test data. N/R refers to the fact that the value of R^2 was not calculated for the single-point test series.

(3) The large displacement shear strength was calculated using the post-peak shear force measured at the end of each test. N/A refers to the fact that the test data was not measured during the test.

(4) Large-displacement shear strengths were not measured for all tests in the series.

TABLE 4-2 (continued)

Test Series Number	Interfaces Tested[1]	Normal Stress (psi)	Peak Shear Strength[2]			Large-Displacement Shear Strength[2,3]			Reference Appendix Figure Numbers
			Friction Angle	Adhesion (psf)	R^2	Friction Angle	Adhesion (psf)	R^2	
18	Clay Soil (AL5291) At 95% Of Maximum Dry Unit Weight And 3.5% Wet Of Optimum Moisture Content/Claymax 500SP GCL (AL5319) With Woven Geotextile In Contact With Clay Soil Under Soaked And Consolidated Conditions	5 to 45	16°	200	0.998	15°	200	0.996	B-43 and B-44
19	Clay Soil (AL5291) At 95% Of Maximum Dry Unit Weight And 2.0% Wet Of Optimum Moisture Content/Bentofix NS GCL (AL5393) With Nonwoven Geotextile In Contact With Clay Soil Under Soaked And Consolidated Conditions	5 to 45	21°	365	0.991	8°[4]	450[4]	0.998	B-45 and B-46
20	Clay Soil (AL5291) At 98% Of Maximum Dry Unit Weight And 2.0% Wet Of Optimum Moisture Content/Claymax 500SP GCL (AL5319) With Woven Geotextile In Contact With Clay Soil Under Soaked And Consolidated Conditions	5 to 45	17°	185	0.995	16°	200	0.991	B-47 and B-48
21	Supplemental Clay Soil (AL5493) At 95% Of Maximum Dry Unit Weight And 3.5% Wet Of Optimum Moisture Content/Bentomat ST GCL (AL5318) With Nonwoven Geotextile In Contact With Supplemental Clay Soil Under Soaked And Consolidated Conditions	5 to 45	14°	255	0.978	14°	250	0.976	B-49 and B-50
22A	Supplemental Clay Soil (AL5493) At 95% Of Maximum Dry Unit Weight And 3.5% Wet Of Optimum Moisture Content/40-mil HD Textured GCL (AL5438) With Textured Side In Contact With Supplemental Clay Soil Under Soaked And Consolidated Conditions	5	31°	0	N/A	31°	0	N/A	B-51 and B-52
22B	Supplemental Clay Soil (AL5493) At 98% of Maximum Dry Unit Weight And 2.0% Wet Of Optimum Moisture Content/40-mil HD Textured Gundseal GCL (AL5438) With Textured Side In Contact With Supplemental Clay Soil Under Soaked And Consolidated Conditions	5	31°	0	N/A	31°	0	N/A	B-53 and C-54

Notes: (1) See Appendix B for detailed test conditions and procedures.

(2) The reported total-stress shear strength parameters of friction angle and adhesion for each test series may not reflect the true shear strength of the interface and/or GCL and caution should be exercised in using these shear strength parameters for applications involving normal stresses outside the range of stresses covered by the test series. The value of R^2, the coefficient of correlation, provides an indication of how well the best-fit shear strength parameters match the test data. N/A refers to the fact that the value of R^2 was not calculated for the single-point test series.

(3) The large-displacement shear strength was calculated using the post-peak shear force measured at the end of each test. N/A refers to the fact that the test data was not measured during the test.

(4) Large-displacement shear strengths were not measured for all tests in the series.

5. DISCUSSION

5.1 Introduction

The purpose of this section of the report is to provide a discussion of the direct shear test results and their relationship to OSDF slope stability calculations. The discussion considers the effects of the variables that were investigated in the testing program. These variables are shear displacement rate, clay compaction conditions, and clay plasticity. This section of the report also includes a comparison of the shear strengths measured in the testing program to those used in the OSDF slope stability calculations.

5.2 Effect of Shear Displacement Rate

The majority of the direct shear tests were conducted using a shear displacement rate of 0.004 in./min (0.1 mm/min.). This rate resulted in the shearing stage of the tests having a duration of 8 to 12 hours. Three clay/GCL interface test series were also conducted using a shear displacement rate that was ten times faster (i.e., 0.04 in./min.), with other test conditions being the same as those used for the slower shear rate tests. Comparison of the measured shear strengths from the tests at differing shear displacement rates provides an indication of the effect of shear displacement rate.

A summary of relevant test results from the three pairs of comparative test series is provided in Table 5-1. The table shows that the ratio of strength measured at the slower shear displacement rate to that measured at the faster rate ranges from approximately 1.4 to 0.8. No significant trend in the strength ratio is apparent with respect to confining stress or peak versus large-displacement values. The average value of the strength ratio is 1.04, indicating that shear strengths measured at the slower shear rate are, on average, slightly higher than those measured at the faster rate.

In summary, the test results indicate that changing the shear displacement rate by a factor of ten resulted in, on average, a change in measured shear strength of only four percent. Based on this observation, and the general trend of a slightly increasing

TABLE 5-1

EFFECT OF SHEAR DISPLACEMENT RATE ON MEASURED SHEAR STRENGTH SOIL-GEOSYNTHETIC INTERFACE DIRECT SHEAR TESTING PROGRAM

Test Series No.	Interface	Normal Stress (psi)	Measured Peak Shear Strength (psi)		Ratio B÷A	Measured Large-Displacement Shear Strength (psi)		Ratio D÷C
			A 0.04 in./min	B 0.004 in./min		C 0.04 in./min	D 0.004 in./min	
13,7	Clay Soil/Bentomat GCL	5	2.7	2.9	1.07	2.5	2.9	1.16
		20	7.6	10.3	1.36	7.4	10.3	1.39
		45	16.8	17.5	1.04	16.1	17.5	1.09
17,12	Clay Soil/Bentofix GCL	5	3.4	3.6	1.06	3.4	3.6	1.06
		20	10.7	NA(1)	--	10.7	NA	--
		45	NA	NA	--	NA	NA	--
18,8	Clay Soil/Claymax GCL	5	2.6	2.0	0.77	2.5	2.0	0.80
		20	7.4	6.7	0.91	7.2	6.7	0.93
		45	14.1	13.5	0.96	13.4	13.5	1.01
					Ave. = 1.02			Ave. = 1.06

(1) NA indicates that value measured in test was not representative of sliding on intended interface.

interface shear strength with decreasing test displacement rate, results from tests performed at a displacement rate of 0.004 in./min (0.1 mm/min) provide an appropriate basis for design.

5.3 Effect of Clay Compaction Conditions

Interface direct shear tests on clay/GCL interfaces were conducted using different target compaction conditions for the clay soil. A number of tests were performed with the target compaction conditions for the clay being 95 percent of maximum dry density and 3.5 percentage points wet of optimum moisture content relative to the standard Proctor compaction maximum and optimum values, respectively. Tests were also performed under the same test conditions but with target compaction conditions of 98 percent relative compaction and 2 percentage points wet. Comparison of the measured shear strengths from the tests at differing clay compaction conditions provides an indication of the effect of clay compaction on interface shear strength.

A summary of relevant test results from the comparative tests is provided in Part A of Table 5-2. The table shows that the ratio of shear strength measured at 98 percent relative compaction and 2 percentage points wet to that measured at 95 percent relative compaction and 3.5 percentage points wet ranges from 0.96 to 1.22. No significant trend in the strength ratio is apparent with respect to confining stress or peak versus large-displacement values. The average value of the strength ratio is 1.08, indicating that shear strengths measured at 98 percent relative compaction and 2 percent wet are, on average, slightly higher.

Additional comparisons can be made for tests from Test Series 7, 15A, and 15B. These tests were performed using the same test conditions with target clay compaction conditions ranging from 95 to 98 percent relative compaction and 0 to 3.5 percentage points wet of optimum. Measured shear strengths in these tests are within 10 percent of each other (Table 5-2, Part B).

Based on the above observations, results of interface tests where the clay component was compacted to a relative compaction of 95 percent (standard Proctor) at

TABLE 5-2 (PART A)

EFFECT OF CLAY COMPACTION CONDITIONS ON MEASURED SHEAR STRENGTH SOIL-GEOSYNTHETIC INTERFACE DIRECT SHEAR TESTING PROGRAM

Interface	Normal Stress (psi)	95%, 3.5% Wet of Optimum[1]			98%, 2% Wet of Optimum[1]			Ratio	
		Test Series	Measured Shear Strength (psi)		Test Series	Measured Shear Strength (psi)		C÷A	D÷B
			A Peak	B Large-Displacement		C Peak	D Large-Displacement		
Clay Soil/ Bentomat GCL	5	13	2.7	2.5	14	2.8	2.7	1.04	1.08
	20		7.6	7.4		9.0	9.0	1.18	1.22
	45		16.8	16.1		18.5	18.1	1.10	1.12
Clay Soil/ Bentofix GCL	5	17	3.4	3.4	19	3.9	3.7	1.15	1.09
	20		10.7	10.7		NA[2]	NA	--	--
	45		NA	NA		NA	NA	--	--
Clay Soil/ Claymax GCL	5	18	2.6	2.5	20	2.5	2.4	0.96	0.96
	20		7.4	7.2		8.0	7.7	1.08	1.07
	45		14.1	13.4		15.1	14.0	1.07	1.04
Clay Soil/ Gundseal GCL	5	16A	3.9	3.9	16B	4.3	4.3	1.10	1.10
Clay Soil/ Gundseal GCL	5	22A	3.0	3.0	22B	3.0	3.0	1.00	1.00
								Ave. = 1.08	Ave. = 1.08

(1) Relative compaction and water content with respect to standard Proctor compaction characteristics
(2) NA indicates that value measured in test was not representative of sliding on intended interface.

TABLE 5-2 (PART B)

EFFECT OF CLAY COMPACTION CONDITIONS ON MEASURED SHEAR STRENGTH SOIL-GEOSYNTHETIC INTERFACE DIRECT SHEAR TESTING PROGRAM

Test Series No.	GCL Type	Compaction Conditions		Normal Stress (psi)	Measured Shear Strength (psi)	
		Relative Compaction (%)	Percentage Points Wet of OMC (%)		Peak	Large-Displacement
7	Bentomat	95	3.5	20	10.3	10.3
15A	Bentomat	95	2.0	20	10.2	10.2
15B	Bentomat	98	0.0	20	9.5	9.5

a moisture content 3.5 percentage points wet of the optimum moisture content provide an appropriate basis for design.

5.4 Effect of Clay Plasticity

Interface direct shear tests on clay/GCL interfaces were conducted using two clay soils with differing plasticity. The majority of tests were conducted using clay soil with a plasticity index (PI) of 20. Five clay/GCL interface shear tests were also performed under same test conditions using the supplemental clay soil which has a PI of 40. For the tests, both the clay and supplemental clay had the same target compaction conditions (i.e., dry unit weight and moisture content) relative to each soil's standard Proctor compaction characteristics. Comparison of the measured shear strengths from the tests with the different soils provides an indication of the effect of soil plasticity.

A summary of relevant test results from the comparative tests is provided in Table 5-3. The table shows that the ratio of shear strength measured with the supplemental clay soil to that measured with the clay soil ranges from 0.70 to 1.01. No significant trend in the strength ratio is apparent with respect to confining stress or peak versus large-displacement values. The average value of the strength ratio is 0.84, indicating that shear strengths measured with the supplemental soil are, on average, about 15 percent lower.

Several factors must be considered in assessing the significance of the effect of clay plasticity. One factor is how the plasticity of the clay used in the testing compares to the actual plasticity of the anticipated borrow materials. Information on the actual plasticity is available from geotechnical investigation reports on the primary anticipated borrow areas, the OSDF area and the East Field Borrow Area (EFBA) [Parsons, 1995, 1996][(1)(2)]. This information indicates that the average PI of the brown till, the anticipated borrow material, is approximately 15 to 20 and the maximum PI is approximately 37. The clay soil used in the testing (PI = 20) is therefore

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(1) Parsons, *Geotechnical Investigation Report, On-Site Disposal Facility*, Fernald Environmental Management Project, Project order 140, December 1995, Revision 0, Figure 4-2.

(2) Parsons, *Geotechnical Data and Evaluation Report for East and South Field Borrow Areas*, Fernald Environmental Management Project, Project Order 154, March 1996, Revision A, Figure 4-7.

TABLE 5-3

EFFECT OF CLAY PLASTICITY ON MEASURED SHEAR STRENGTH SOIL-GEOSYNTHETIC INTERFACE DIRECT SHEAR TESTING PROGRAM

Test Series	Interface	Normal Stress (psi)	Measured Peak Shear Strength (psi)			Measured Large-Displacement Shear Strength(psi)		
			A Clay	B Supplemental Clay	Ratio B÷A	C Clay	D Supplemental Clay	Ratio D÷C
13,21	Clay Soil/ Bentomat GCL	5	2.7	2.5	0.93	2.5	2.4	0.96
		20	7.6	7.6	1.00	7.4	7.5	1.01
		45	16.8	12.6	0.75	16.1	12.4	0.77
16A,22A	Clay Soil/ Gundseal GCL	5	3.9	3.0	0.77	3.9	3.0	0.77
16B,22B	Clay Soil/ Gundseal GCL	5	4.3	3.0	0.70	4.3	3.0	0.70
					Ave. = 0.83			Ave. = 0.84

representative of average plasticity and the supplemental clay soil (PI = 40) is therefore representative of upper bound plasticity. It is unlikely that upper bound plasticity conditions would prevail in the field except in localized areas.

Another factor to be considered is that it is likely that the supplemental clay soil could be placed in the field at a wider range of relative compaction and moisture content than the clay soil. This is because the higher plasticity allows a low-permeability to be maintained at a wider range of conditions. Therefore, it is likely that the supplemental clay soil could be placed in the field under compaction conditions that would produce a higher interface shear strength than the compaction conditions used in the testing program.

As described above, the test results indicate that the measured shear strength using the supplemental clay soil may be approximately 15 percent lower than that using the clay soil. The factors discussed above indicate, however, that soil similar to the supplemental clay soil is likely to be encountered only in localized areas and that actual strength differences in the field should be less than 15 percent. Therefore, results of tests performed using the clay soil provide an appropriate basis for design.

5.5 Comparison of Assumed and Measured Shear Strength

5.5.1 Background

Slope stability calculations performed for the OSDF used assumed shear strength parameters for GCLs, and for interfaces between GCLs and adjacent materials, in the liner and final cover systems. Information on the calculations and assumed parameters is summarized in Table 5-4. The table includes the analysis category, the assumed shear strength parameters, and the range of normal stresses involved in each analysis.

The purpose of this section of the report is to compare the shear strengths measured in the laboratory testing program to those used in the slope stability analyses. The comparison considers a number of factors that affect GCL internal and interface shear strengths, such as rate of shear, effect of clay compaction conditions on clay-GCL interfaces, normal stress level, and clay plasticity. It is noted that another important

TABLE 5-4

SHEAR STRENGTH PARAMETERS USED FOR OSDF SLOPE STABILITY ANALYSES INVOLVING GCLs AND GCL INTERFACES

Identification Letter	Analysis	Section of Calculations	Static or Seismic	Short- or Long-term	Normal Stress Range (psi)	Shear Strength Parameters[1]	Peak or Large-Displacement Strength
A	Impacted Material Interim Configuration[3]	3.3.1	Static	Short	3 to 53	$\phi = 17°$[2]	Peak
B	Impacted Material Interim Configuration[3]	4.3	Seismic	Short	3 to 53	$\phi = 17°$[2]	Peak
C	Impacted Material Final Configuration	3.3.2	Static	Long	14 to 53	Varies with normal stress[2] $\phi = 7°$ for 14 psi $\phi = 7°$ for 24 psi $\phi = 6.5°$ for 43 psi $\phi = 6°$ for 53 psi	Large-Displacement
D	Impacted Material Final Configuration	3.3.2	Static	Long	14 to 53	Varies with normal stress $\phi = 12°$ for 14 psi $\phi = 10°$ for 24 psi $\phi = 8°$ for 43 psi $\phi = 8°$ for 53 psi	Peak
E	Impacted Material Final Configuration[3]	4.3	Seismic	Short	14 to 53	Same as for Analysis C[2]	Large-Displacement
F	Liner System	3.2	Static	Short	1 to 2	$\phi = 20°$	Peak
G	Final Cover System	3.5	Static	Short	6	$\phi = 20°$	Peak
H	Final Cover System	3.5	Static	Long	6	$\phi = 13°$	Large-Displacement
I	Final Cover System	3.5	Static	Long	6	$\phi = 15°$	Peak
J	Final Cover System[3]	4.3	Seismic	Short	6	$\phi = 13°$[3]	Large-Displacement

(1) All analyses assumed cohesion of zero.

(2) Shear strength parameters that will be used for final design. These parameters differ from those used in the prefinal design. The prefinal design parameters were revised based on the testing results presented herein.

(3) Shear strength parameters that will be used for final design. These parameters differ from those used in the prefinal design in that they reflect large-displacement conditions while the parameters for the prefinal design reflected peak conditions.

factor, GCL moisture conditions, has been addressed in the laboratory testing program by soaking all test specimens for seven days at a normal stress of 3 psi (21 kPa) and then consolidating for two days at a normal stress equal to that used for shearing. This soaking and consolidation protocol provides a conservative simulation of field conditions because it allows the GCL to hydrate under a normal stress representative of only 3 to 4 ft (0.9 to 1.2m) of soil cover. Experience indicates that hydration under small normal stress often results in lower values of GCL internal and interface shear strength compared to strengths obtained under hydration at higher normal stress.

5.5.2 Impacted Material - Interim Configuration

Assumed Shear Strength Parameters

The shear strength parameters presented in Table 5-4 (identification letters A and B) were used in the stability analyses for interim configurations of the impacted material. These parameters reflect peak, short-term strengths for all GCLs and GCL interfaces in the liner and system. The strength envelope for these assumed parameters is presented in Figures 5-1, 5-2, and 5-3.

Measured Shear Strengths

The peak strengths measured in the testing program are appropriate for direct comparison to the assumed strengths described above. The measured peak strengths from all of the GCL and GCL/geomembrane interface tests, and for select clay/GCL interface tests, are plotted on Figures 5-1, 5-2, and 5-3, respectively. The select clay/GCL interface tests consist of those performed at a shear displacement rate of 0.004 in./min (0.1 mm/min.) using the clay soil (i.e., not the supplemental clay soil) compacted to 95 percent relative compaction at 3.5 percent wet of optimum. These tests were selected for comparison to assumed shear strengths based on the discussion of testing effects provided in Sections 5.2 to 5.4 of this report.

ASSUMED AND MEASURED SHEAR STRENGTHS FOR GCLS (INTERNAL SHEAR)
IMPACTED MATERIAL - INTERIM CONFIGURATION
ANALYSIS CASES A AND B [TABLE 5-4]

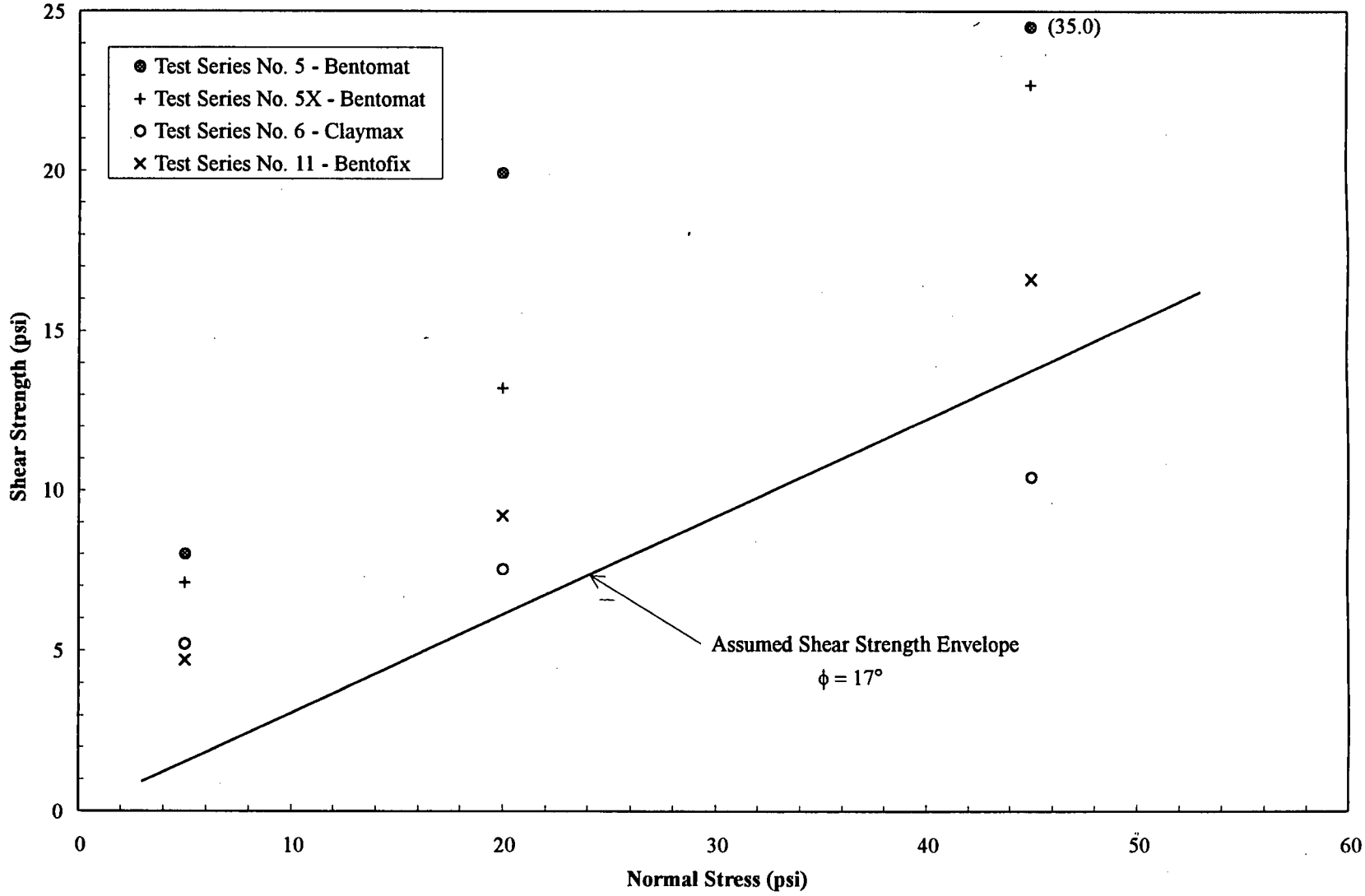

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FIGURE NO.	5-1
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	FERMCO9.3

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bc3

ASSUMED AND MEASURED SHEAR STRENGTHS FOR GCL/GEOMEMBRANE INTERFACES
IMPACTED MATERIAL - INTERIM CONFIGURATION
ANALYSIS CASES A AND B [TABLE 5-4]

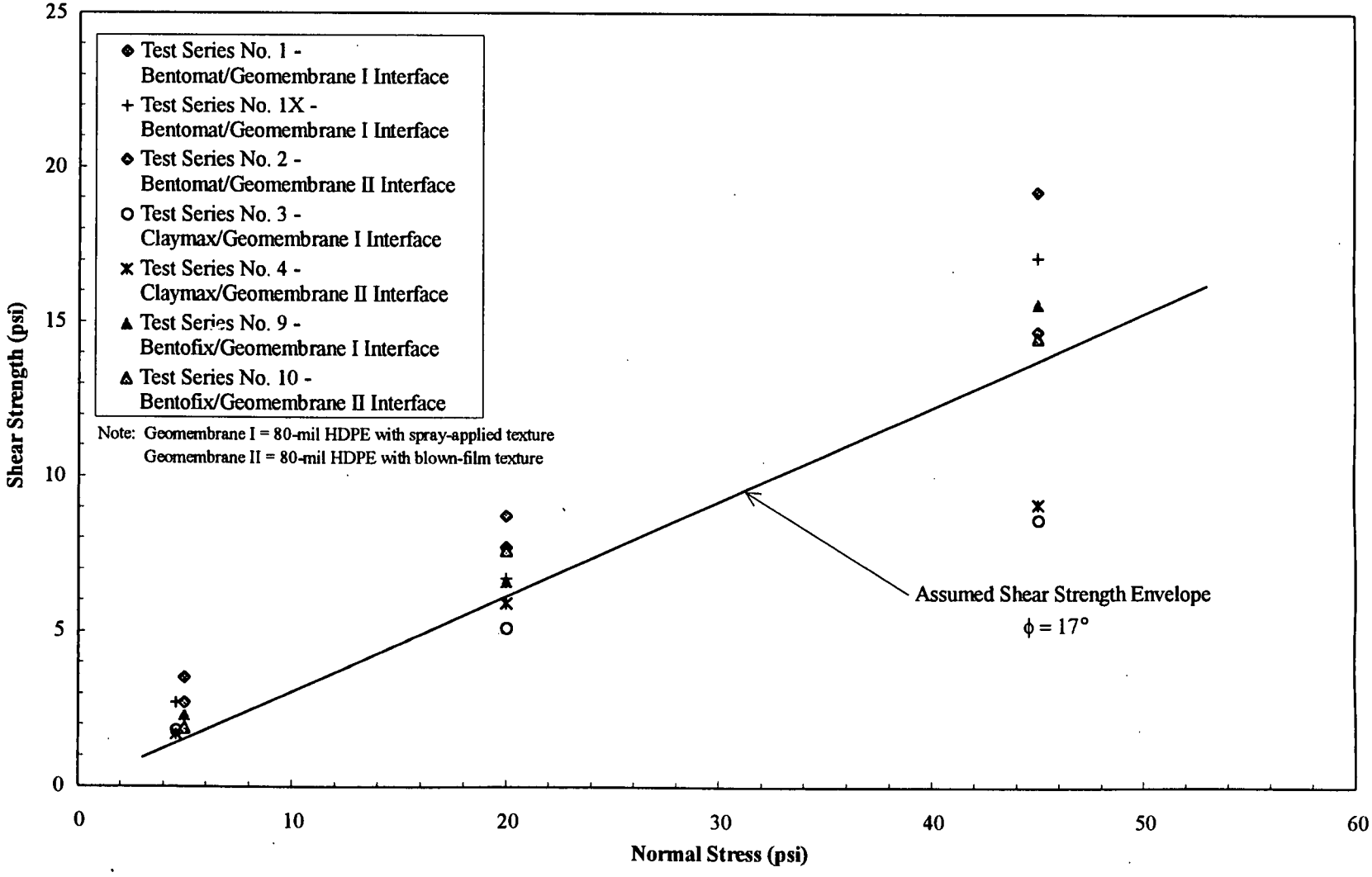

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FIGURE NO.	5-2
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	FERMC09.3

ASSUMED AND MEASURED SHEAR STRENGTHS FOR CLAY/GCL INTERFACES
IMPACTED MATERIAL - INTERIM CONFIGURATION
ANALYSIS CASES A AND B [TABLE 5-4]

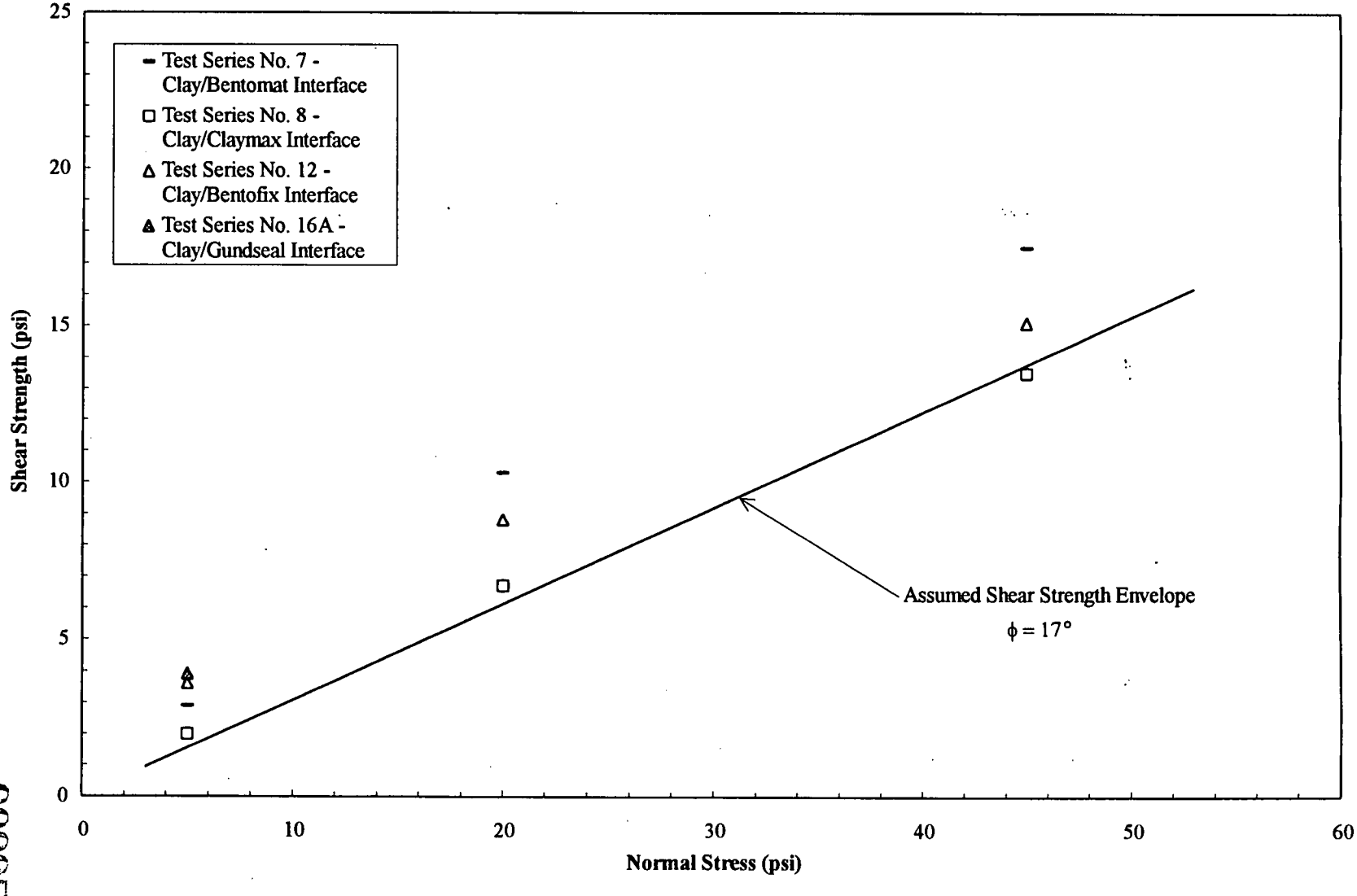

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FIGURE NO.	5-3
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	FERMCO9.3

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Comparison

Comparison of the assumed and measured shear strengths for GCLs (internal shear) shown in Figure 5-1 indicates that all measured shear strengths exceed the assumed values with the exception of the measured strength of the Claymax GCL at a normal stress of 45 psi (310 kPa).

Comparison of the assumed and measured shear strengths for GCL/geomembrane interfaces shown in Figure 5-2 results in the following observations:

- all measured shear strengths at a normal stress of 5 psi (35 kPa) exceed the assumed value;

- the majority of the measured shear strengths at a normal stress of 20 psi (140 kPa) exceed the assumed value; the measured shear strength for the Claymax GCL/geomembrane Type I interface is less than the assumed value; although the measured shear strength for the Claymax GCL/geomembrane Type II interface is slightly smaller than the assumed value, by approximately three percent, the assumed and measured strengths are considered to be equal for practical purposes; and

- the majority of measured shear strengths at a normal stress of 45 psi (310 kPa) exceed the assumed value; the measured shear strengths for the two Claymax GCL/geomembrane interfaces are less than the assumed value.

Comparison of the assumed and measured shear strengths for clay/GCL interfaces shown in Figure 5-3 indicates that all measured shear strengths exceed the assumed value with the exception of the measured strength of the clay/Claymax GCL interface at a normal stress of 45 psi (310 kPa). Although the measured strength for this interface is slightly smaller than the assumed value, by approximately two percent, the assumed and measured strengths are considered to be equal for practical purposes.

Based on these observations, the shear strengths used in the slope stability analyses for the impacted material in the interim configuration are conservative with respect to the measured shear strengths of the majority of the GCLs and GCL interfaces. It is

noted that all measured shear strengths which are less than the strengths used in the analyses are associated with Claymax GCLs.

5.5.3 Impacted Material - Final Configuration

Assumed Shear Strength Parameters

The shear strength parameters presented in Table 5-4 (identification letters C, D, and E) were used in the stability analyses for the final configuration of the impacted material. These parameters reflect long-term conditions and both peak and large-displacement strengths for all GCLs and GCL interfaces in the liner system. These parameters were developed using the information presented by Bonaparte et al. [1996][3]. The approximate strength envelopes for these assumed parameters are presented in Figures 5-4 through 5-9. Peak strength is presented in Figures 5-4 to 5-6 and large-displacement strength is presented in Figures 5-7 to 5-9.

Measured Shear Strengths

The measured peak shear strengths from GCL and GCL/geomembrane interface tests and from selected clay/GCL interface tests, for normal stresses in the range considered for the final configuration analyses, are plotted in Figures 5-4 to 5-6. The selected clay/GCL interface tests are the same as discussed in Section 5.5.2. The corresponding large-displacement shear strengths measured in the testing program are plotted in Figures 5-7 to 5-9.

Comparison

Comparison of the assumed and measured peak shear strength shown in Figure 5-4 to 5-6 indicates that all measured shear strengths exceed the assumed strengths.

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(3) 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 Workshop on Geosynthetic Clay Liners*, U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, 1996, in press.

ASSUMED AND MEASURED PEAK SHEAR STRENGTHS FOR GCLS (INTERNAL SHEAR)
IMPACTED MATERIAL - FINAL CONFIGURATION
ANALYSIS CASE D [TABLE 5-4]

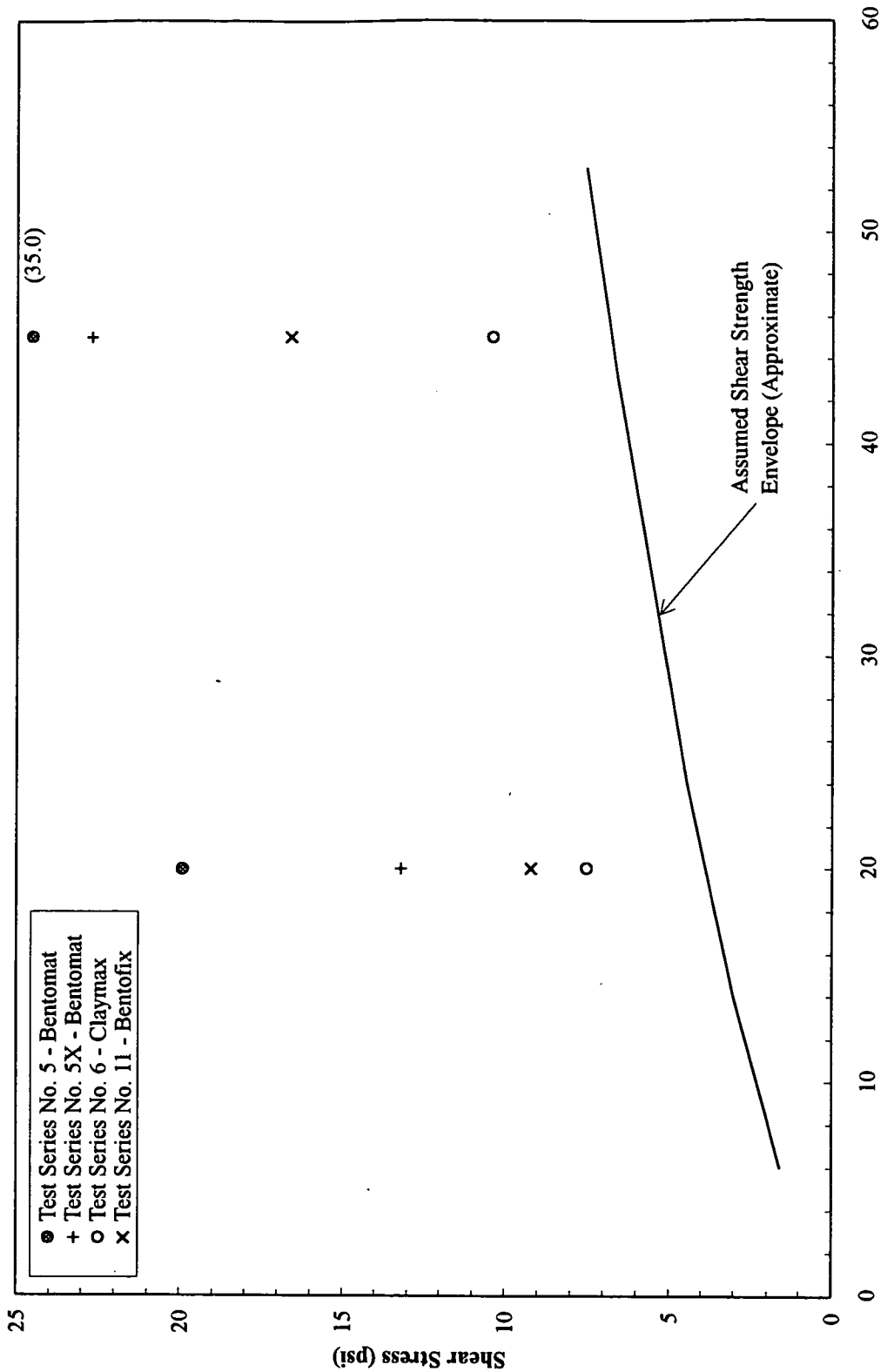

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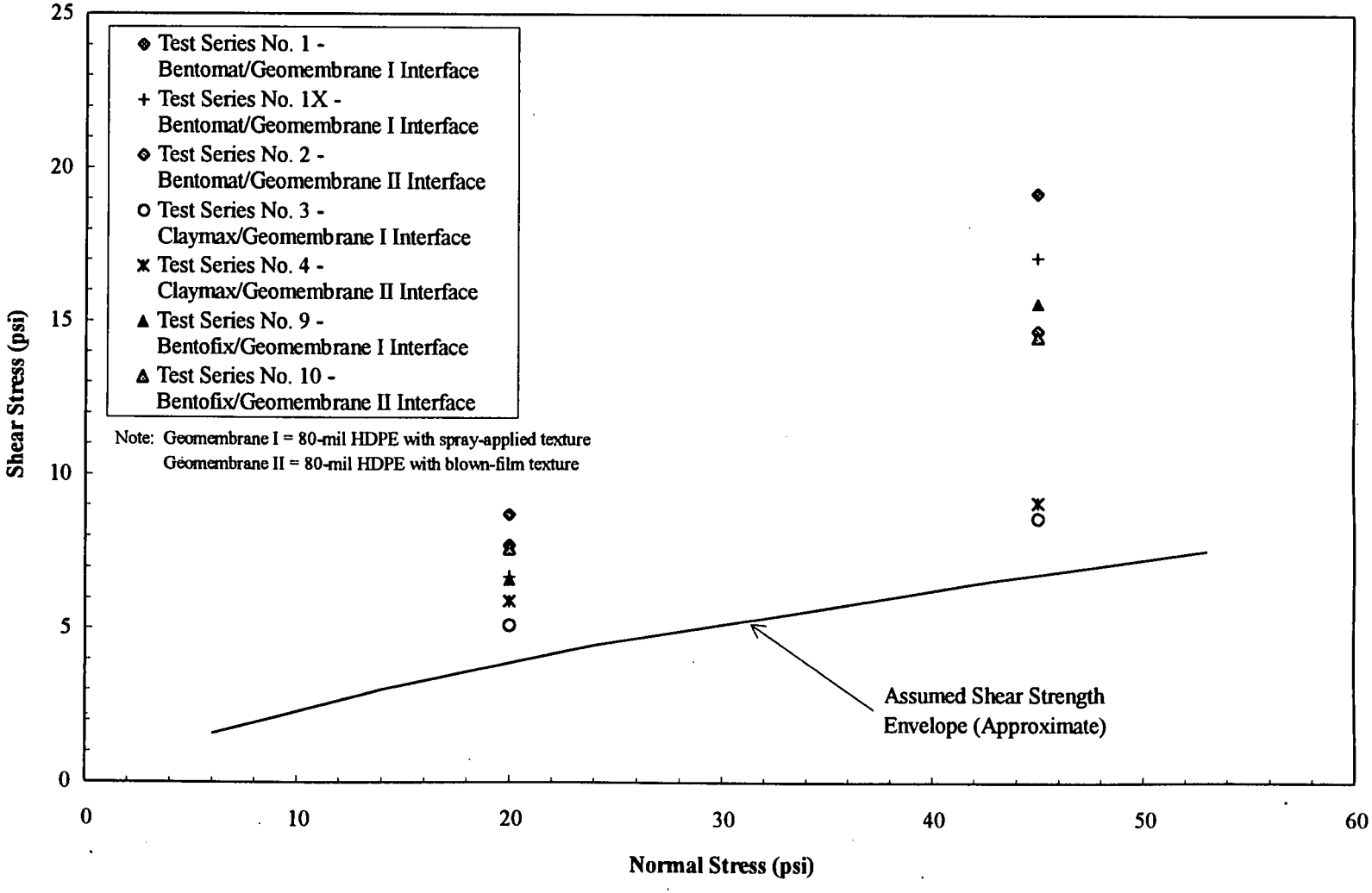
FIGURE NO. 5-4	
PROJECT NO. GE3900-9.3	
DOCUMENT NO. F964S006	
FILE NO. FERMCO9.3	

ASSUMED AND MEASURED PEAK SHEAR STRENGTHS FOR GCL/GEOMEMBRANE INTERFACES
IMPACTED MATERIAL - FINAL CONFIGURATION
ANALYSIS CASE D [TABLE 5-4]



GEOSYNTEC CONSULTANTS
ATLANTA, GEORGIA

FIGURE NO. 5-5
PROJECT NO. GE3900-9.3
DOCUMENT NO. F964S006
FILE NO. FERMC09.3

000052

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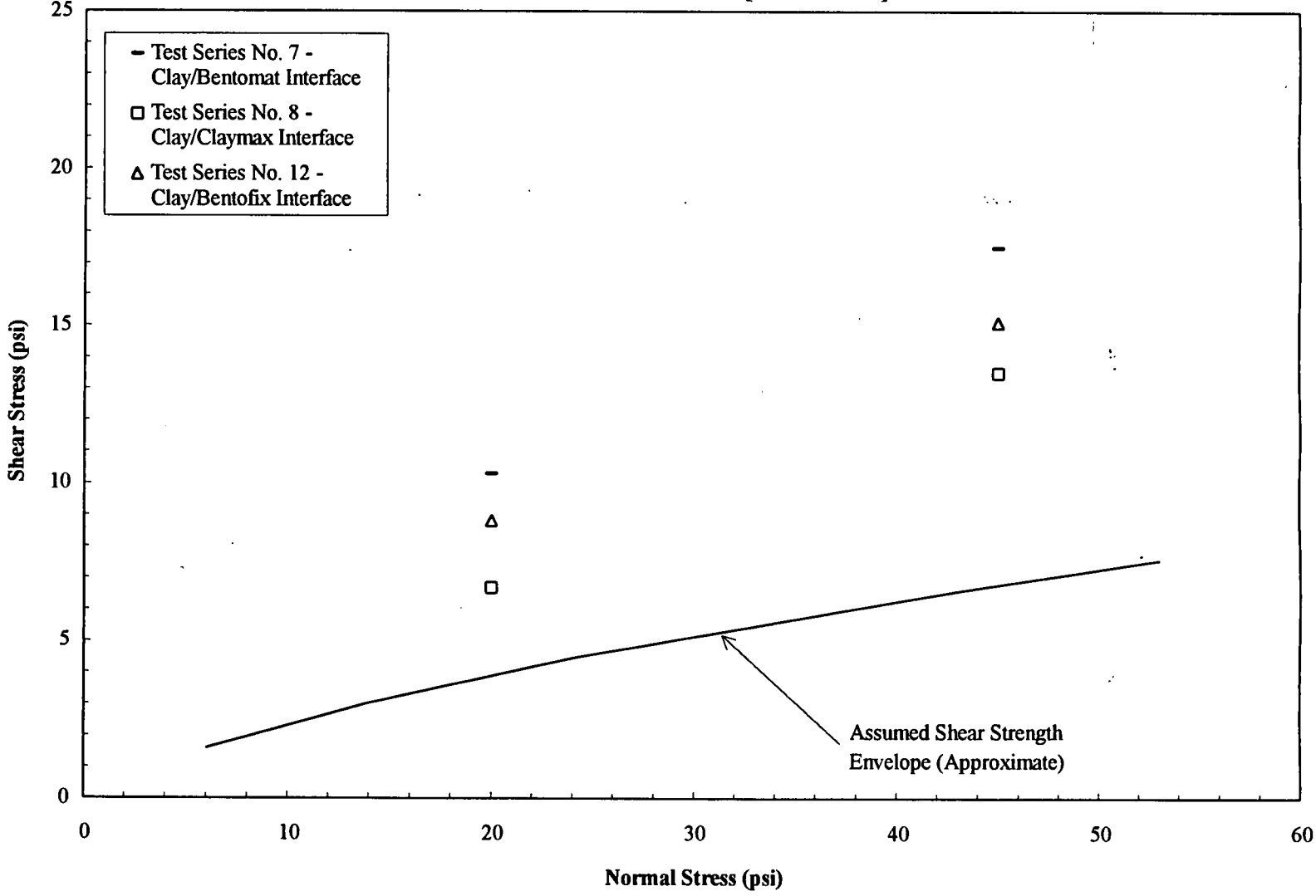
ASSUMED AND MEASURED PEAK SHEAR STRENGTHS FOR CLAY/GCL INTERFACES
IMPACTED MATERIAL - FINAL CONFIGURATION
ANALYSIS CASE D [TABLE 5-4]

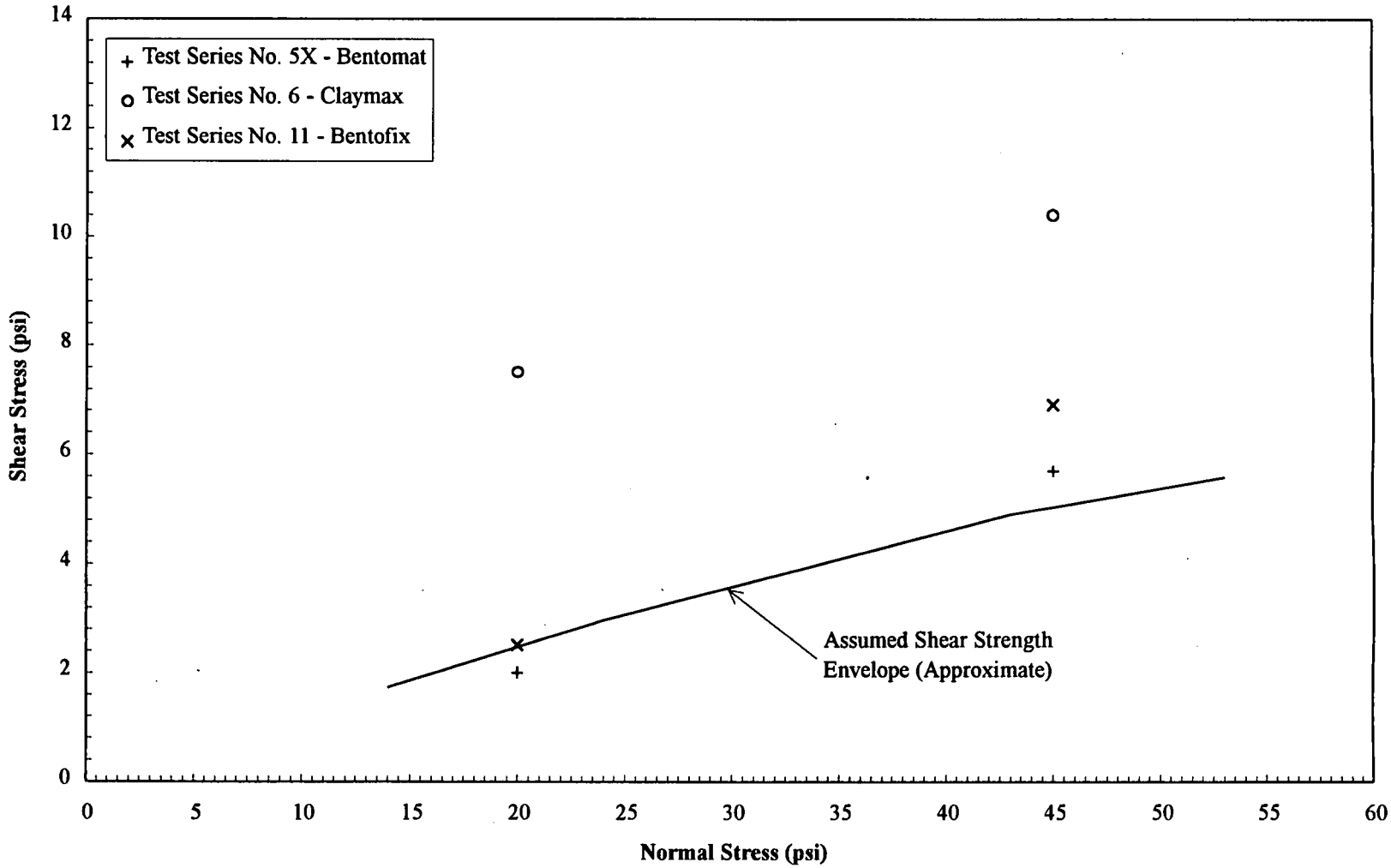


GEOSYNTEC CONSULTANTS
ATLANTA, GEORGIA

FIGURE NO.	5-6
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	FERMC09.3

000058

ASSUMED AND MEASURED LARGE-DISPLACEMENT SHEAR STRENGTHS FOR GCLS (INTERNAL SHEAR) IMPACTED MATERIAL - FINAL CONFIGURATION ANALYSIS CASES C AND E [TABLE 5-4]

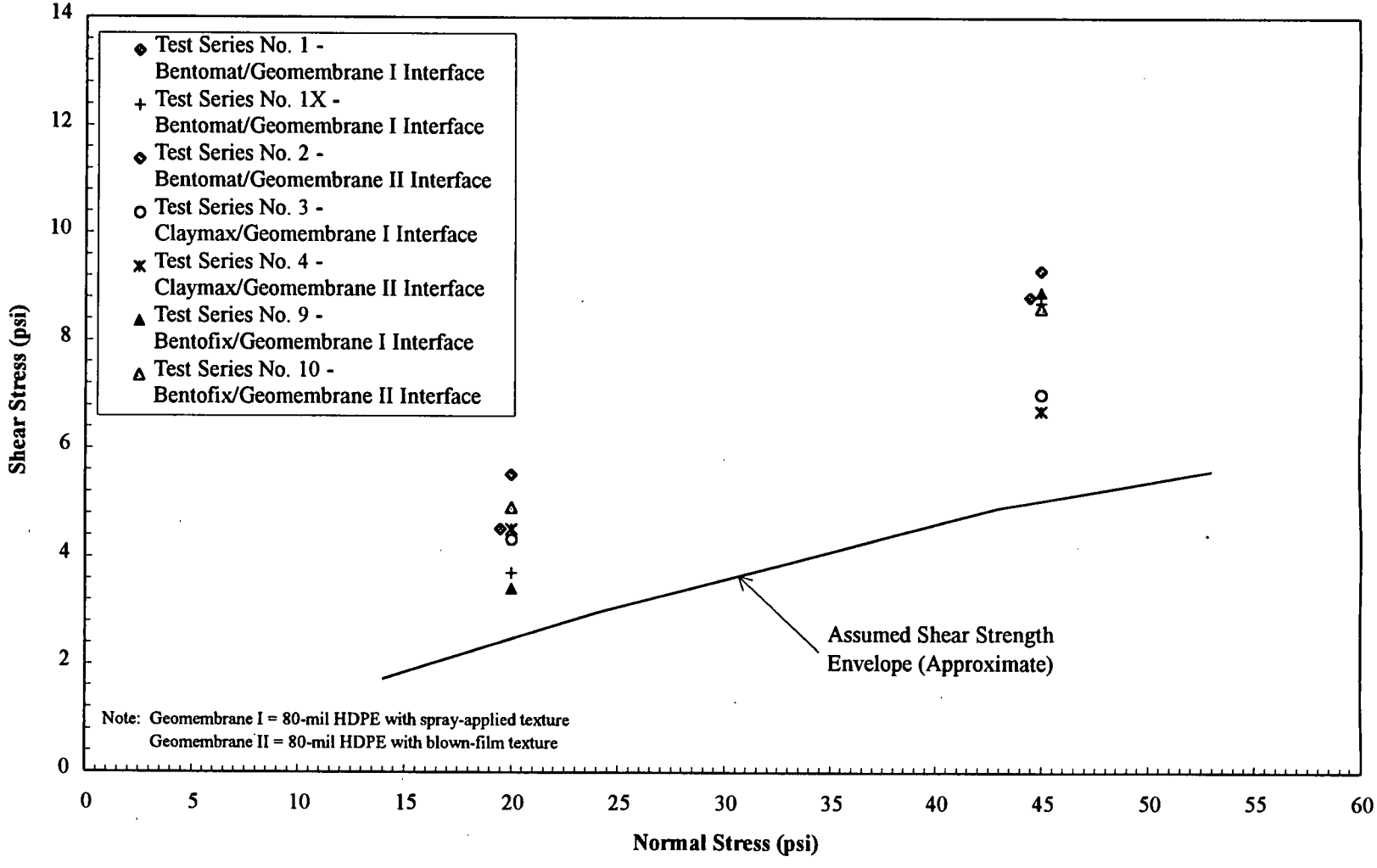


GEOSYNTEC CONSULTANTS
ATLANTA, GEORGIA

FIGURE NO.	5-7
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	FERMCC9.3

000079

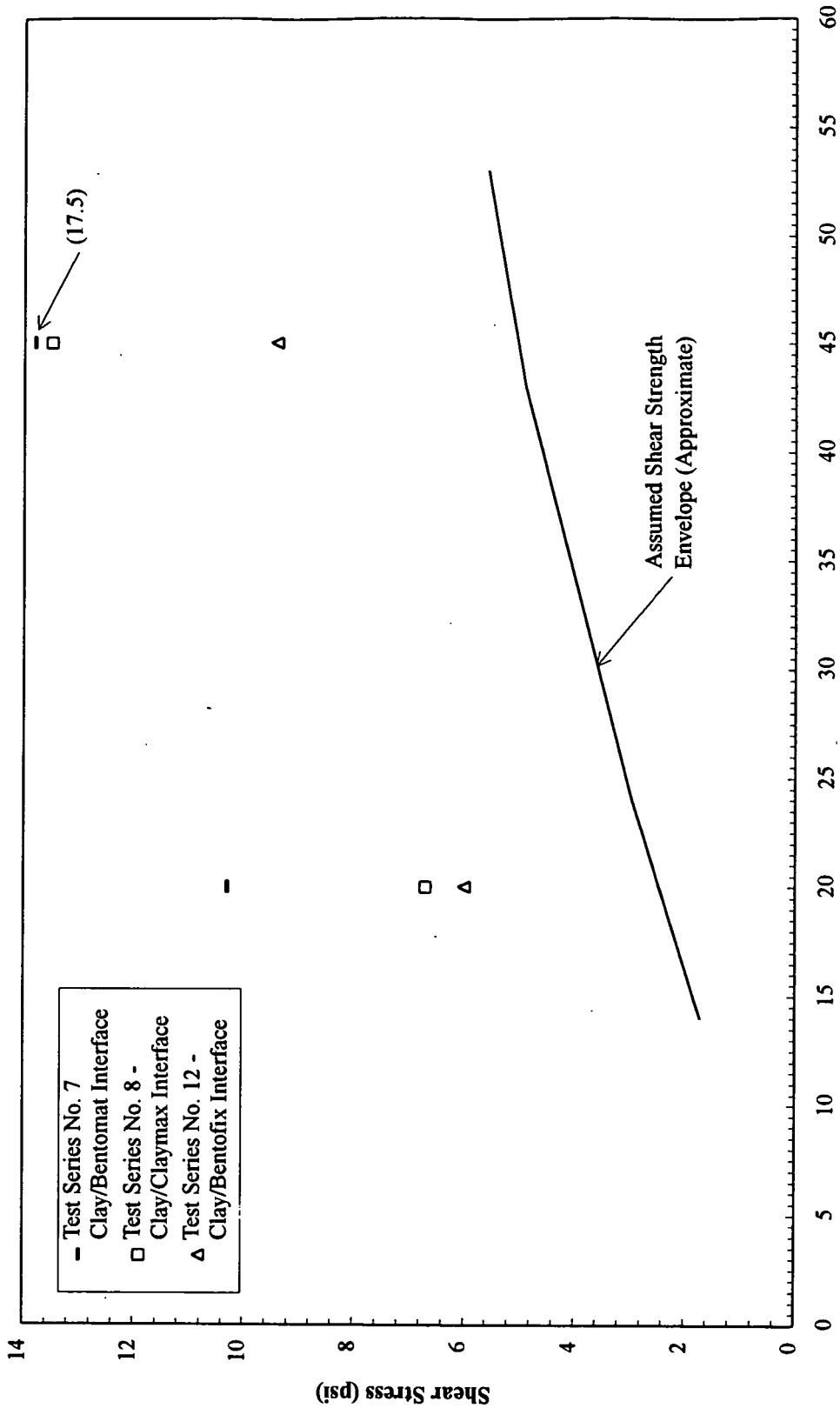
ASSUMED AND MEASURED LARGE-DISPLACEMENT SHEAR STRENGTHS FOR GCL/GEOMEMBRANE INTERFACES IMPACTED MATERIAL - FINAL CONFIGURATION ANALYSIS CASES C AND E [TABLE 5-4]



GEOSYNTEC CONSULTANTS
ATLANTA, GEORGIA

FIGURE NO. 5-8
PROJECT NO. GE3900-9.3
DOCUMENT NO. F964S006
FILE NO. FERMC09.3

ASSUMED AND MEASURED LARGE-DISPLACEMENT SHEAR STRENGTHS FOR CLAY/GCL INTERFACES
IMPACTED MATERIAL - FINAL CONFIGURATION
ANALYSIS CASES C AND E [TABLE 5-4]



000061

GeoSyntec Consultants
ATLANTA, GEORGIA

FIGURE NO.	5-9
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	FERMCO9.3

Comparison of the assumed and measured large-displacement shear strengths shown in Figures 5-7 to 5-9 indicates that all measured shear strengths exceed the assumed strengths with the exception of the measured strength of the Bentomat GCL (internal shear) at normal stress of 20 psi (140 kPa). It is noted, however, that experience indicates that the measured large-displacement shear strength of Bentomat GCL under similar test conditions is typically larger than the value used in the slope stability analyses.

Based on these observations, the shear strengths used in the slope stability analyses for the impacted material in the final configuration are conservative with respect to the measured shear strengths of the GCLs and GCL interfaces, with one exception. The single exception involves the measured internal strength of a Bentomat GCL at one confining stress level.

5.5.4 Liner and Final Cover Systems

Assumed Shear Strength Parameters

The shear strength parameters presented in Table 5-4 (identification letters F through J) were used in the stability analyses for the liner and final cover systems. These parameters are equivalent friction angles which reflect both short- and long-term conditions and both peak and large-displacement strengths, for all GCLs and GCL interfaces in the liner and final cover systems. The assumed equivalent friction angles are as follows:

- short-term conditions, peak strength: 20 degrees;
- long-term conditions, peak strength: 15 degrees; and
- short- and long-term conditions, large-displacement strength: 13 degrees.

Measured Shear Strengths

The measured peak and large-displacement shear strengths from GCL and GCL/geomembrane interface tests and from selected clay/GCL interface tests, for the normal stress relevant to the liner and final cover system stability analyses (i.e., 5 psi), are presented in Table 5-5. Equivalent friction angles calculated from the measured shear strengths, referred to as the measured equivalent friction angles, are also presented in the table. The selected clay/GCL interface tests are the same as discussed in Section 5.5.2.

Comparison

Comparison of the measured equivalent friction angles presented in Table 5-5 to the assumed values results in the observations presented below.

- All measured values for peak strength exceed the assumed values of 15 and 20 degrees for short- and long-term conditions with the exception that the measured values for two Claymax GCL/geomembrane interfaces are slightly less than 20 degrees (Test Series Nos. 3 and 4). Specifically, for Test Series No. 3, the measured value was 19.8 degrees which is considered equal to 20 degrees for practical purposes. For Test Series No. 4, the measured value was 18.8 degrees, approximately five percent less than the assumed value.

- All of the measured values for large-displacement strength exceed the assumed value of 13 degrees for short- and long-term conditions.

Based on these observations, the large-displacement shear strengths assumed in the slope stability analyses for the liner and final cover systems are conservative with respect to all of the measured large-displacement shear strengths. The assumed peak shear strengths are conservative with respect to the measured peak strengths, with the exception of two Claymax GCL/geomembrane interfaces.

TABLE 5-5
MEASURED SHEAR STRENGTHS FOR GCLs AND GCL INTERFACES
FINAL COVER SYSTEM
SOIL-GEOSYNTHETIC INTERFACE DIRECT SHEAR TESTING PROGRAM

Interface or GCL	Test Series No.	Normal Stress (psi)	Measured Shear Strength (psi)		Equivalent Friction Angle (deg)	
			Peak	Large-Displacement	Peak	Large-Displacement
Clay/Bentomat GCL	7	5	2.9	2.9	30.1	30.1
Clay/Bentofix GCL	12	5	3.6	3.6	35.8	35.8
Clay/Claymax GCL	8	5	2.0	2.0	21.8	21.8
Clay/Gundseal GCL	16A	5	3.9	3.9	38.0	38.0
Bentomat GCL/ Geomembrane I[1]	1,1X	5 5	3.5 2.7	1.9 1.7	35.0 28.4	20.8 18.8
Bentomat GCL/ Geomembrane II[1]	2	5	2.7	2.1	28.4	22.8
Bentofix GCL/ Geomembrane I	9	5	2.3	1.4	24.7	15.6
Bentofix GCL/ Geomembrane II	10	5	1.9	1.4	20.8	15.6
Claymax GCL/ Geomembrane I	3	5	1.8	1.6	19.8	17.7
Claymax GCL/ Geomembrane II	4	5	1.7	1.5	18.8	16.7
Bentomat GCL	5,5X	5 5	8.0 7.1	NA[2] 1.2	58.0 54.8	NA 13.5
Bentofix GCL	11	5	4.7	1.2	43.2	13.5
Claymax GCL	6	5	5.2	NA	46.1	NA

(1) Geomembrane I is 80-mil HDPE with spray-applied texture.
Geomembrane II is 80-mil HDPE with blown-film texture.

(2) NA indicates that large-displacement value was not measured.

5.5.5 Conclusions

The comparison of shear strengths measured in the laboratory to those used in the OSDF slope stability analyses involves two activities. The first activity is an assessment of the laboratory testing conditions that form an appropriate basis for design. The second activity is a comparison of measured shear strengths to those used in the analyses. Conclusions regarding these two activities are presented in this section.

The assessment of testing conditions resulted in the following conclusions with respect to appropriate test conditions for the direct shear testing program:

- shear displacement rate of 0.004 in./min. (0.1 mm./min.);
- clay compaction conditions of 95 percent standard Proctor relative compaction at 3.5 percentage points wet of optimum moisture content;
- use of the clay soil composite sample (PI=20); and
- GCL soaking and consolidation protocol as described previously in this section.

Based on the above conclusions, the comparisons between measured and assumed shear strengths are made using the results of the tests performed with the following conditions: (i) shear displacement rate of 0.004 in./min. (0.1 mm./min.); (ii) clay compaction conditions of 95 percent standard Proctor relative compaction and 3.5 percentage points wet of optimum moisture content; and (iii) clay soil composite sample with PI of 20. The comparison resulted in the conclusions listed below.

- The measured shear strengths of GCLs (internal shear) exceeded the shear strengths used in the OSDF slope stability analyses in all but two cases (Table 5-6). These two cases are outlined below.
  - Claymax GCL at a normal pressure of 45 psi (310 kPa) to be used for analysis of interim OSDF configurations.
  - Bentomat GCL (large-displacement conditions) at a normal pressure of 20 psi (140 kPa) to be used for analysis of final OSDF configurations.

TABLE 5-6
COMPARISON OF ASSUMED AND MEASURED SHEAR STRENGTHS
GCL INTERNAL SHEAR
SOIL-GEOSYNTHETIC INTERFACE DIRECT SHEAR TESTING PROGRAM

Test Series No.	GCL Type	Test Normal Stress (psi)	Comparison to Assumed Strength by Analysis Category (See Table 5-4)[1]					
			A,B	C,E	D	F,G	H,J	I
5	Bentomat	5	P	NA	NA	P	P	P
		20	P	NA	P	NA	NA	NA
		45	P	NA	P	NA	NA	NA
5X	Bentomat	5	P	NA	NA	P	P	P
		20	P	**FAIL**	P	NA	NA	NA
		45	P	P	P	NA	NA	NA
6	Claymax	5	P	NA	NA	P	P	P
		20	P	P	P	NA	NA	NA
		45	**FAIL**	P	P	NA	NA	NA
11	Bentofix	5	P	NA	NA	P	P	P
		20	P	P	P	NA	NA	NA
		45	P	P	P	NA	NA	NA

Notes: (1) P = measured strength equal to or greater than assumed strength
FAIL = measured strength less than assumed strength
NA = Not Applicable

It is noted that experience indicates that the measured large-displacement shear strength of Bentomat GCL under similar test conditions is typically larger than the value used in the slope stability analyses.

- The measured shear strengths of GCL/geomembrane interfaces exceeded the shear strengths used in the OSDF slope stability analyses in all but four cases (Table 5-7). These four cases are outlined below.
  - Claymax GCL/geomembrane interface (spray-applied texture) at normal stresses of 20 and 45 psi (140 and 310 kPa) to be used for analysis of interim OSDF configurations.
  - Claymax GCL/geomembrane interface (blown-film texture) at normal stress of 45 psi (310 kPa) to be used for analysis of interim OSDF configurations.
  - Claymax GCL/geomembrane interface (blown-film texture) at normal stress of 5 psi (35 kPa) to be used for short-term analysis of final cover slopes.

- The measured shear strengths of clay/GCL interfaces exceeded the shear strengths used in the OSDF slope stability analyses in all cases (Table 5-8).

These conclusions indicate that, with only a few exceptions, the shear strengths used in the OSDF slope stability analysis can be achieved by the GCLs, geomembranes, and clay used in the interface direct shear testing program. Five of the six cases in which the shear strengths were not achieved involve Claymax GCLs. Given this result, it is recommended that the GCL construction specification only allow use of GCLs manufactured through needle-punching of the geotextile backings. It is further recommended that this specification require quality control testing to demonstrate that the GCL provided for use on the project have internal shear strength at least equal to the assumed design value.

TABLE 5-7
COMPARISON OF ASSUMED AND MEASURED SHEAR STRENGTHS GCL/GEOMEMBRANE INTERFACES SOIL-GEOSYNTHETIC INTERFACE DIRECT SHEAR TESTING PROGRAM

Test Series No.	GCL Type	Geomembrane[1]	Test Normal Stress (psi)	Comparison to Assumed Strength by Analysis Category (See Table 5-4)[2]					
				A,B	C,E	D	F,G	H,J	I
1	Bentomat	Type I	5	P	NA	NA	P	P	P
			20	P	P	P	NA	NA	NA
			45	P	P	P	NA	NA	NA
1X	Bentomat	Type I	5	P	NA	NA	P	P	P
			20	P	P	P	NA	NA	NA
			45	P	P	P	NA	NA	NA
2	Bentomat	Type II	5	P	NA	NA	P	P	P
			20	P	P	P	NA	NA	NA
			45	P	P	P	NA	NA	NA
3	Claymax	Type I	5	P	NA	NA	P	P	P
			20	**FAIL**	P	P	NA	NA	NA
			45	**FAIL**	P	P	NA	NA	NA
4	Claymax	Type II	5	P	NA	NA	**FAIL**	P	P
			20	P	P	P	NA	NA	NA
			45	**FAIL**	P	P	NA	NA	NA
9	Bentofix	Type I	5	P	NA	NA	P	P	P
			20	P	P	P	NA	NA	NA
			45	P	P	P	NA	NA	NA
10	Bentofix	Type II	5	P	NA	NA	P	P	P
			20	P	P	P	NA	NA	NA
			45	P	P	P	NA	NA	NA

Notes: (1) Geomembrane I is 80-mil HDPE with spray-applied texture.
Geomembrane II is 80-mil HDPE with blown-film texture.

(2) P = measured strength equal to or greater than assumed strength
FAIL = measured strength less than assumed strength
NA = Not Applicable

TABLE 5-8
COMPARISON OF ASSUMED AND MEASURED SHEAR STRENGTHS
CLAY/GCL INTERFACES
SOIL-GEOSYNTHETIC INTERFACE DIRECT SHEAR TESTING PROGRAM

Test Series No.	GCL Type	Test Normal Stress (psi)	Comparison to Assumed Strength by Analysis Category (See Table 5-4)[2]					
			A,B	C,E	D	F,G	H,J	I
7	Bentomat	5	P	NA	NA	P	P	P
		20	P	P	P	NA	NA	NA
		45	P	P	P	NA	NA	NA
8	Claymax	5	P	NA	NA	P	P	P
		20	P	P	P	NA	NA	NA
		45	P	P	P	NA	NA	NA
12	Bentofix	5	P	NA	NA	P	P	P
		20	P	P	P	NA	NA	NA
		45	P	P	P	NA	NA	NA
16A	Gundseal	5	P	NA	NA	P	P	P

Notes: (1) P = measured strength equal to or greater than assumed strength
FAIL = measured strength less than assumed strength
NA = Not Applicable

6. LIMITATIONS

The reported results and discussions apply only to the materials and test conditions used in the laboratory testing program. The results and discussions do not necessarily apply to other materials or test conditions, or to any project other than the FEMP OSDF project.

APPENDIX A

APPENDIX A

SOIL PROPERTY TEST RESULTS

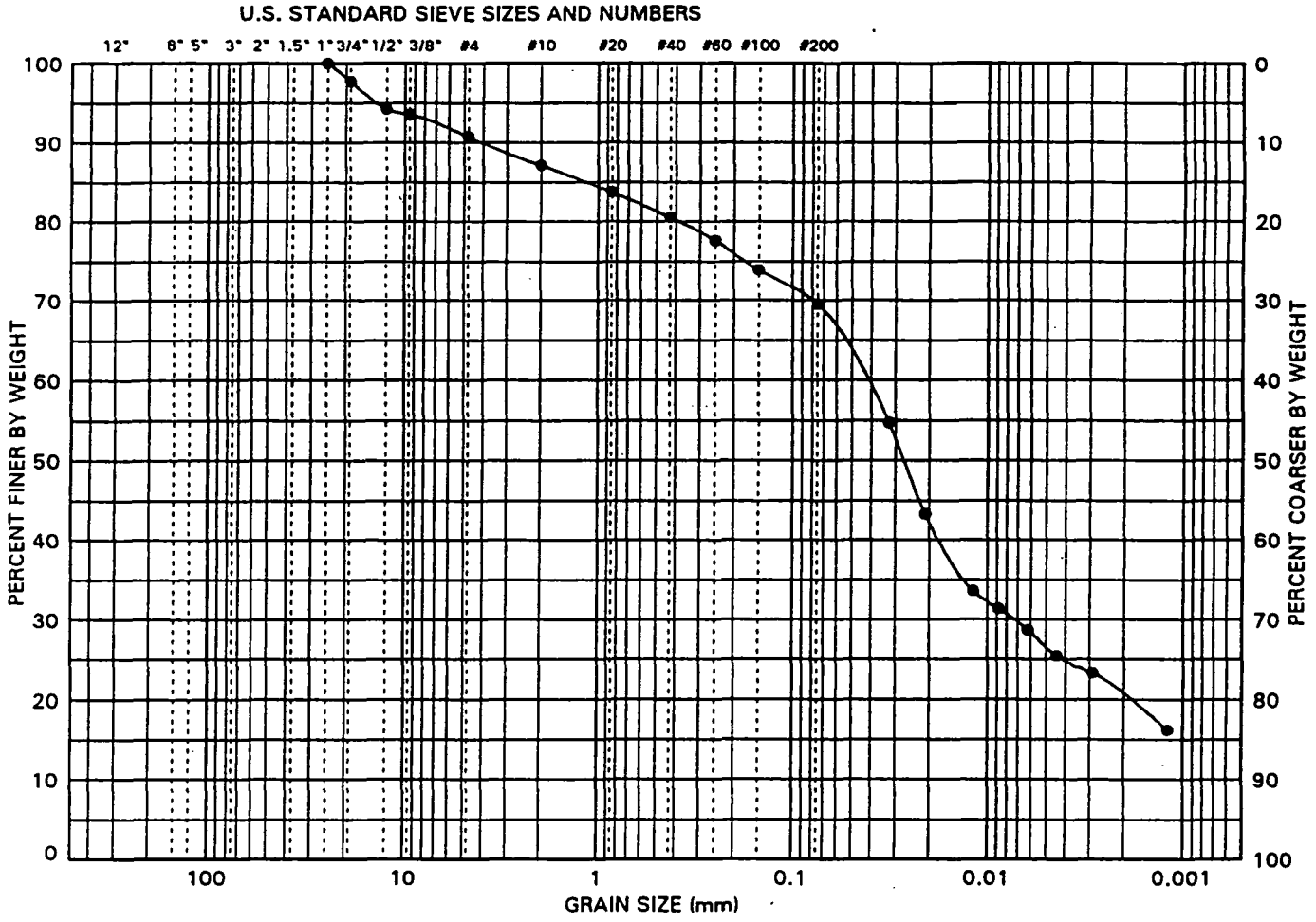
GEO SYNTEC CONSULTANTS
Geomechanics and Environmental Laboratory
Atlanta, Georgia

FIGURE A-1
PROJECT: FERMCO-OSDF
PROJECT NO.: GE3900-9.2
DOCUMENT NO.: F964S006

GS FORM: 4PS2 12/10/95

PARTICLE SIZE DISTRIBUTION AND PHYSICAL PROPERTIES

ASTM C 136, D 422, D 2487 D 3042 AND D 4318



BOULDERS	COBBLES	GRAVEL: COARSE	GRAVEL: FINE	SAND: COARSE	SAND: MEDIUM	SAND: FINE	FINES: SILT	FINES: CLAY

SITE SAMPLE ID	AL5291	LIQUID LIMIT (%)	36
LAB. SAMPLE NO.	95L17	PLASTIC LIMIT (%)	16
SAMPLE DEPTH (ft)		PLASTICITY INDEX	20

SOIL CLASSIFICATION:
CL - Sandy Lean Clay

SOIL FRACTIONS	
GRAVEL (%)	9.3
SAND (%)	21.2
FINES (%)	69.5
SILT (%)	49.2
CLAY(%)	20.3
COEFF. UNIFORMITY (Cu)	
COEFF. CURVATURE (Cc)	

PERCENT PASSING U.S. STANDARD SIEVE SIZES AND NUMBERS

3"	2"	1.5"	1"	3/4"	1/2"	3/8"	#4	#10	#20	#40	#60	#100	#200
PERCENT PASSING SIEVE SIZES (mm)													
75	50	37.5	25	19	12.5	9.5	4.75	2.00	0.850	0.425	0.250	0.150	0.075
00	100	100	100	98	94	94	91	87	84	81	78	74	70

PERCENT FINER THAN HYDROMETER PARTICLE DIAMETER (mm)

0.050	0.020	0.005	0.002	0.001
62	42	27	20	

NOTES: CLAY SOIL

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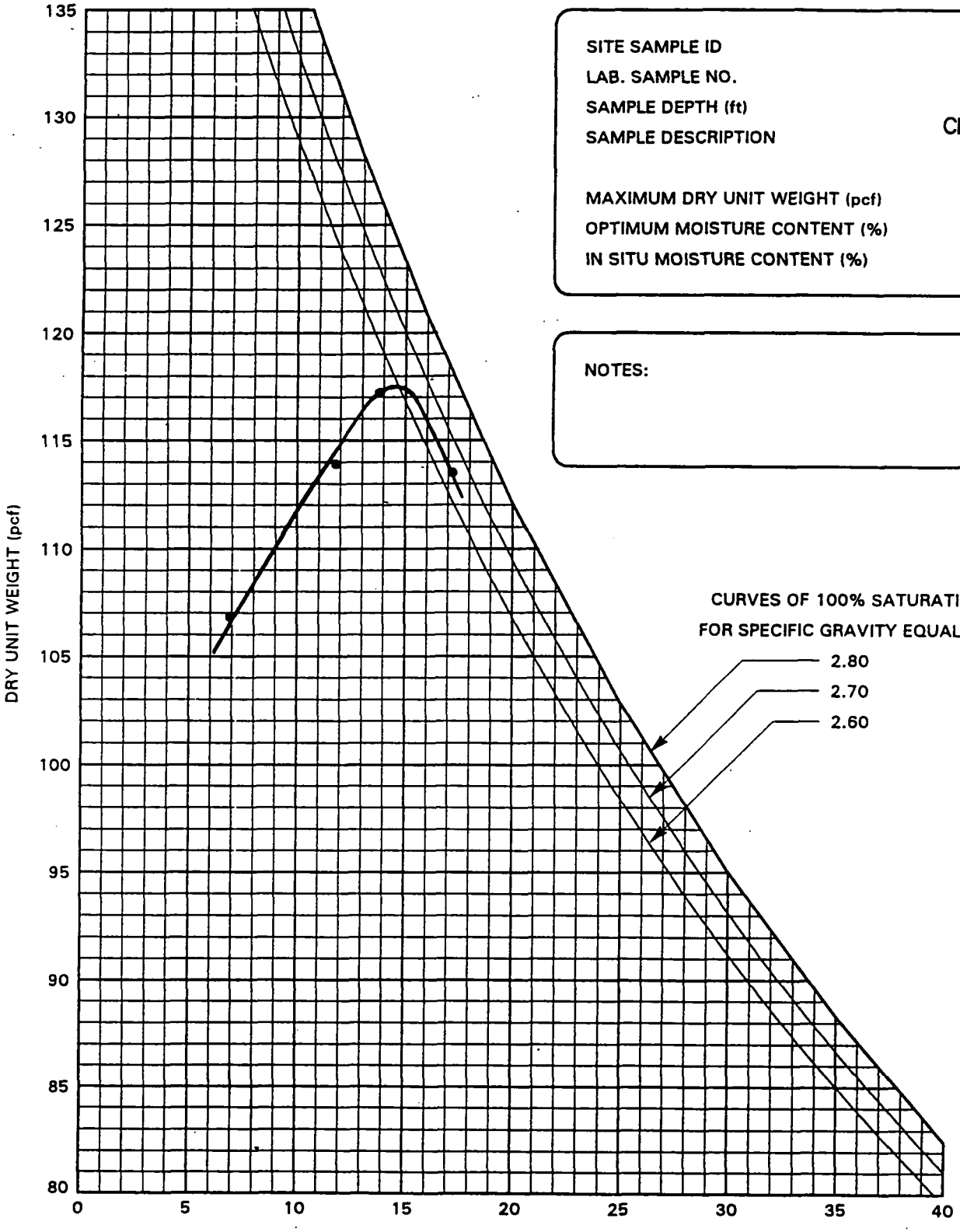
GEO SYNTEC CONSULTANTS
Geomechanics and Environmental Laboratory
Atlanta, Georgia

FIGURE A-2
PROJECT: FERMCO-OSDF
PROJECT NO.: GE3900-9.2
DOCUMENT NO.: F964S006

GS FORM: 4MD1 12/11/95

MOISTURE-DENSITY RELATIONSHIP, COMPACTION TESTING

ASTM D-698-A



SITE SAMPLE ID	AL5291
LAB. SAMPLE NO.	95L17
SAMPLE DEPTH (ft)	
SAMPLE DESCRIPTION	CLAY SOIL
MAXIMUM DRY UNIT WEIGHT (pcf)	117.5
OPTIMUM MOISTURE CONTENT (%)	14.5
IN SITU MOISTURE CONTENT (%)	

NOTES:

000073

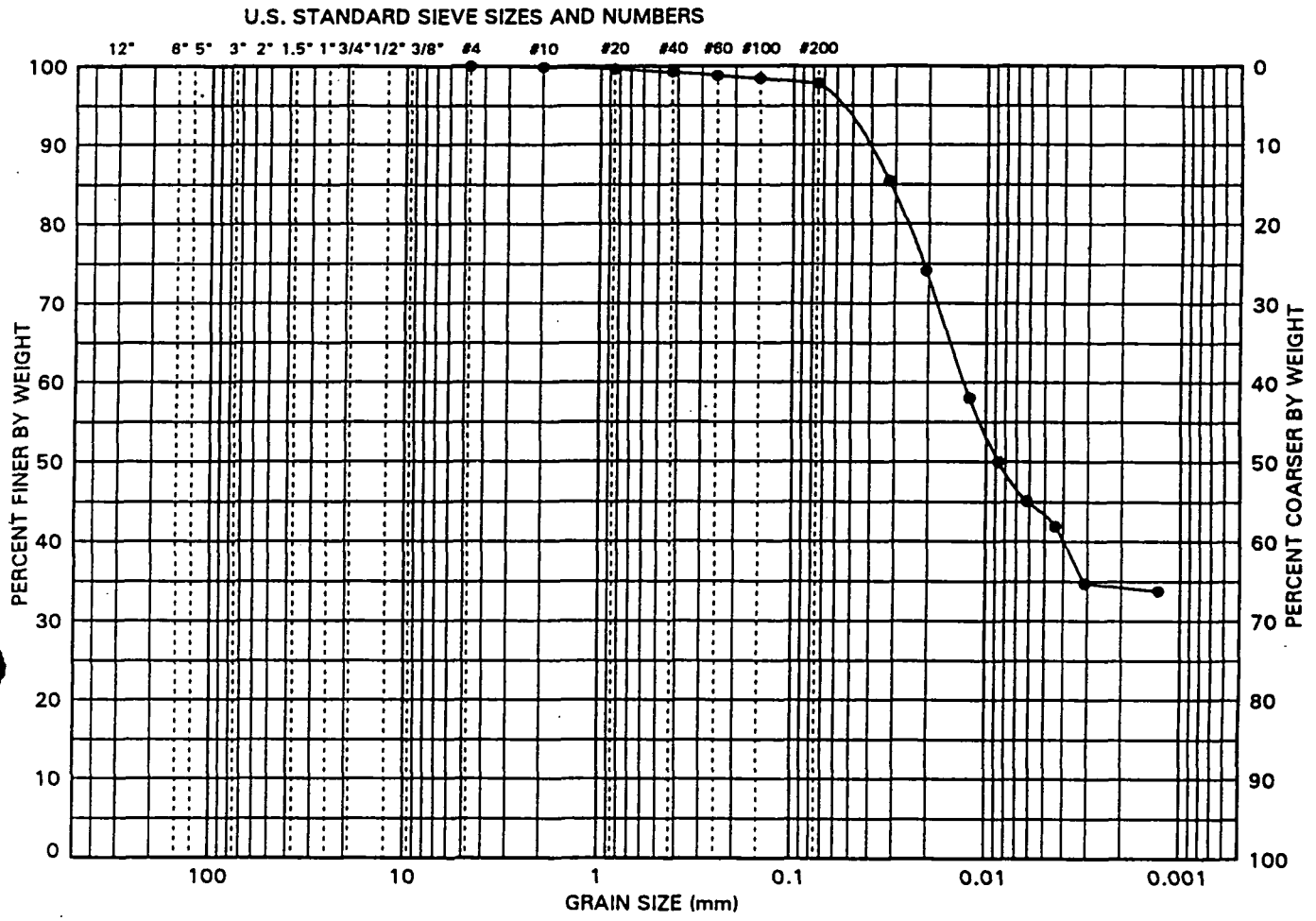
GEO SYNTEC CONSULTANTS
Geomechanics and Environmental Laboratory
Atlanta, Georgia

FIGURE A-3
PROJECT: FERMCO-OSDF
PROJECT NO.: GE3900-9.2
DOCUMENT NO.: F964S006

GS FORM: 4PS2 03/06/96

PARTICLE SIZE DISTRIBUTION AND PHYSICAL PROPERTIES

ASTM C 136, D 422, D 2487 D 3042 AND D 4318



SITE SAMPLE ID	AL5493	LIQUID LIMIT (%)	63
LAB. SAMPLE NO.	96B104	PLASTIC LIMIT (%)	23
SAMPLE DEPTH (ft)		PLASTICITY INDEX	40

SOIL CLASSIFICATION:
CH - Fat Clay

SOIL FRACTIONS	
GRAVEL (%)	0.0
SAND (%)	2.2
FINES (%)	97.8
SILT (%)	63.6
CLAY(%)	34.2
COEFF. UNIFORMITY (Cu)	
COEFF. CURVATURE (Cc)	

PERCENT PASSING U.S. STANDARD SIEVE SIZES AND NUMBERS

3"	2"	1.5"	1"	3/4"	1/2"	3/8"	#4	#10	#20	#40	#60	#100	#200
PERCENT PASSING SIEVE SIZES (mm)													
75	50	37.5	25	19	12.5	9.5	4.75	2.00	0.850	0.425	0.250	0.150	0.075
0	100	100	100	100	100	100	100	100	100	99	99	98	98

PERCENT FINER THAN HYDROMETER PARTICLE DIAMETER (mm)

0.050	0.020	0.005	0.002	0.001
92	73	43	34	

NOTES: SUPPLEMENTAL CLAY SOIL

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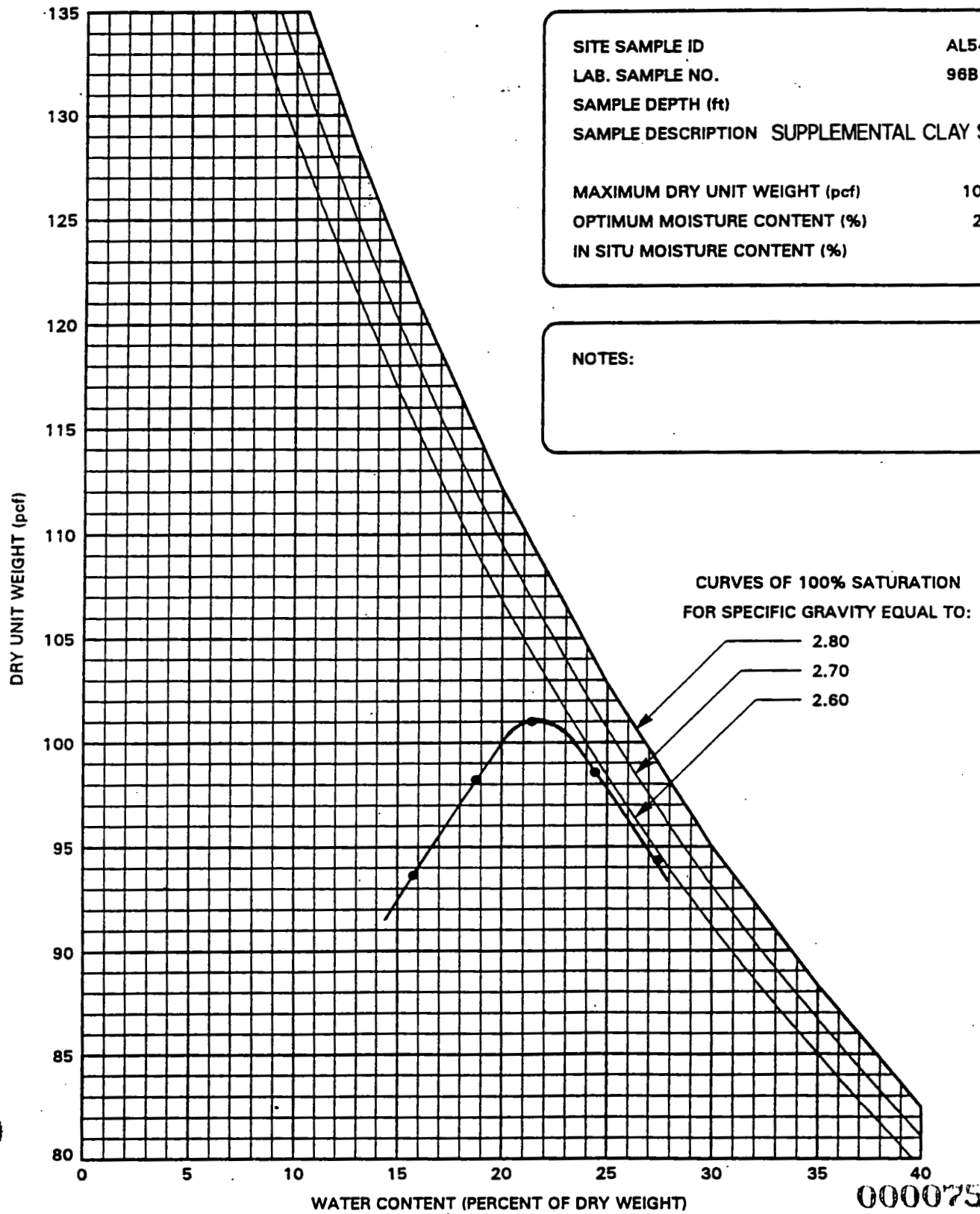
GEO SYNTEC CONSULTANTS
Geomechanics and Environmental Laboratory
Atlanta, Georgia

FIGURE A-4
PROJECT: FERMCO-OSDF
PROJECT NO.: GE3900-9.2
DOCUMENT NO.: F964S006

GS FORM: 4MD1 03/06/96

MOISTURE-DENSITY RELATIONSHIP, COMPACTION TESTING

ASTM D-698-B



SITE SAMPLE ID	AL5493
LAB. SAMPLE NO.	96B104
SAMPLE DEPTH (ft)	
SAMPLE DESCRIPTION	SUPPLEMENTAL CLAY SOIL
MAXIMUM DRY UNIT WEIGHT (pcf)	101.0
OPTIMUM MOISTURE CONTENT (%)	21.7
IN SITU MOISTURE CONTENT (%)	

NOTES:

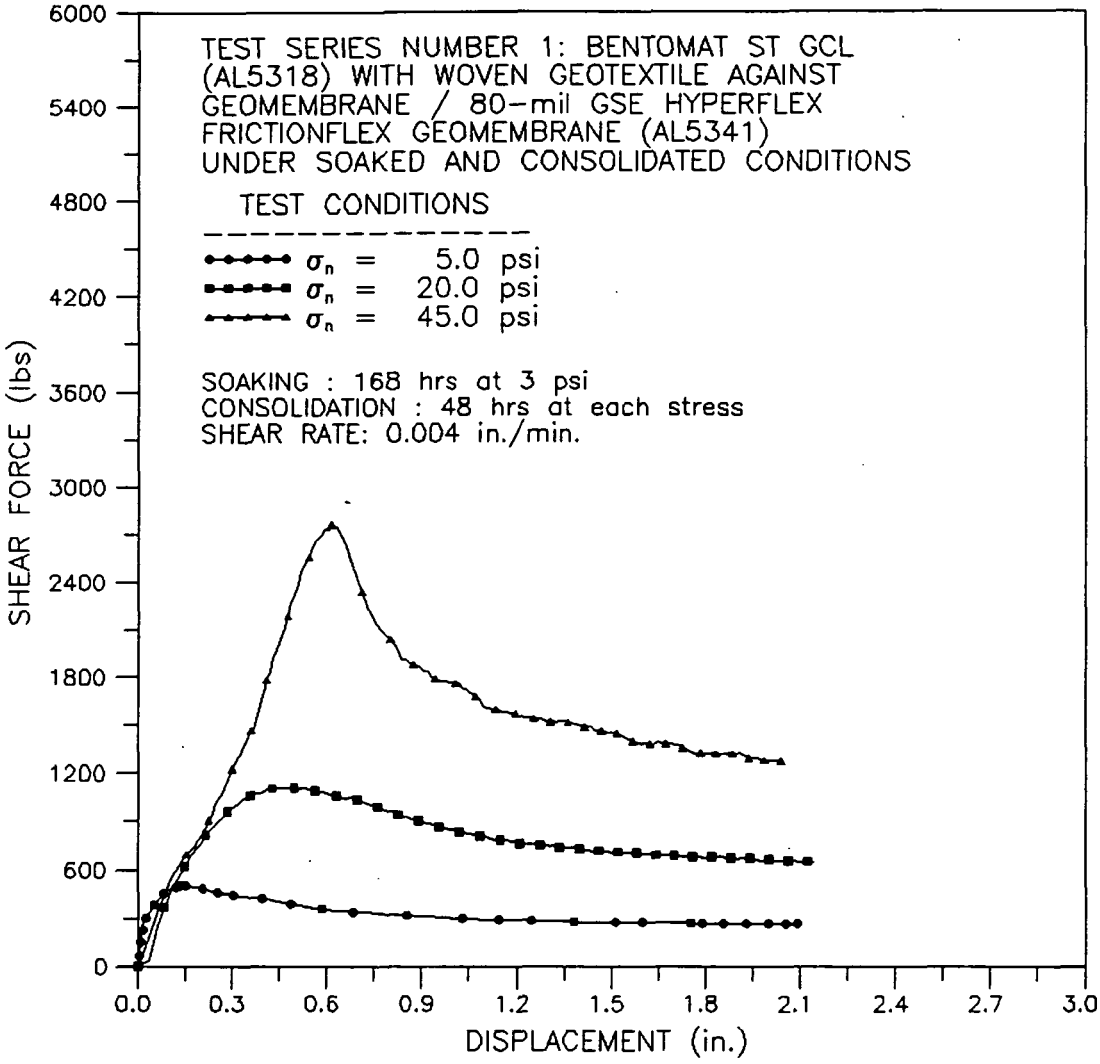
000075

APPENDIX B

APPENDIX B

DIRECT SHEAR TEST RESULTS

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTE: The shear box size was 12 in. by 12 in. (300 mm by 300 mm), and the contact area remained constant throughout the entire test.

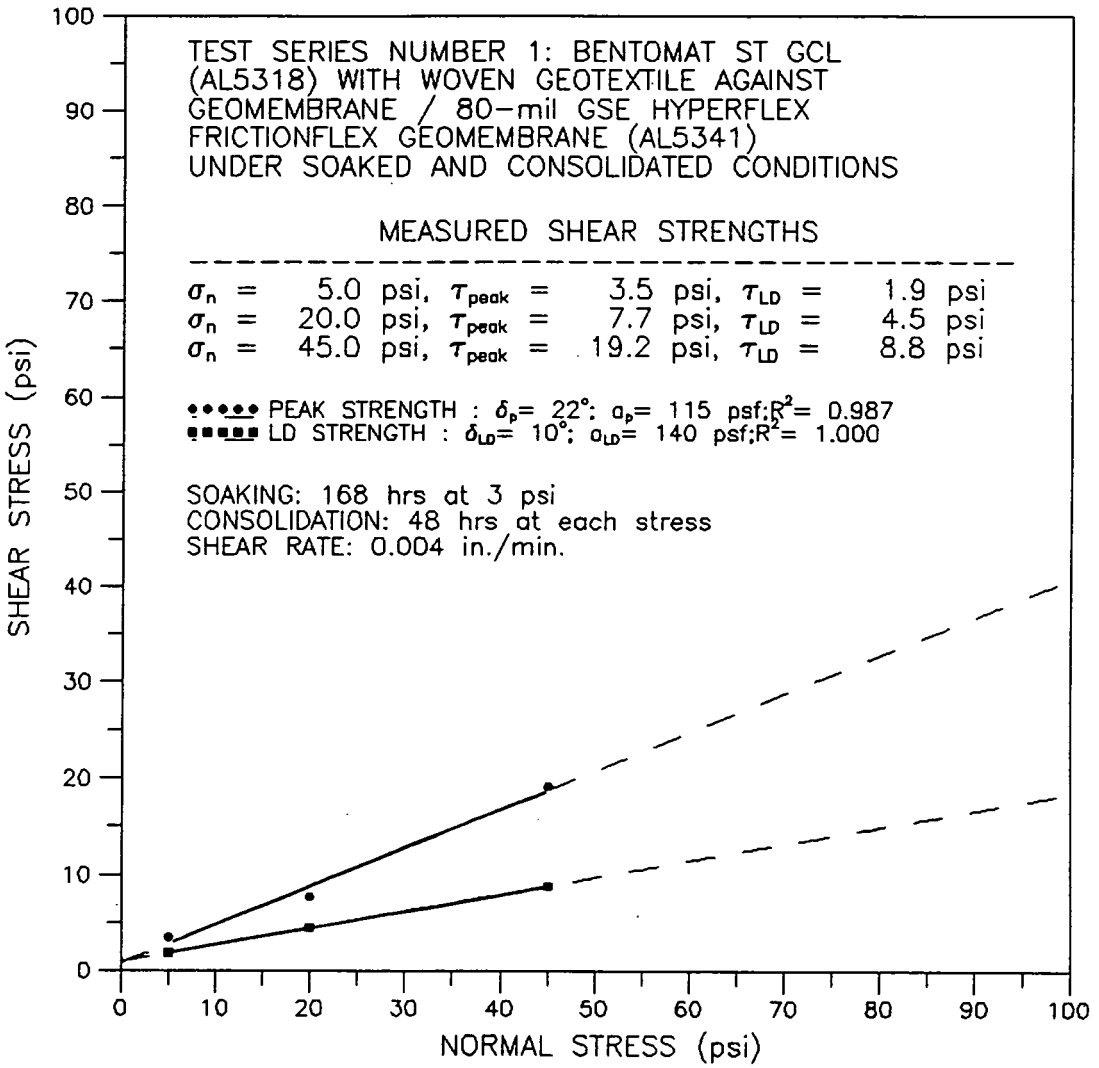
DATE TESTED: 5 TO 15 FEBRUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-1
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	G68077

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTES: (1) The reported total-stress shear strength parameters of friction angle and adhesion may not reflect the true shear strength of the interface, and caution should be exercised in using these shear strength parameters for applications involving normal stresses outside the range of stresses covered by the test.

(2) The large displacement shear strength (τ_{LD}) was calculated using the post-peak shear force measured at the end of each test.

000078

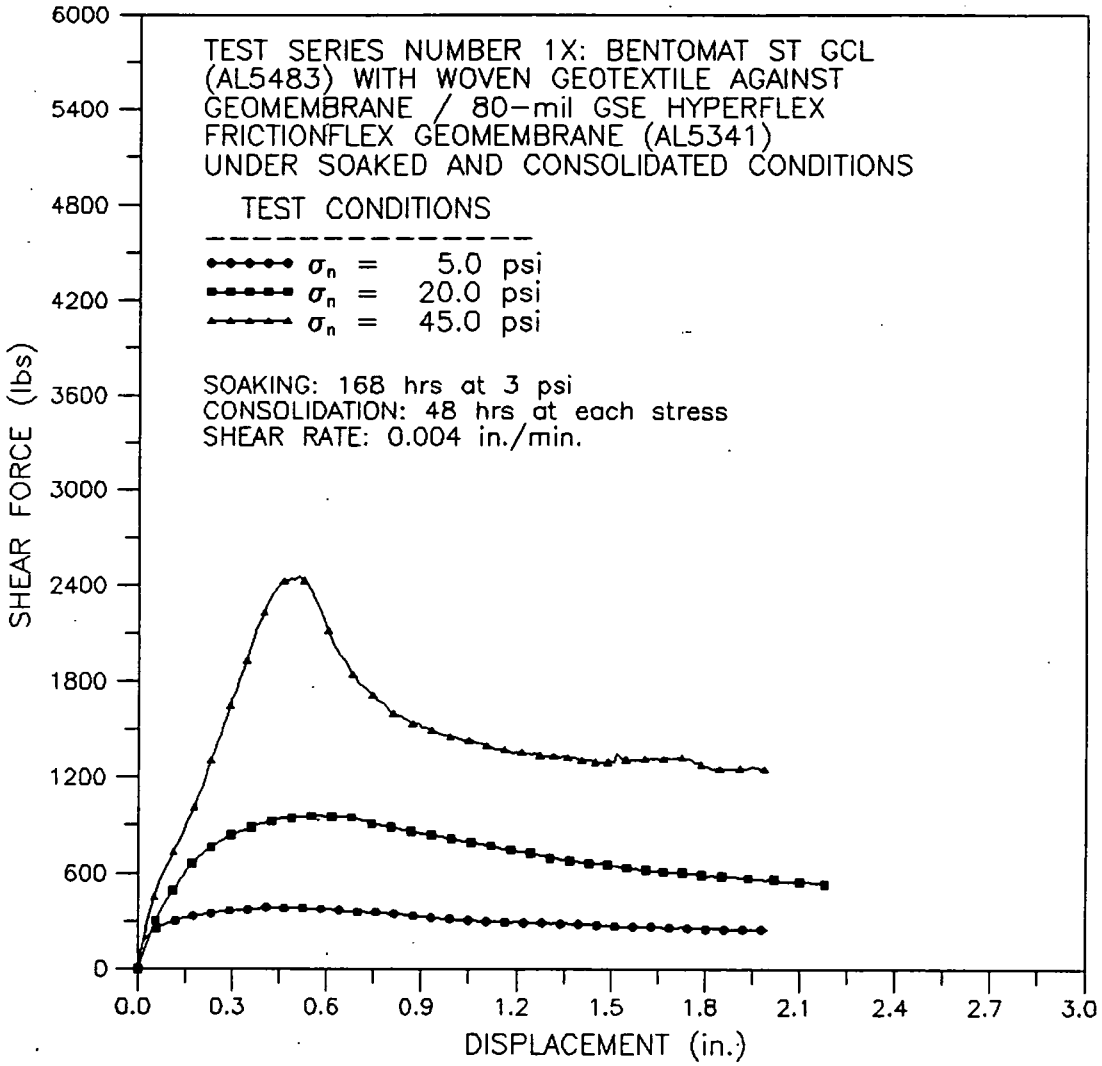
DATE TESTED: 5 TO 15 FEBRUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-2
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTE: The shear box size was 12 in. by 12 in.(300 mm by 300 mm), and the contact area remained constant throughout the entire test.

000079

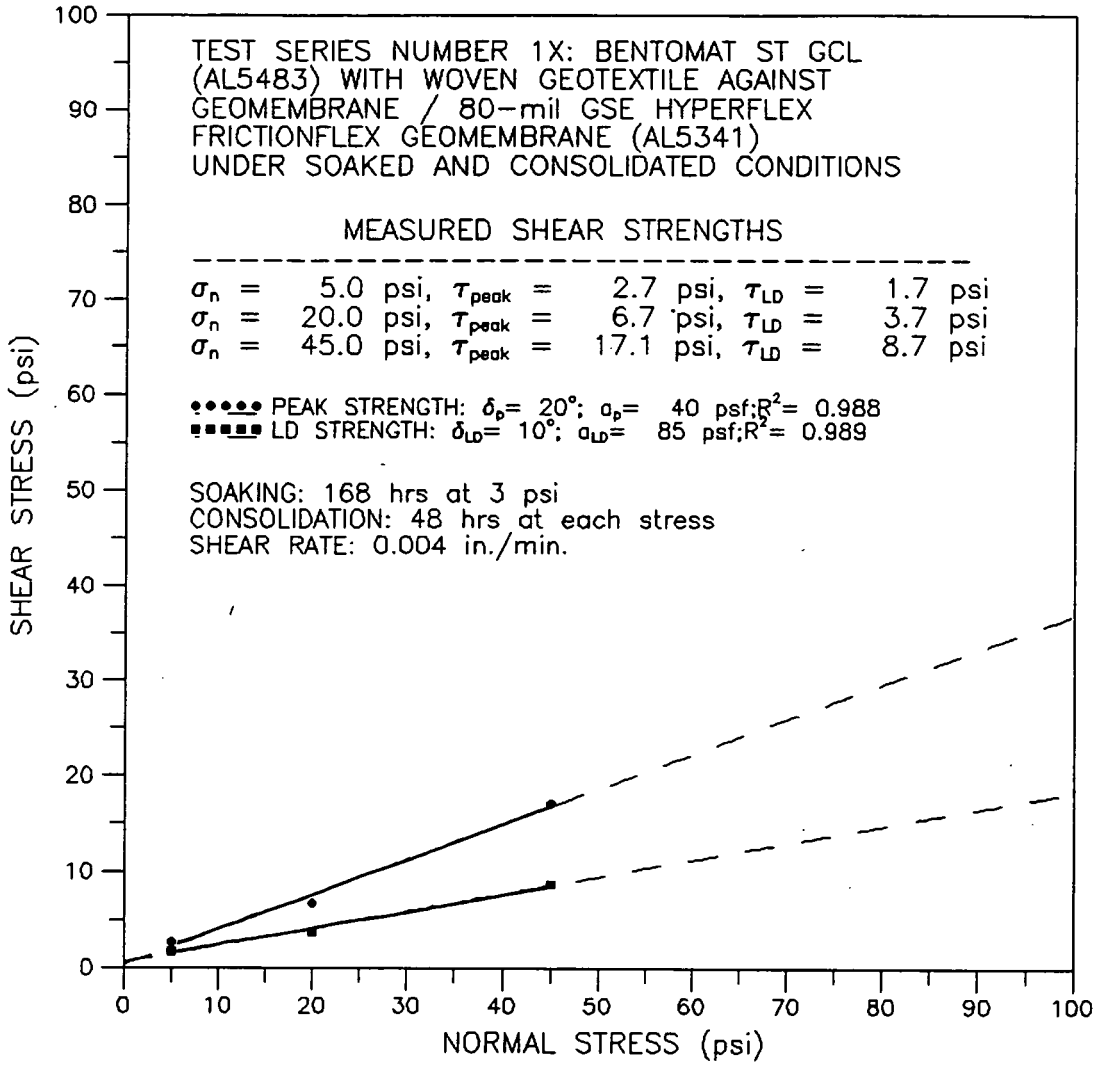
DATE TESTED: 20 FEBRUARY TO 1 MARCH 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-3
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTES: (1) The reported total-stress shear strength parameters of friction angle and adhesion may not reflect the true shear strength of the interface, and caution should be exercised in using these shear strength parameters for applications involving normal stresses outside the range of stresses covered by the test.

(2) The large displacement shear strength (τ_{LD}) was calculated using the post-peak shear force measured at the end of each test.

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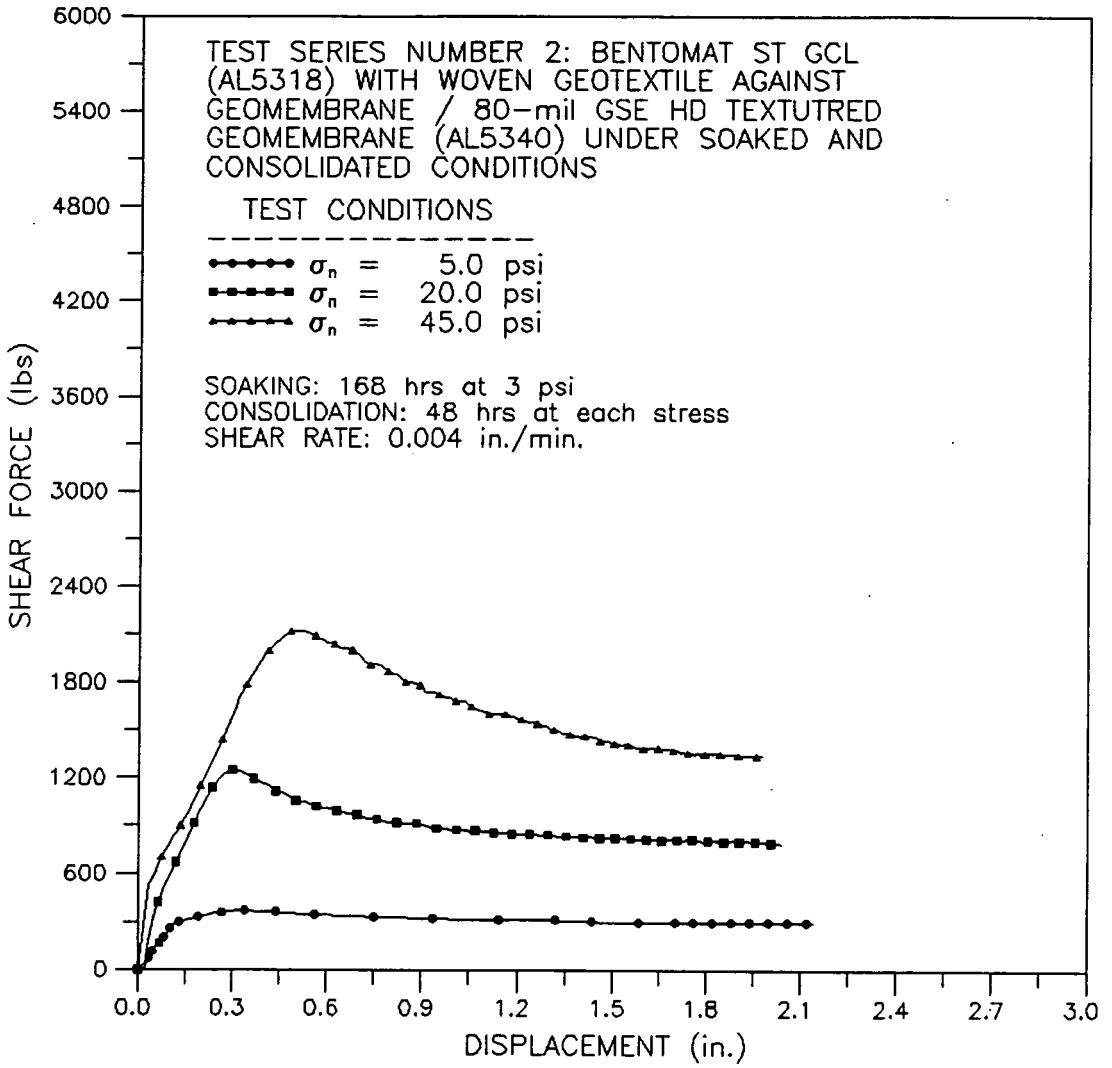
DATE TESTED: 20 FEBRUARY TO 1 MARCH 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-4
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTE: The shear box size was 12 in. by 12 in. (300 mm by 300 mm), and the contact area remained constant throughout the entire test.

000081

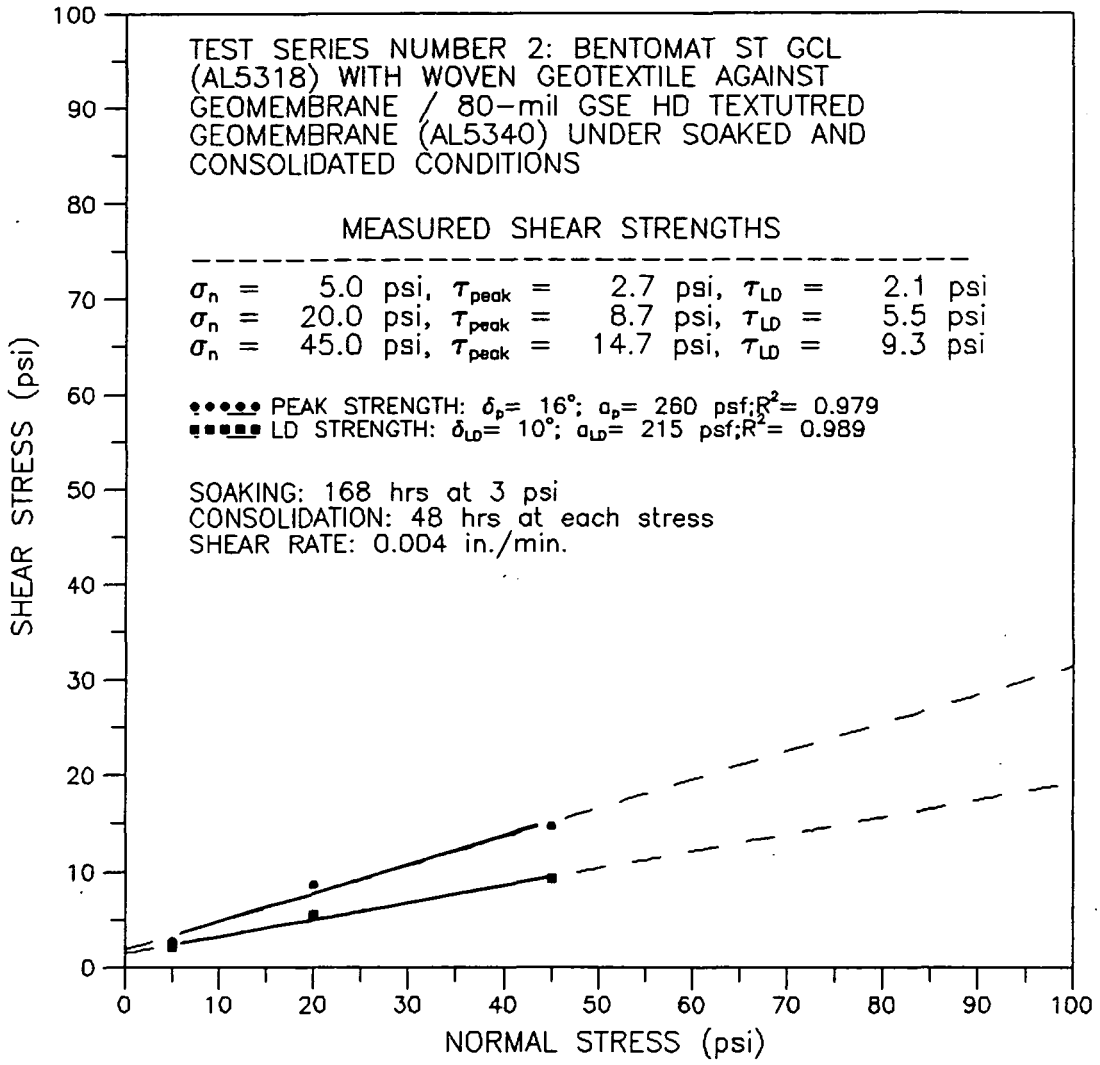
DATE TESTED: 7 TO 17 JANUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-5
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTES: (1) The reported total-stress shear strength parameters of friction angle and adhesion may not reflect the true shear strength of the interface, and caution should be exercised in using these shear strength parameters for applications involving normal stresses outside the range of stresses covered by the test.

(2) The large displacement shear strength (τ_{LD}) was calculated using the post-peak shear force measured at the end of each test.

000082

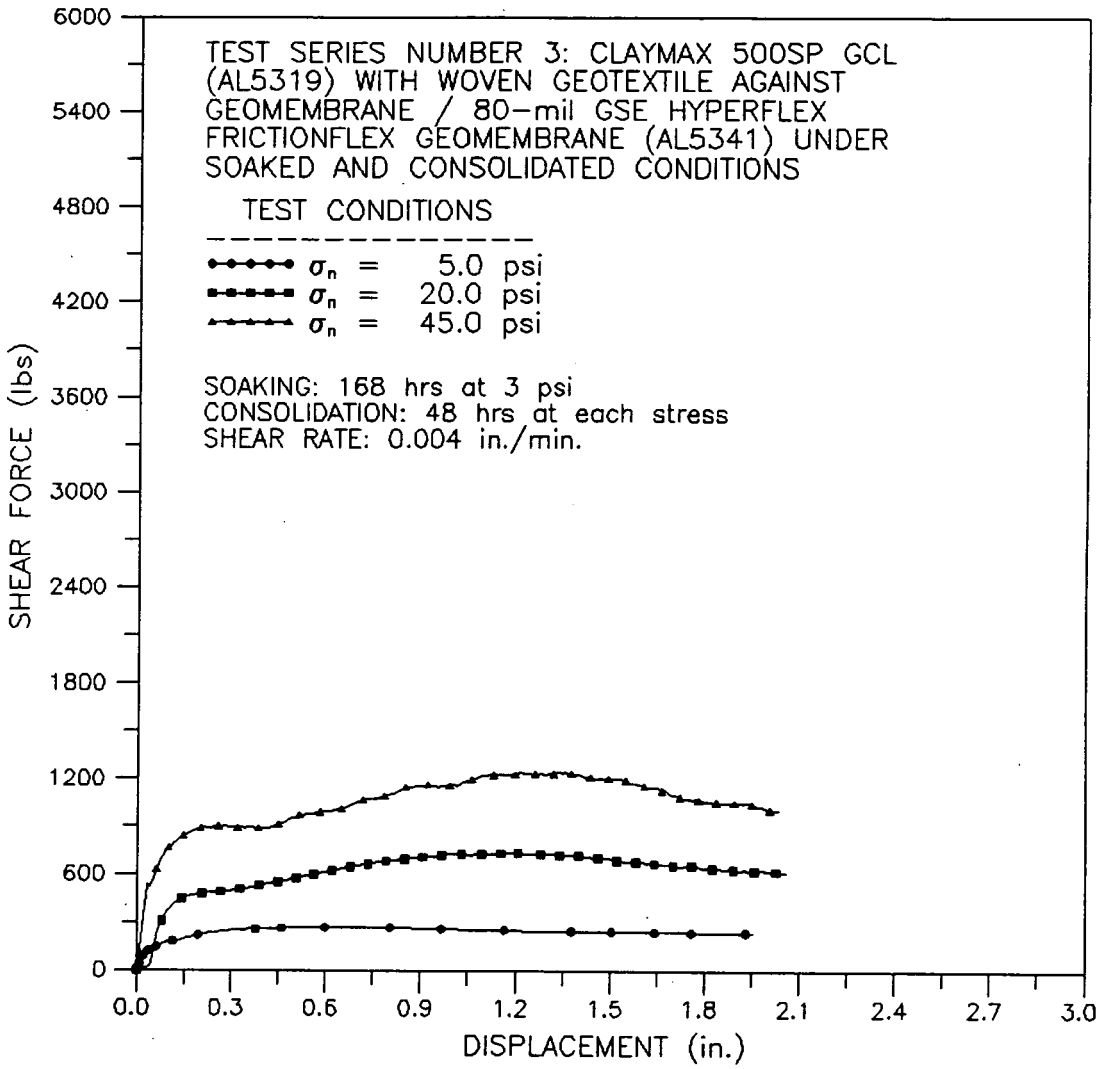
DATE TESTED: 7 TO 17 JANUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-6
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTE: The shear box size was 12 in. by 12 in. (300 mm by 300 mm), and the contact area remained constant throughout the entire test.

DATE TESTED: 9 TO 19 JANUARY 1996

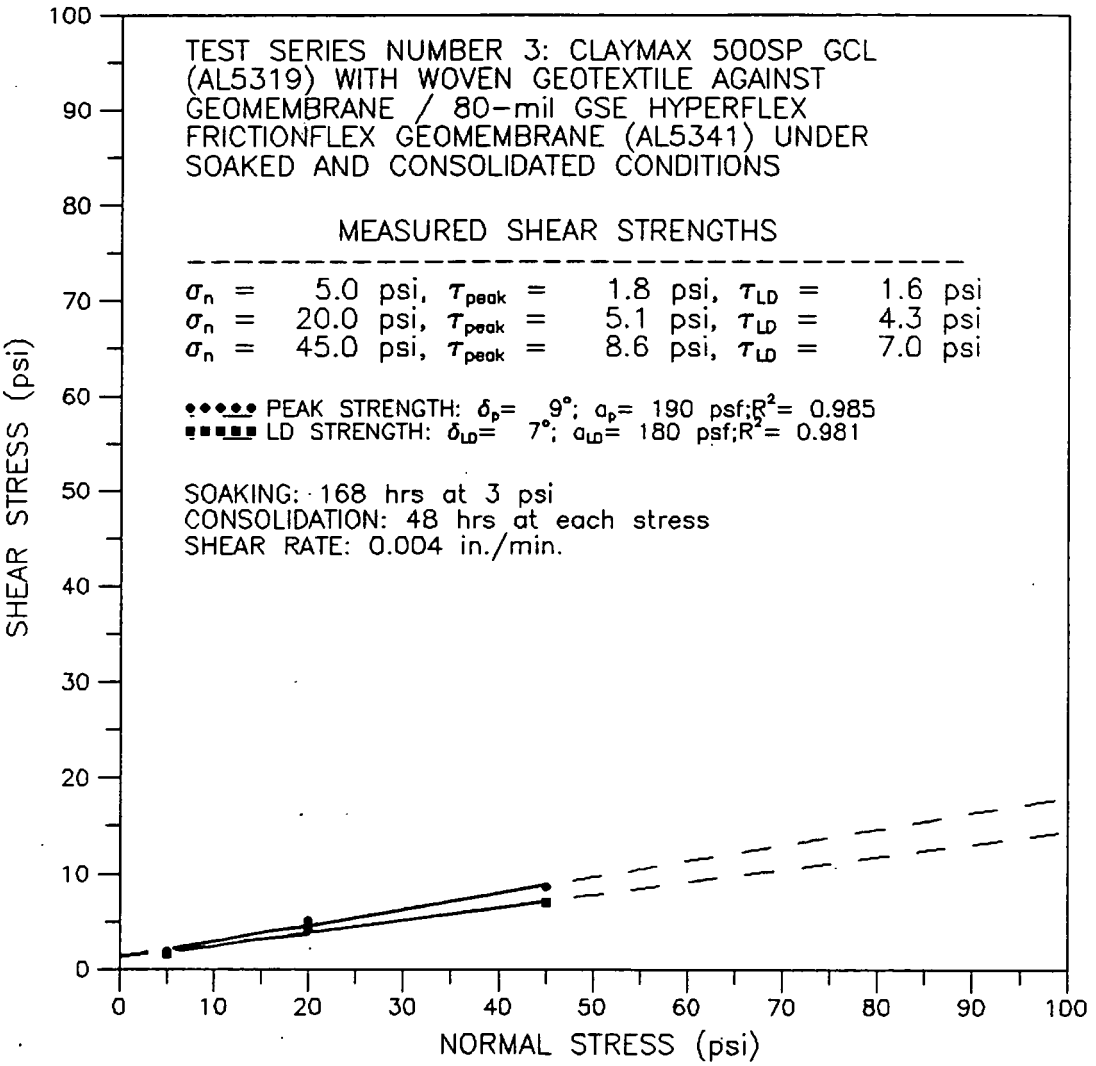
000083

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-7
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTES: (1) The reported total-stress shear strength parameters of friction angle and adhesion may not reflect the true shear strength of the interface, and caution should be exercised in using these shear strength parameters for applications involving normal stresses outside the range of stresses covered by the test.

(2) The large displacement shear strength (τ_{LD}) was calculated using the post-peak shear force measured at the end of each test.

000084

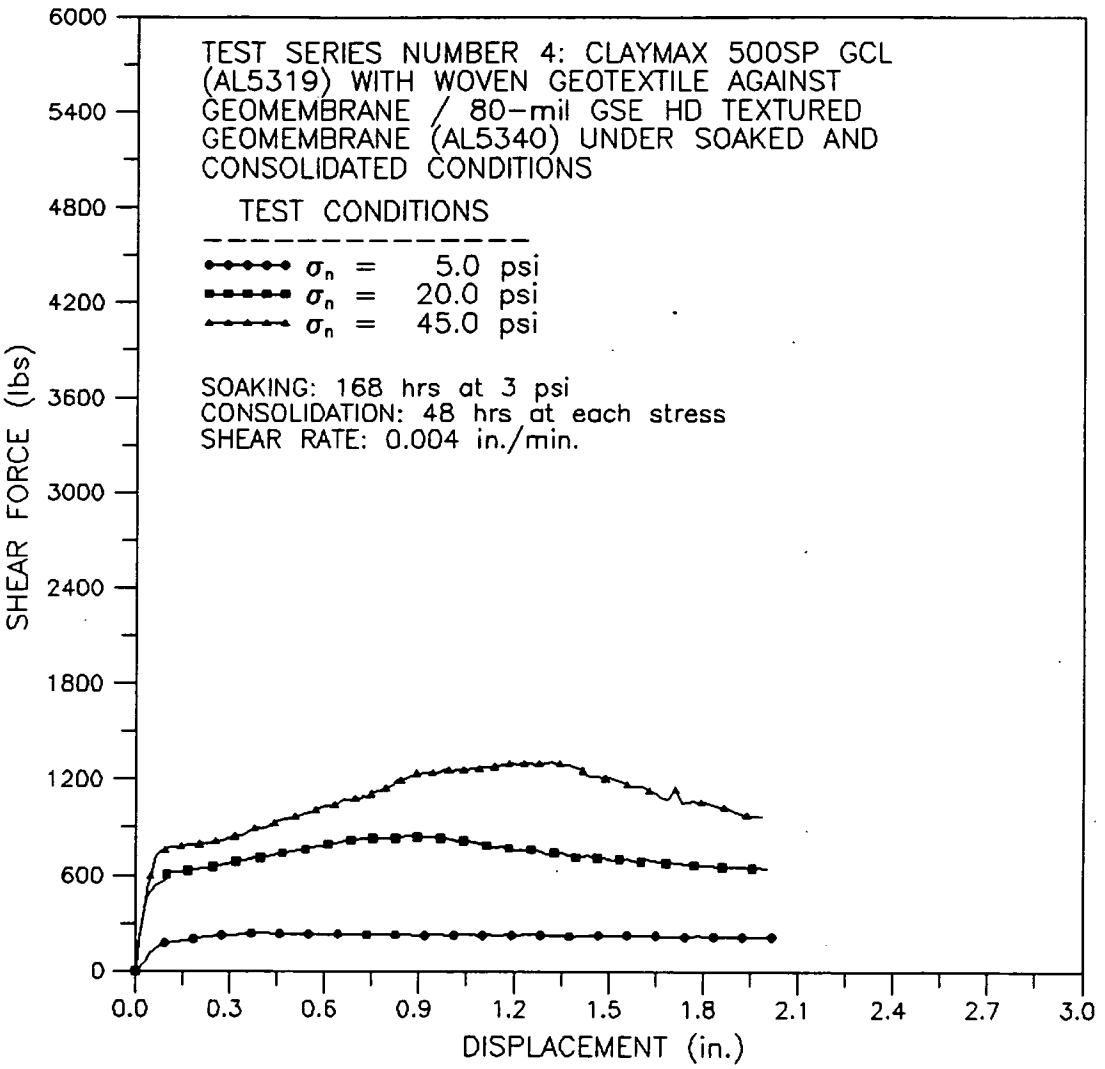
DATE TESTED: 9 TO 19 JANUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-8
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTE: The shear box size was 12 in. by 12 in. (300 mm by 300 mm), and the contact area remained constant throughout the entire test.

000085

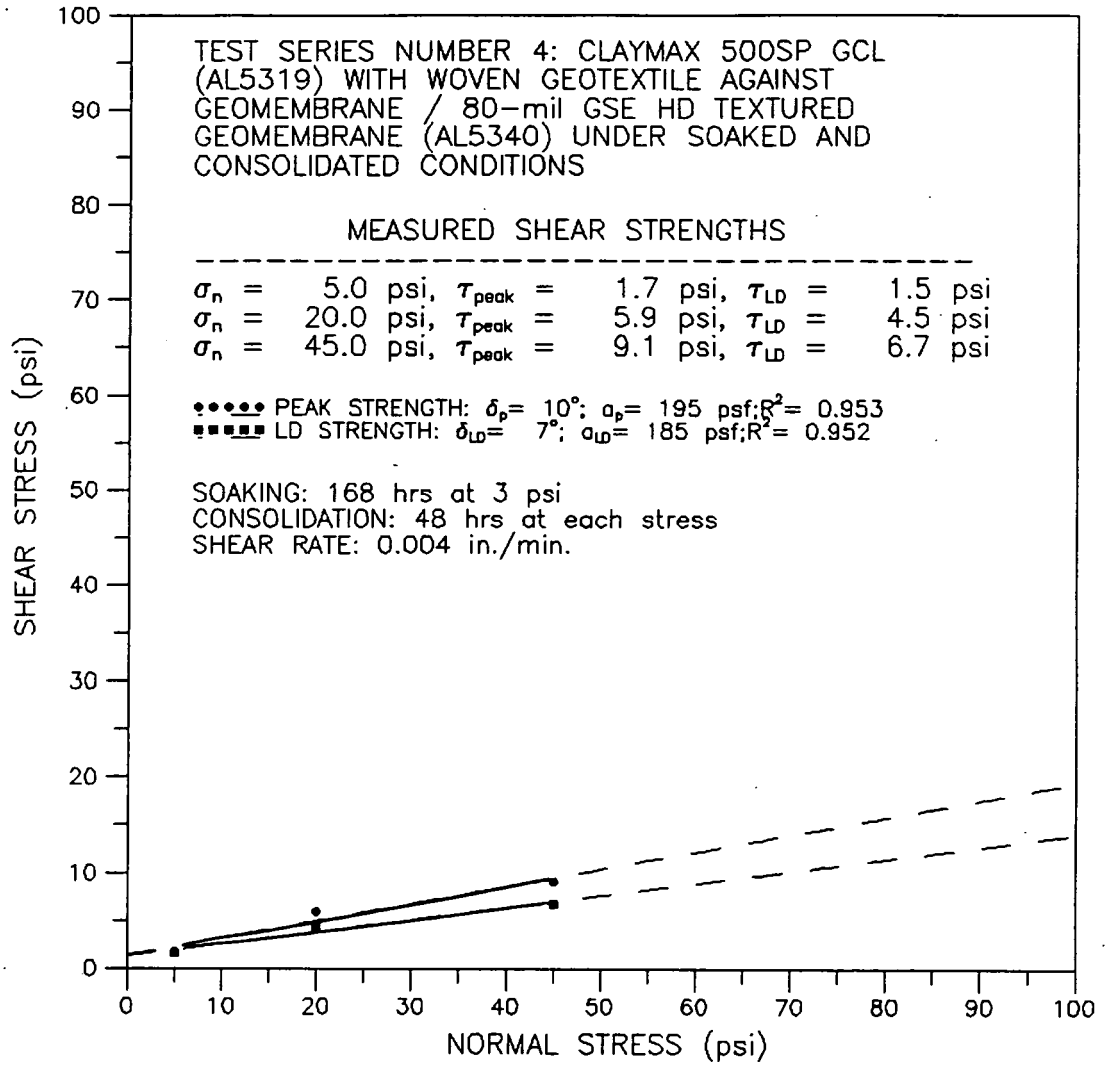
DATE TESTED: 12 TO 22 JANUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-9
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTES: (1) The reported total-stress shear strength parameters of friction angle and adhesion may not reflect the true shear strength of the interface, and caution should be exercised in using these shear strength parameters for applications involving normal stresses outside the range of stresses covered by the test.

(2) The large displacement shear strength (τ_{LD}) was calculated using the post-peak shear force measured at the end of each test.

000086

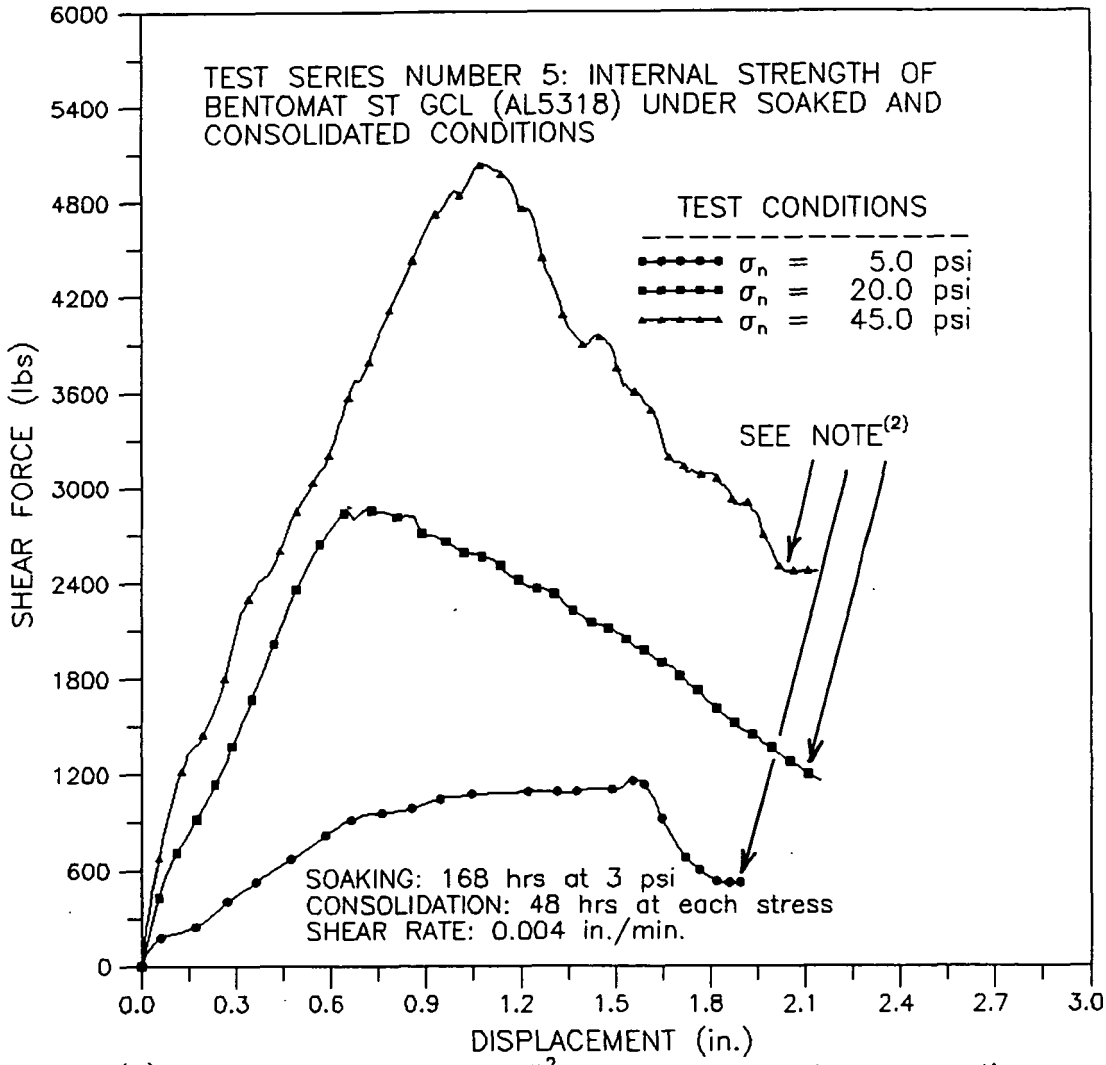
DATE TESTED: 12 TO 22 JANUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-10
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
DIRECT SHEAR TESTING



NOTES: (1) A constant area of 1 ft^2 was assumed when computing normal and shear stresses.

(2) Sliding (i.e., shear failure) was observed to involve both internal shear within the GCL and tensile rupture of the nonwoven geotextile.

000087

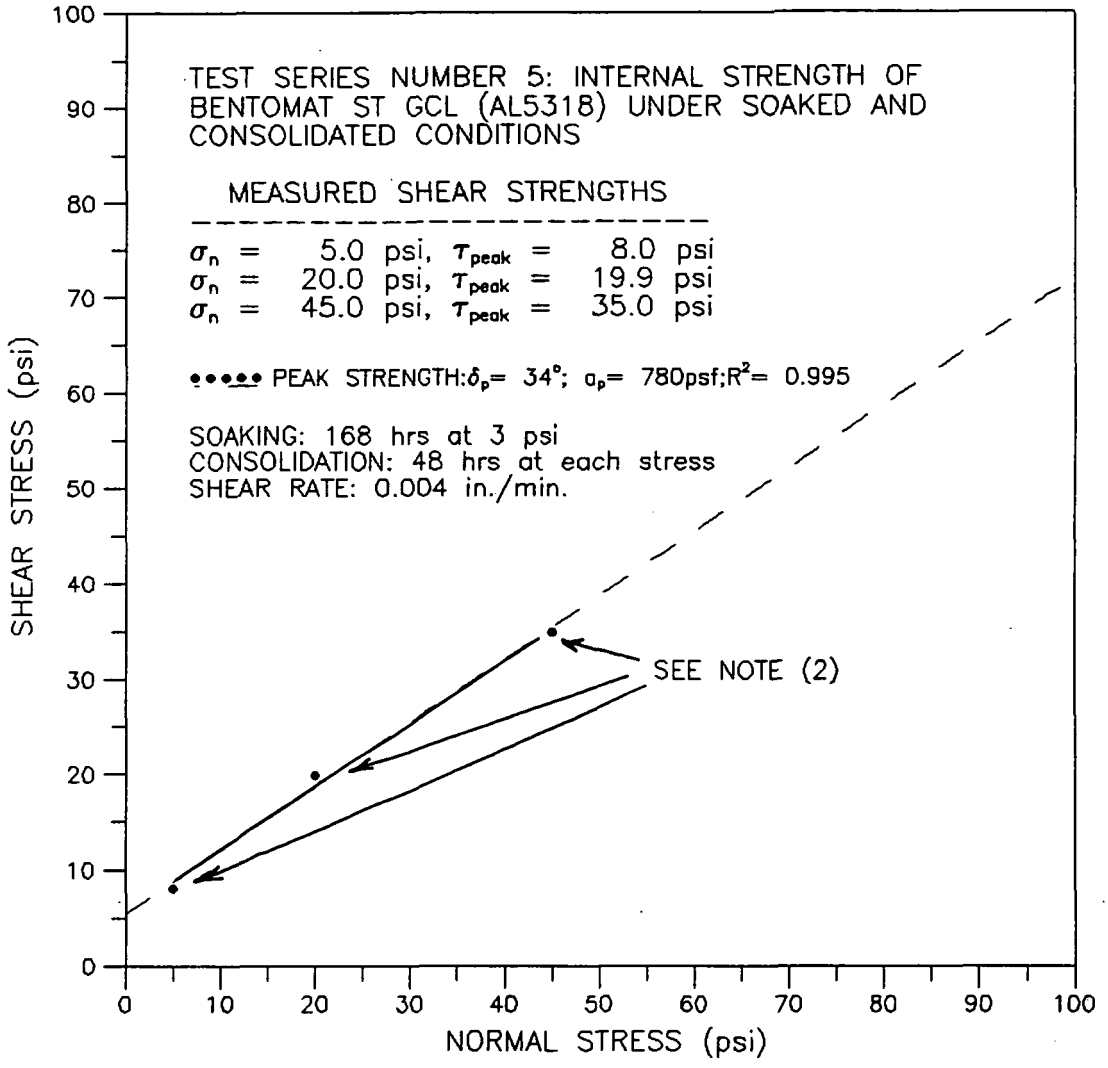
DATE TESTED: 26 JANUARY TO 5 FEBRUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-11
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	SGI96064
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
DIRECT SHEAR TESTING



NOTES: (1) The reported total-stress shear strength parameters of friction angle and adhesion may not reflect the true shear strength of the GCL, and caution should be exercised in using these shear strength parameters for applications involving normal stresses outside the range of stresses covered by the test.

(2) Sliding (i.e., shear failure was observed to invlove both internal shear within the GCL and tensile rupture of the nonwoven geotextile. Accordingly, large displacement shear strength (τ_{LD}) were not calculated.

000088

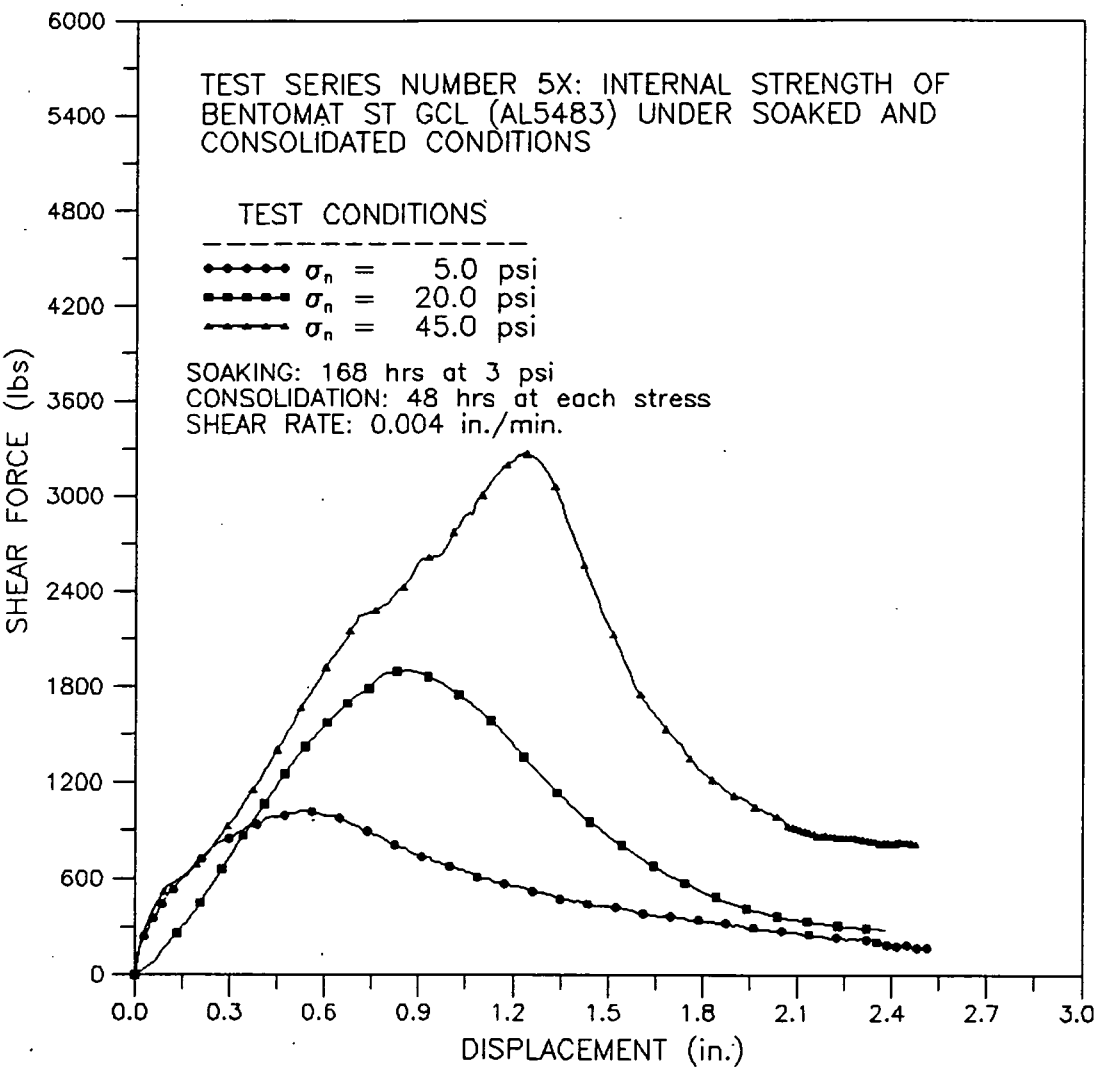
DATE TESTED: 26 JANUARY TO 5 FEBRUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-12
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
DIRECT SHEAR TESTING



NOTE: A constant area of 1 ft^2 was assumed when computing normal and shear stresses.

000089

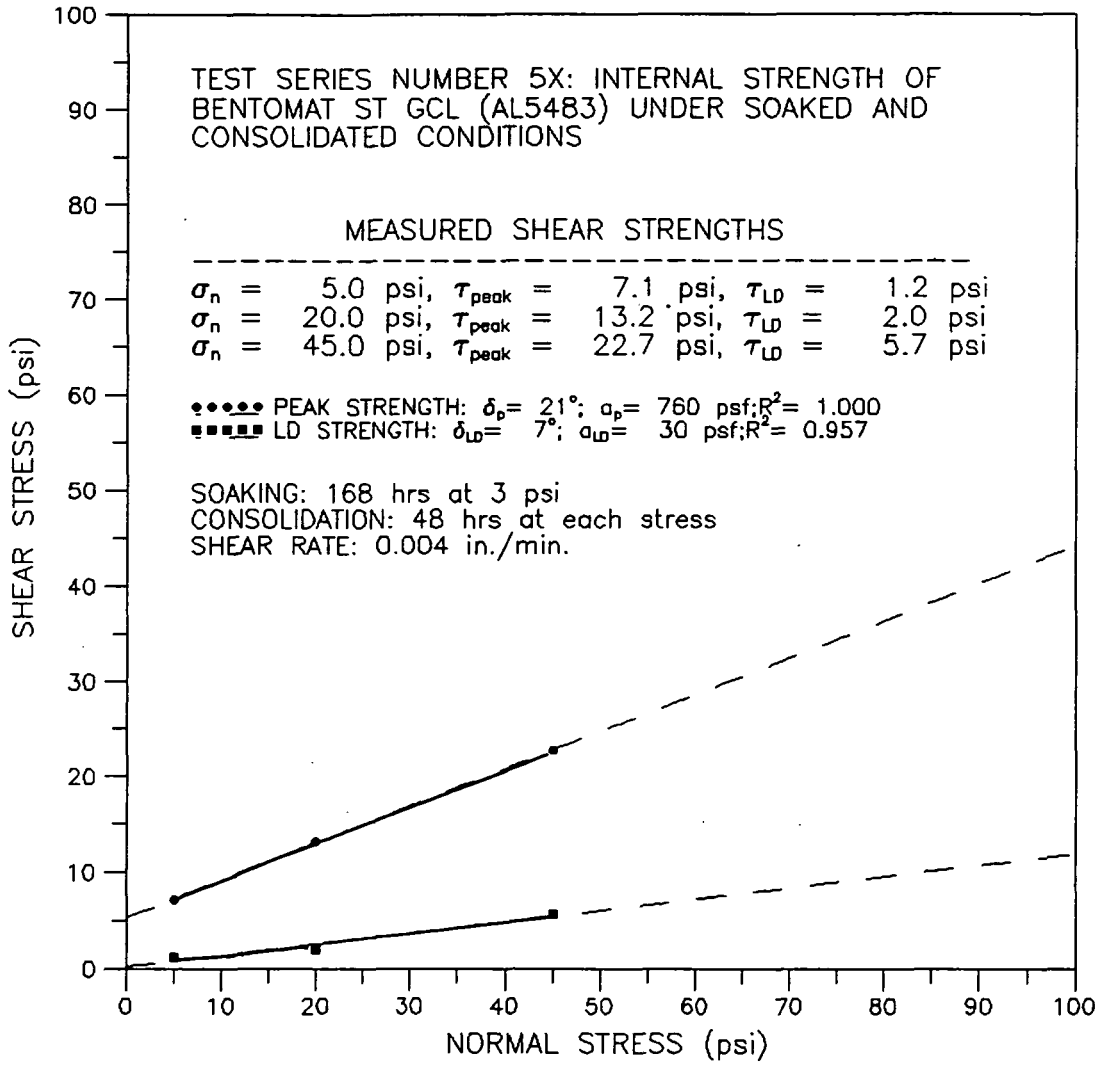
DATE TESTED: 23 FEBRUARY TO 4 MARCH 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-13
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
DIRECT SHEAR TESTING



NOTES: (1) The reported total-stress shear strength parameters of friction angle and adhesion may not reflect the true shear strength of the GCL, and caution should be exercised in using these shear strength parameters for applications involving normal stresses outside the range of stresses covered by the test.

(2) The large displacement shear strength (τ_{LD}) was calculated using the post-peak shear force measured at the end of each test.

000090

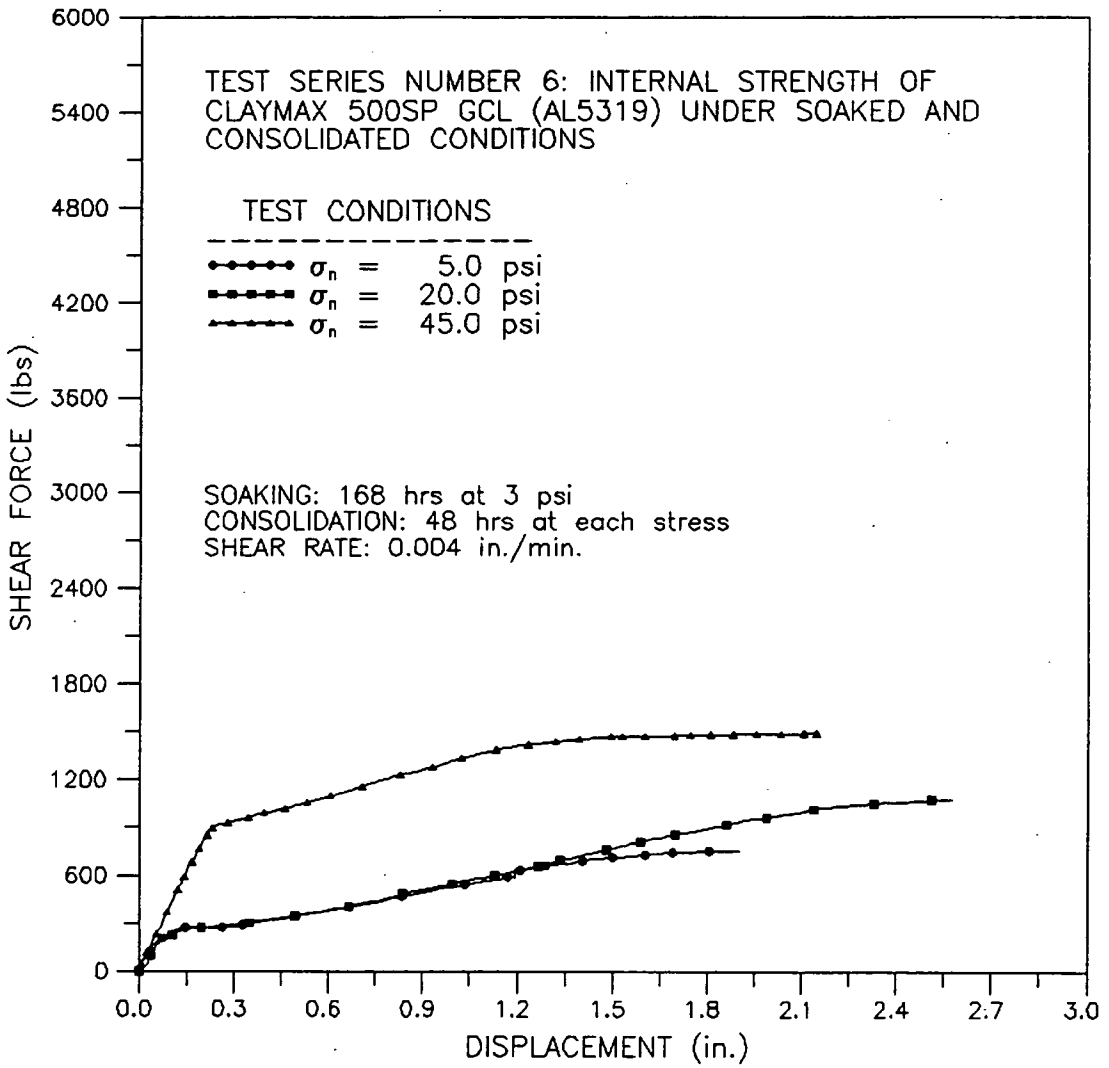
DATE TESTED: 23 FEBRUARY TO 4 MARCH 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-14
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
DIRECT SHEAR TESTING



NOTE: A constant area of 1 ft^2 was assumed when computing normal and shear stresses.

000091

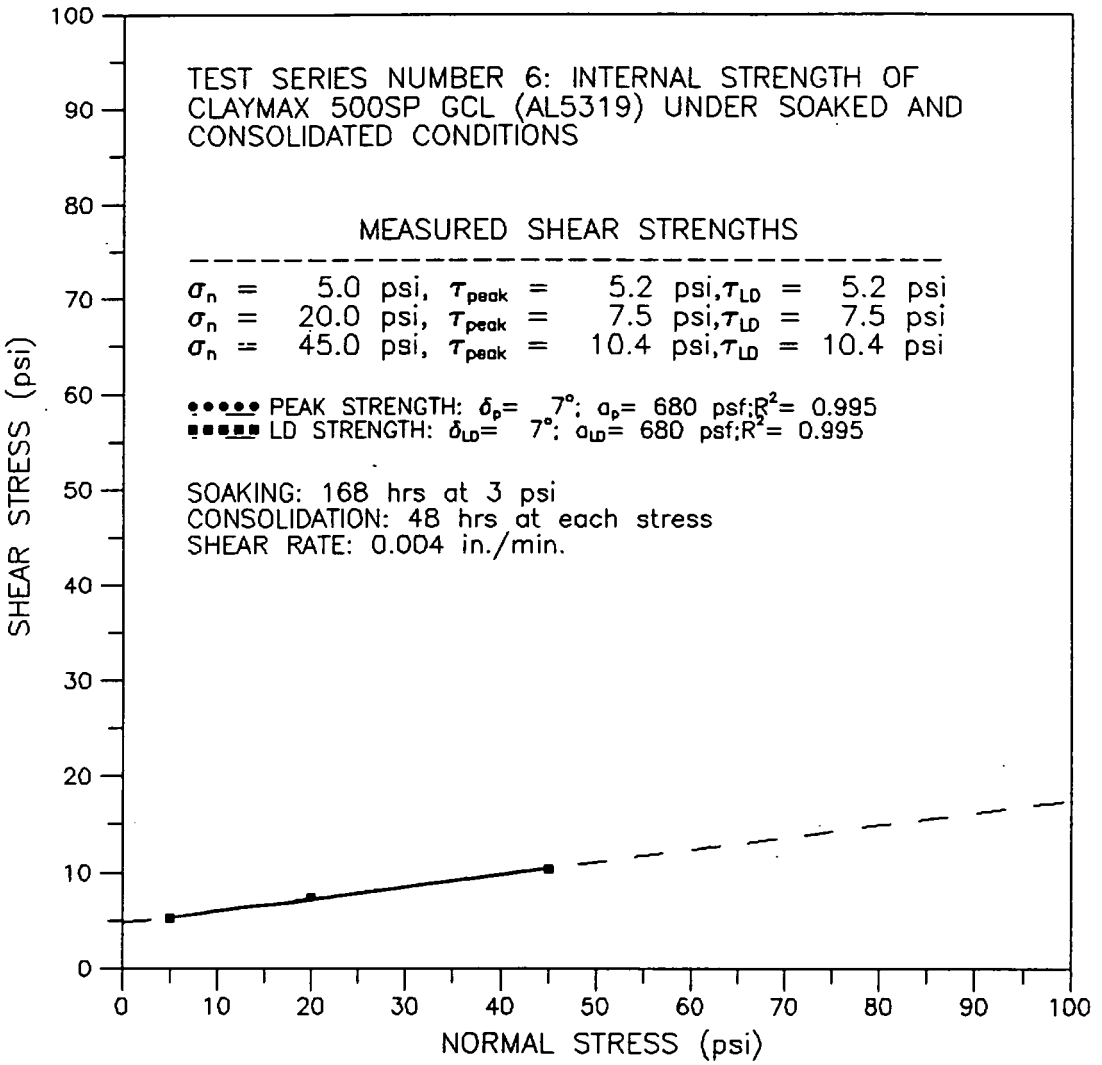
DATE TESTED: 16 JANUARY TO 26 MARCH 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-15
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
DIRECT SHEAR TESTING



NOTES: (1) The reported total-stress shear strength parameters of friction angle and adhesion may not reflect the true shear strength of the interface, and caution should be exercised in using these shear strength parameters for applications involving normal stresses outside the range of stresses covered by the test.

(2) The large displacement shear strength (τ_{LD}) was calculated using the post-peak shear force measured at the end of each test.

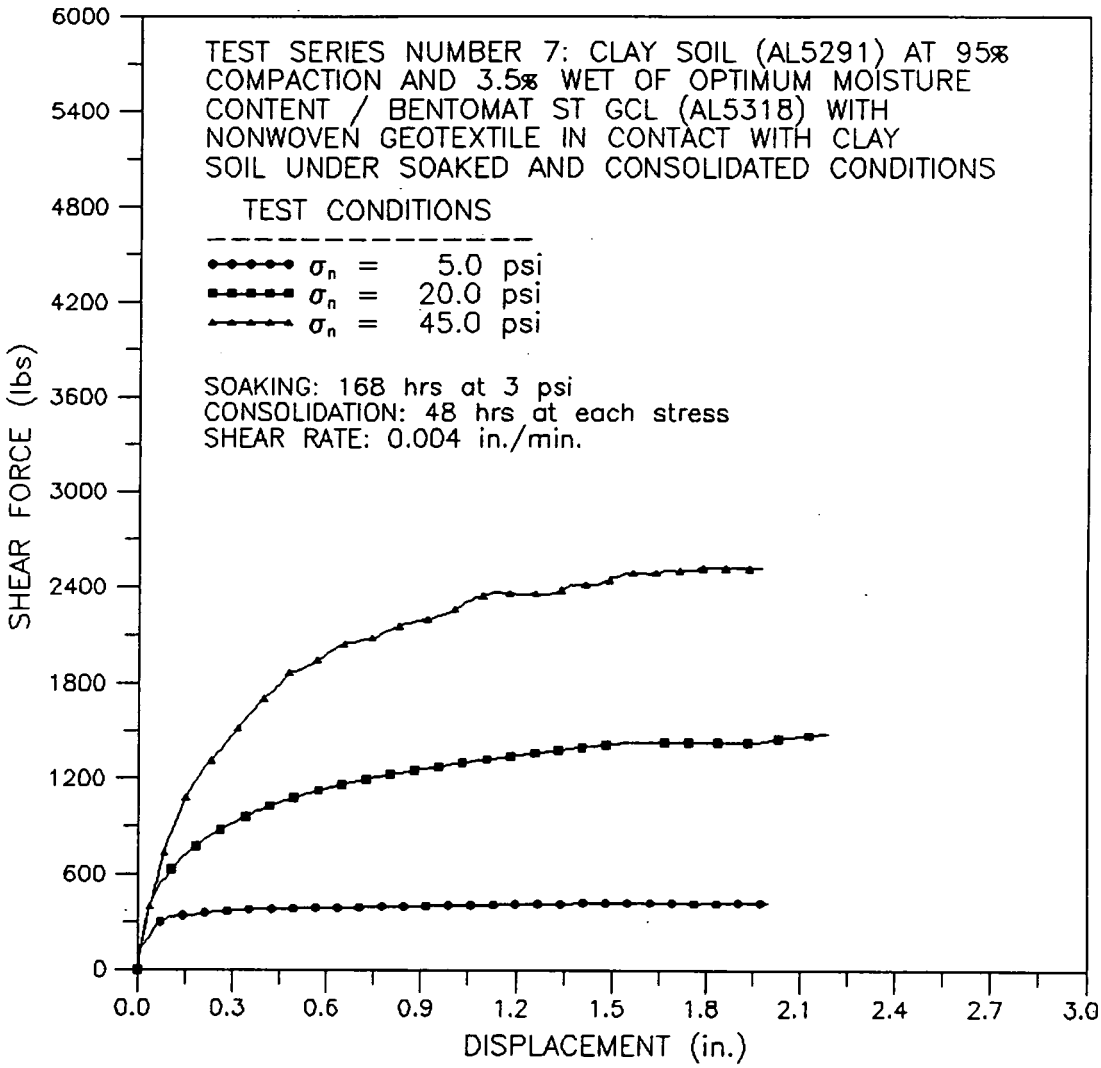
DATE TESTED: 16 JANUARY TO 26 MARCH 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-16
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTE: The shear box size was 12 in. by 12 in. (300 mm by 300 mm), and the contact area remained constant throughout the entire test.

000093

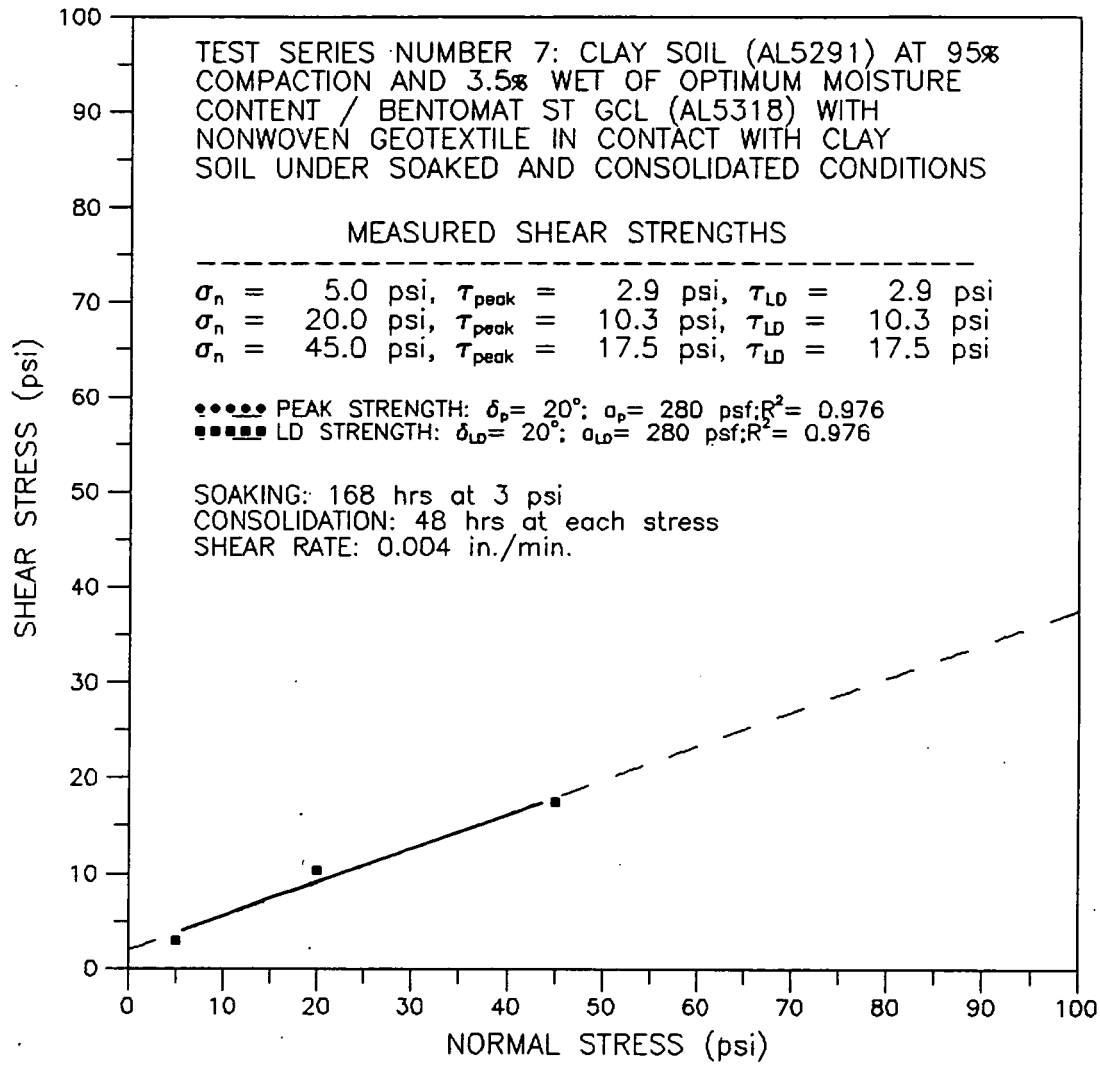
DATE TESTED: 19 JANUARY TO 29 MARCH 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-17
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTES: (1) The reported total-stress shear strength parameters of friction angle and adhesion may not reflect the true shear strength of the interface, and caution should be exercised in using these shear strength parameters for applications involving normal stresses outside the range of stresses covered by the test.

(2) The large displacement shear strength (τ_{LD}) was calculated using the post-peak shear force measured at the end of each test.

000094

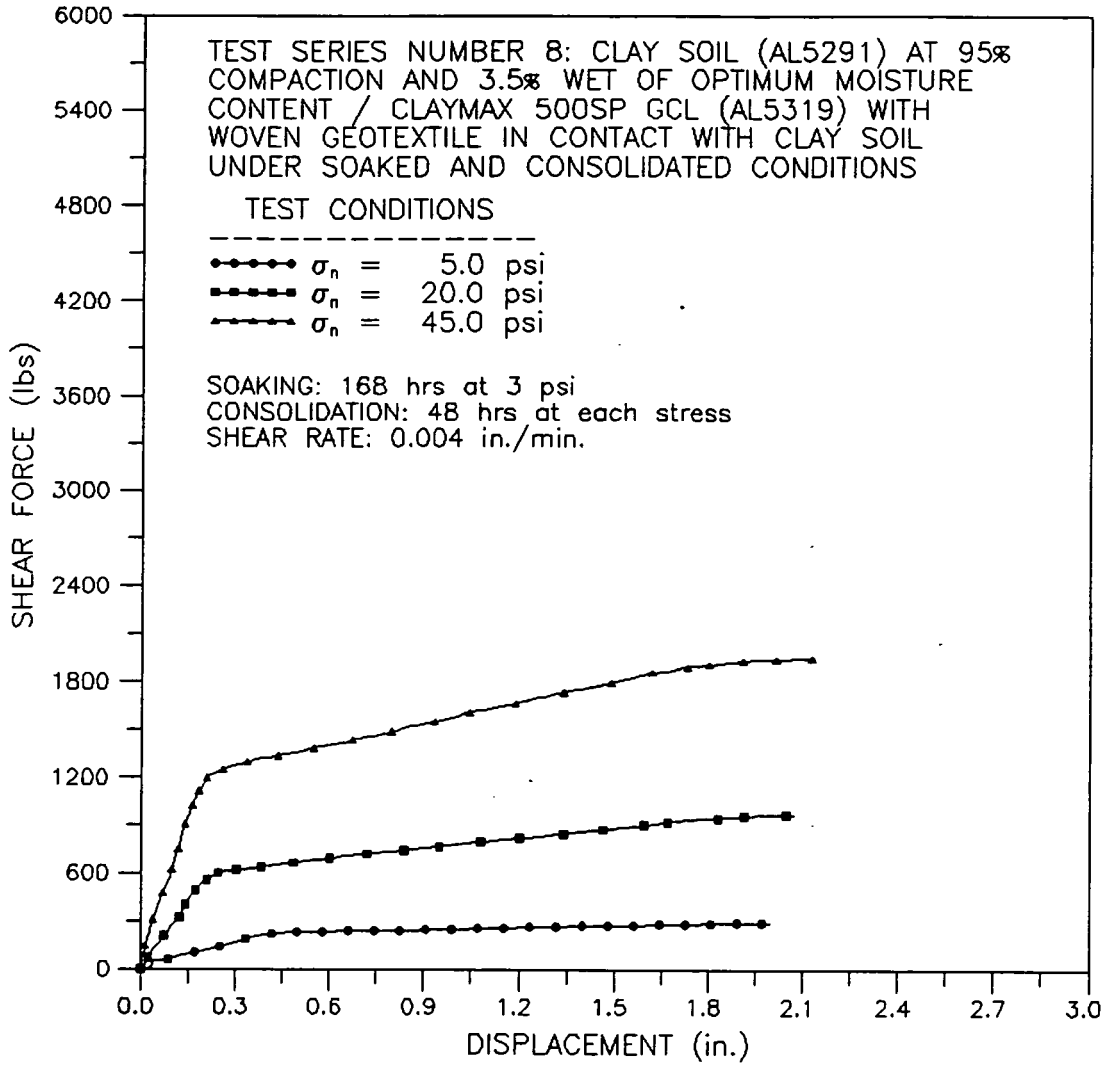
DATE TESTED: 19 JANUARY TO 29 MARCH 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-18
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTE: The shear box size was 12 in. by 12 in. (300 mm by 300 mm), and the contact area remained constant throughout the entire test.

000095

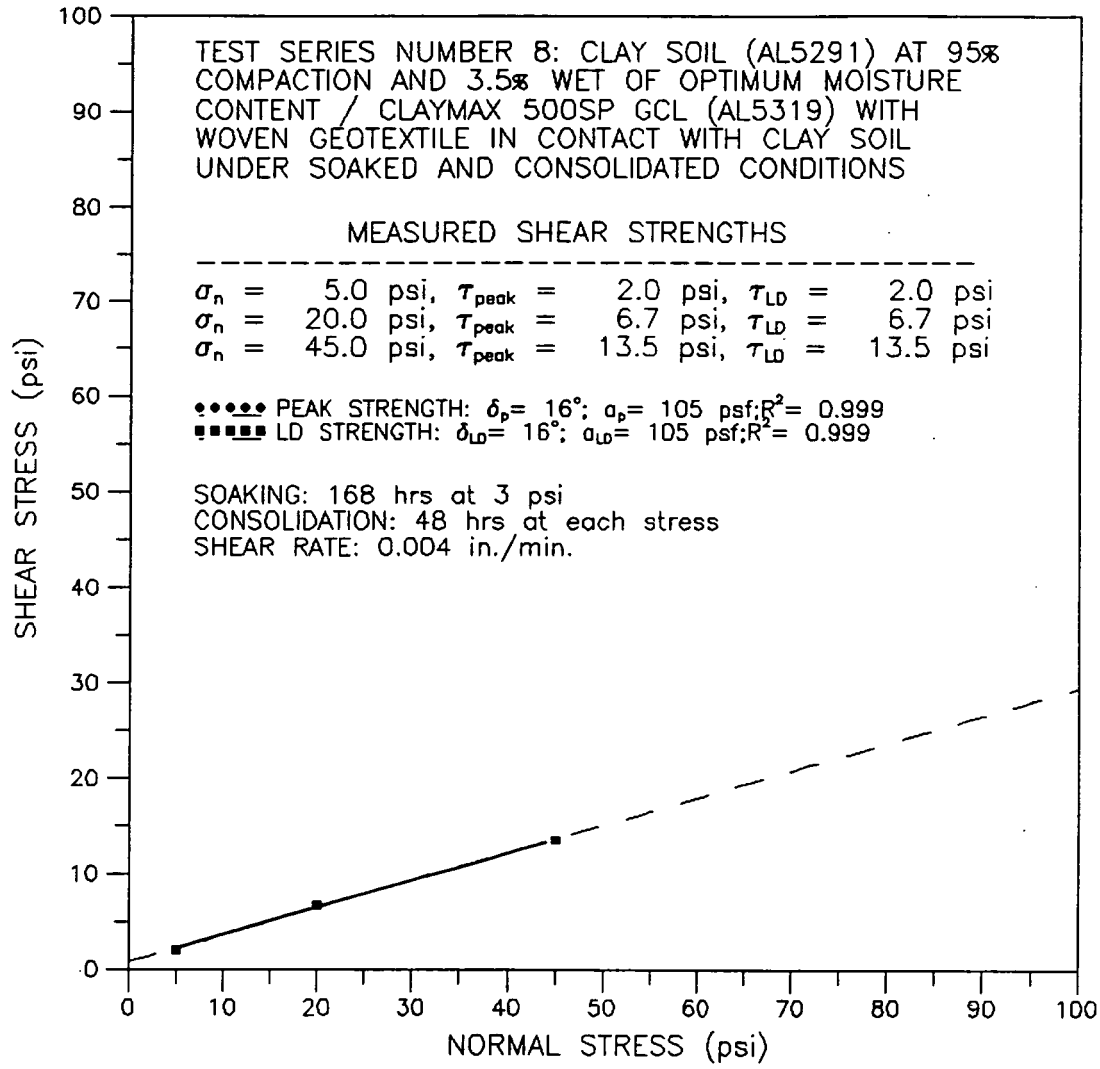
DATE TESTED: 21 JANUARY TO 31 FEBRUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-19
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTES: (1) The reported total-stress shear strength parameters of friction angle and adhesion may not reflect the true shear strength of the interface, and caution should be exercised in using these shear strength parameters for applications involving normal stresses outside the range of stresses covered by the test.

(2) The large displacement shear strength (τ_{LD}) was calculated using the post-peak shear force measured at the end of each test.

DATE TESTED: 21 JANUARY TO 31 FEBRUARY 1996

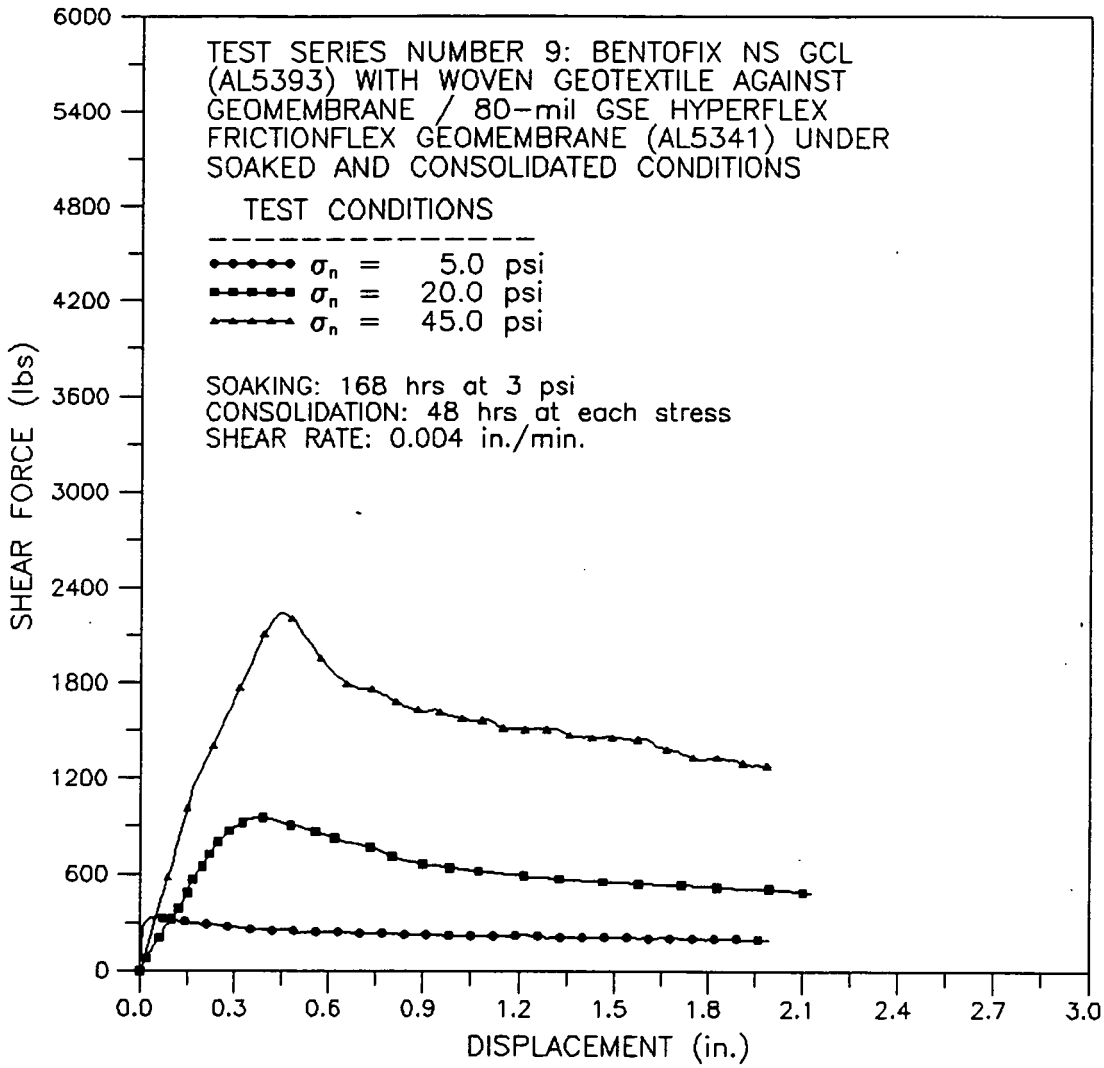
000096

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-20
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTE: The shear box size was 12 in. by 12 in. (300 mm by 300 mm), and the contact area remained constant throughout the entire test.

000097

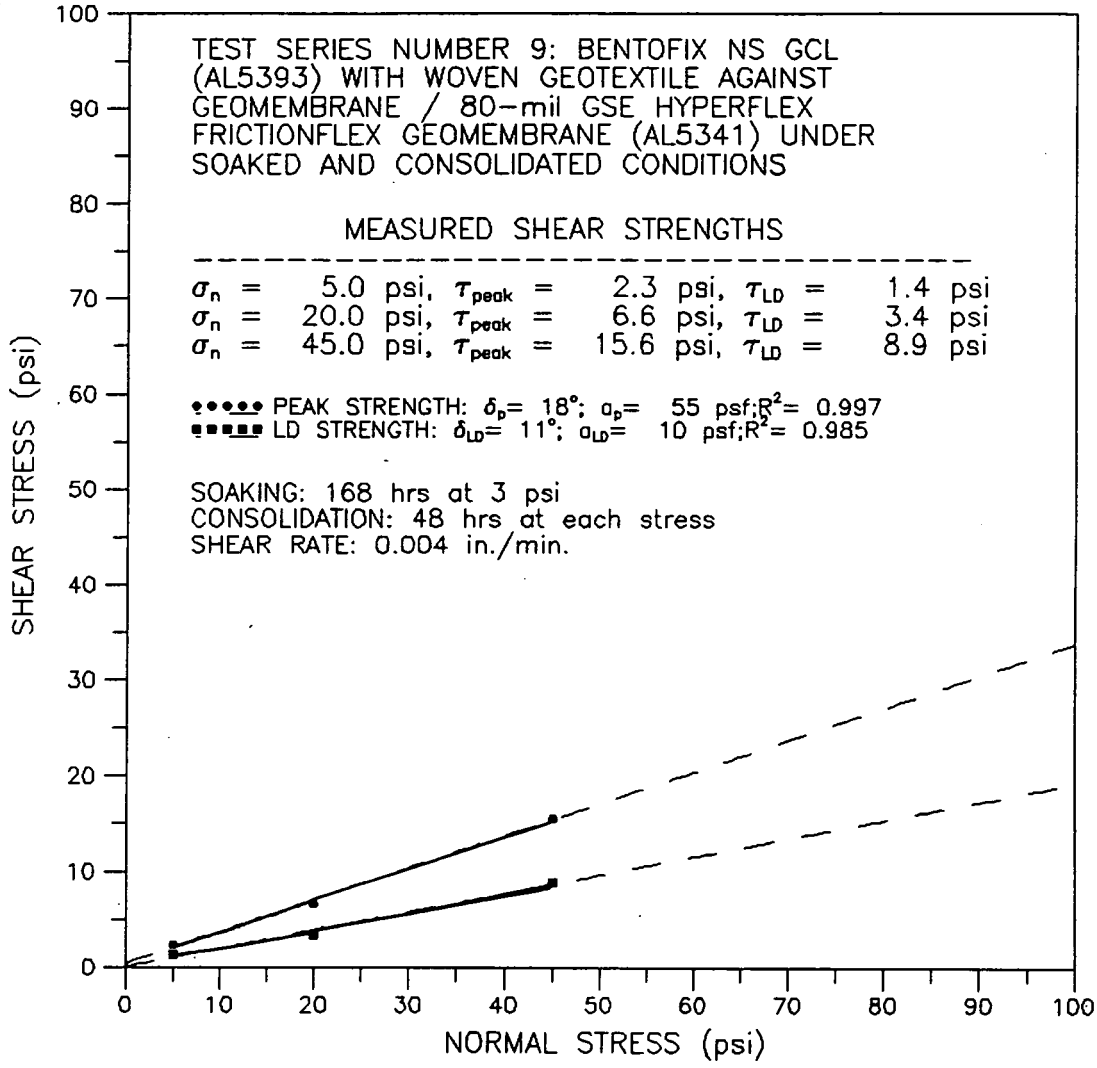
DATE TESTED: 23 JANUARY TO 2 FEBRUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-21
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTES: (1) The reported total-stress shear strength parameters of friction angle and adhesion may not reflect the true shear strength of the interface, and caution should be exercised in using these shear strength parameters for applications involving normal stresses outside the range of stresses covered by the test.

(2) The large displacement shear strength (τ_{LD}) was calculated using the post-peak shear force measured at the end of each test.

000098

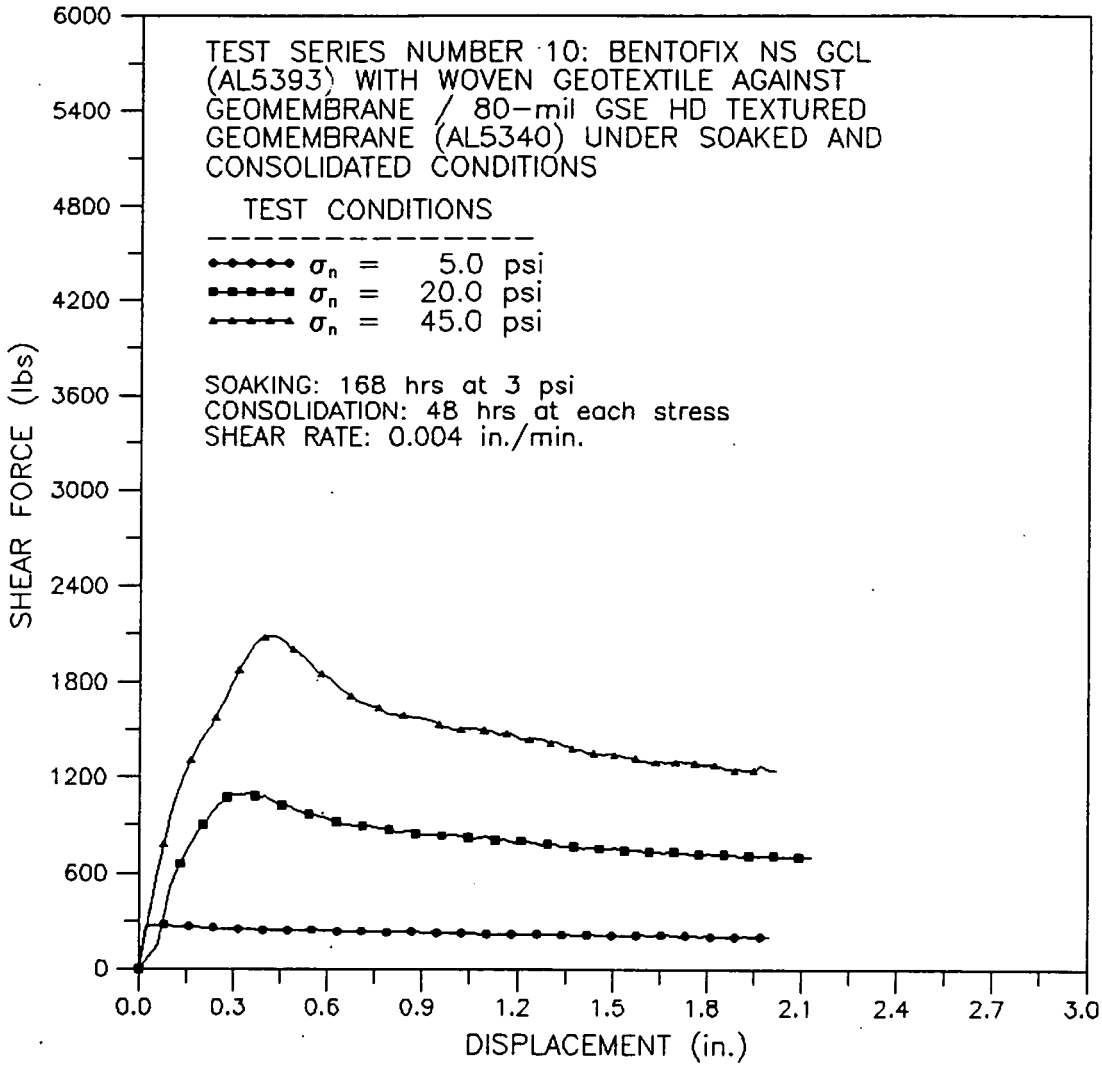
DATE TESTED: 23 JANUARY TO 2 FEBRUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-22
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTE: The shear box size was 12 in. by 12 in. (300 mm by 300 mm), and the contact area remained constant throughout the entire test.

000099

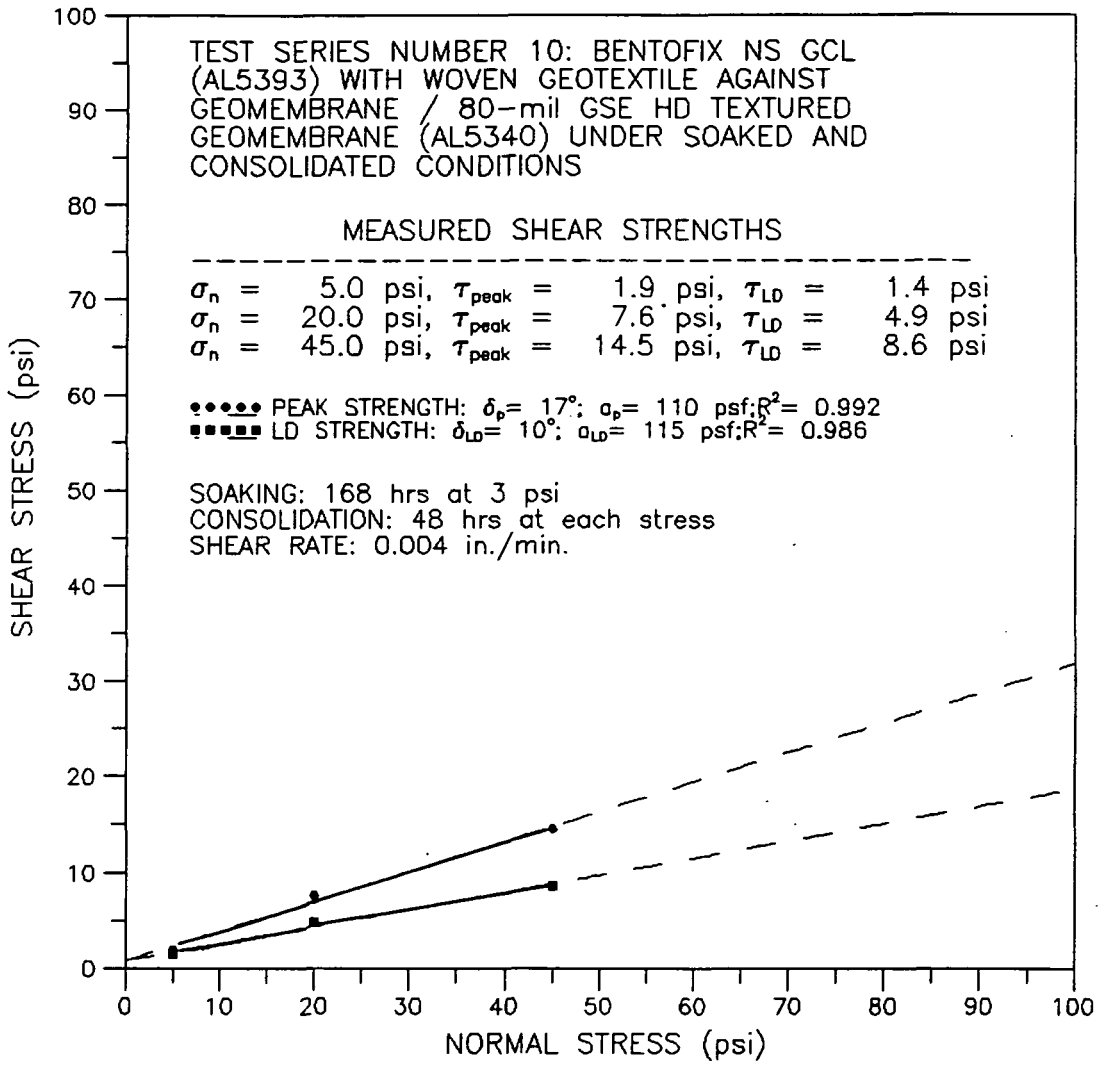
DATE TESTED: 28 JANUARY TO 7 FEBRUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-23
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTES: (1) The reported total-stress shear strength parameters of friction angle and adhesion may not reflect the true shear strength of the interface, and caution should be exercised in using these shear strength parameters for applications involving normal stresses outside the range of stresses covered by the test.

(2) The large displacement shear strength (τ_{LD}) was calculated using the post-peak shear force measured at the end of each test.

000100

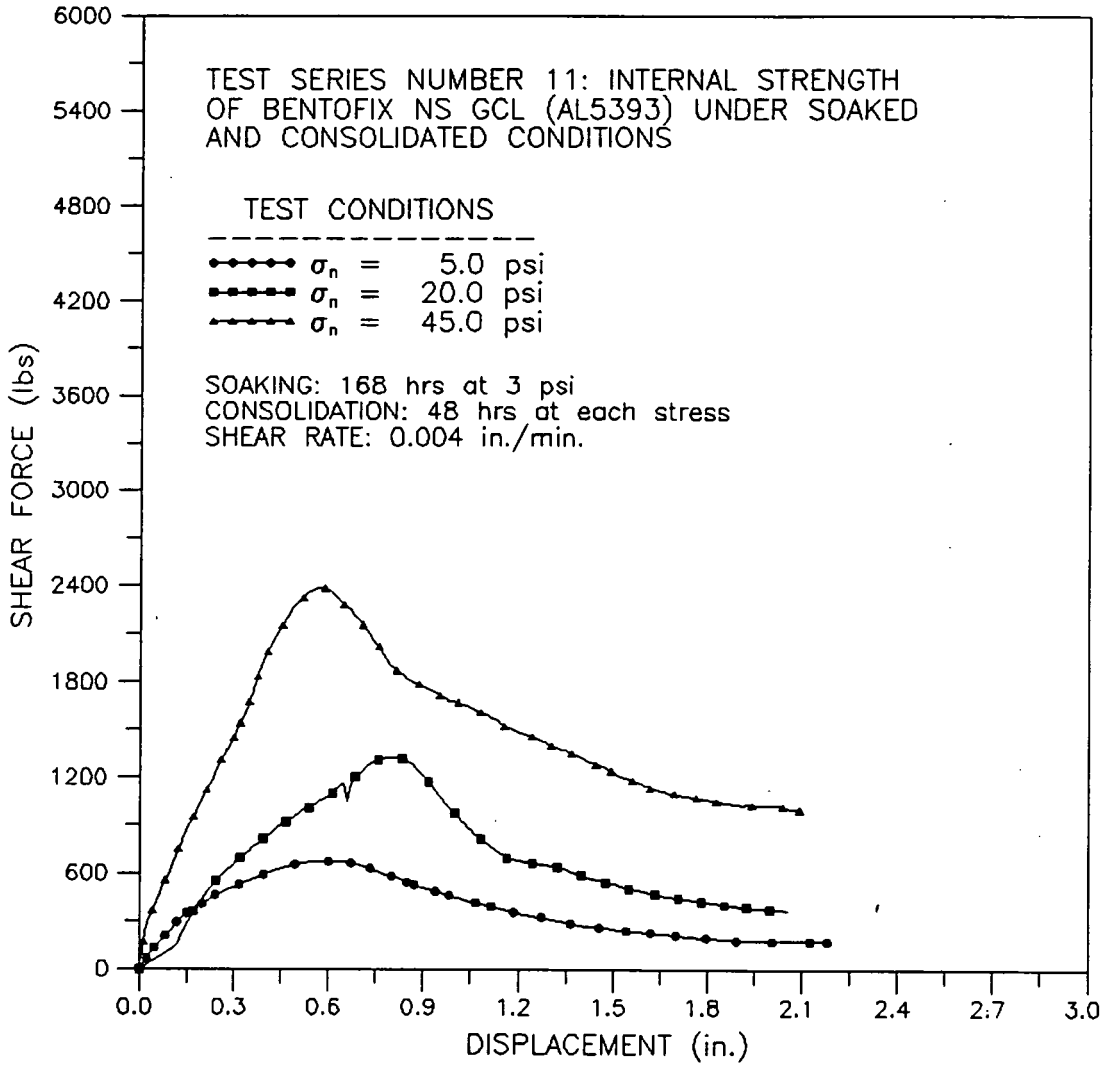
DATE TESTED: 28 JANUARY TO 7 FEBRUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-24
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
DIRECT SHEAR TESTING



NOTE: A constant area of 1 ft^2 was assumed when computing normal and shear stresses.

000101

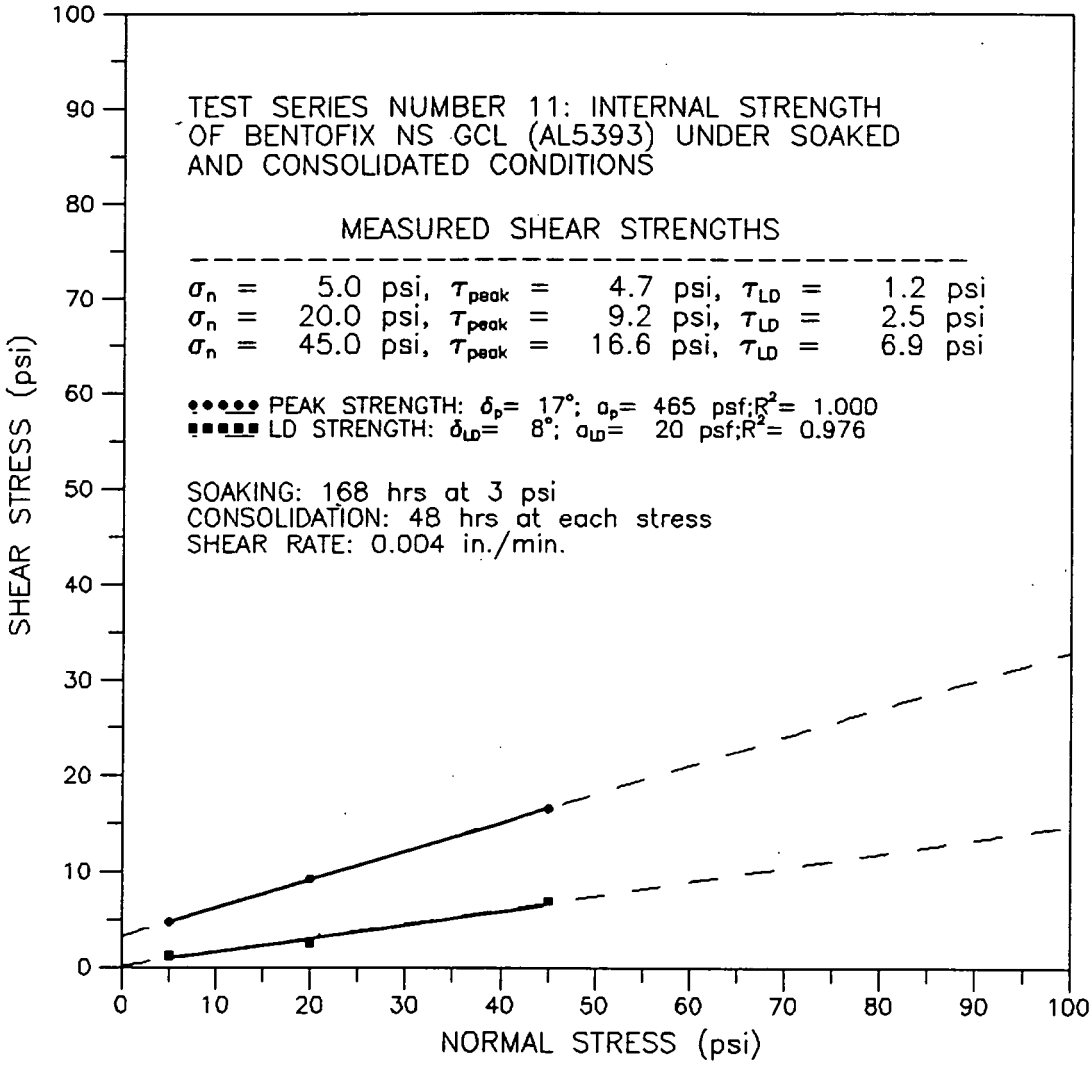
DATE TESTED: 30 JANUARY TO 11 FEBRUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-25
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
DIRECT SHEAR TESTING



NOTES: (1) The reported total-stress shear strength parameters of friction angle and adhesion may not reflect the true shear strength of the interface, and caution should be exercised in using these shear strength parameters for applications involving normal stresses outside the range of stresses covered by the test.

(2) The large displacement shear strength (τ_{LD}) was calculated using the post-peak shear force measured at the end of each test.

000102

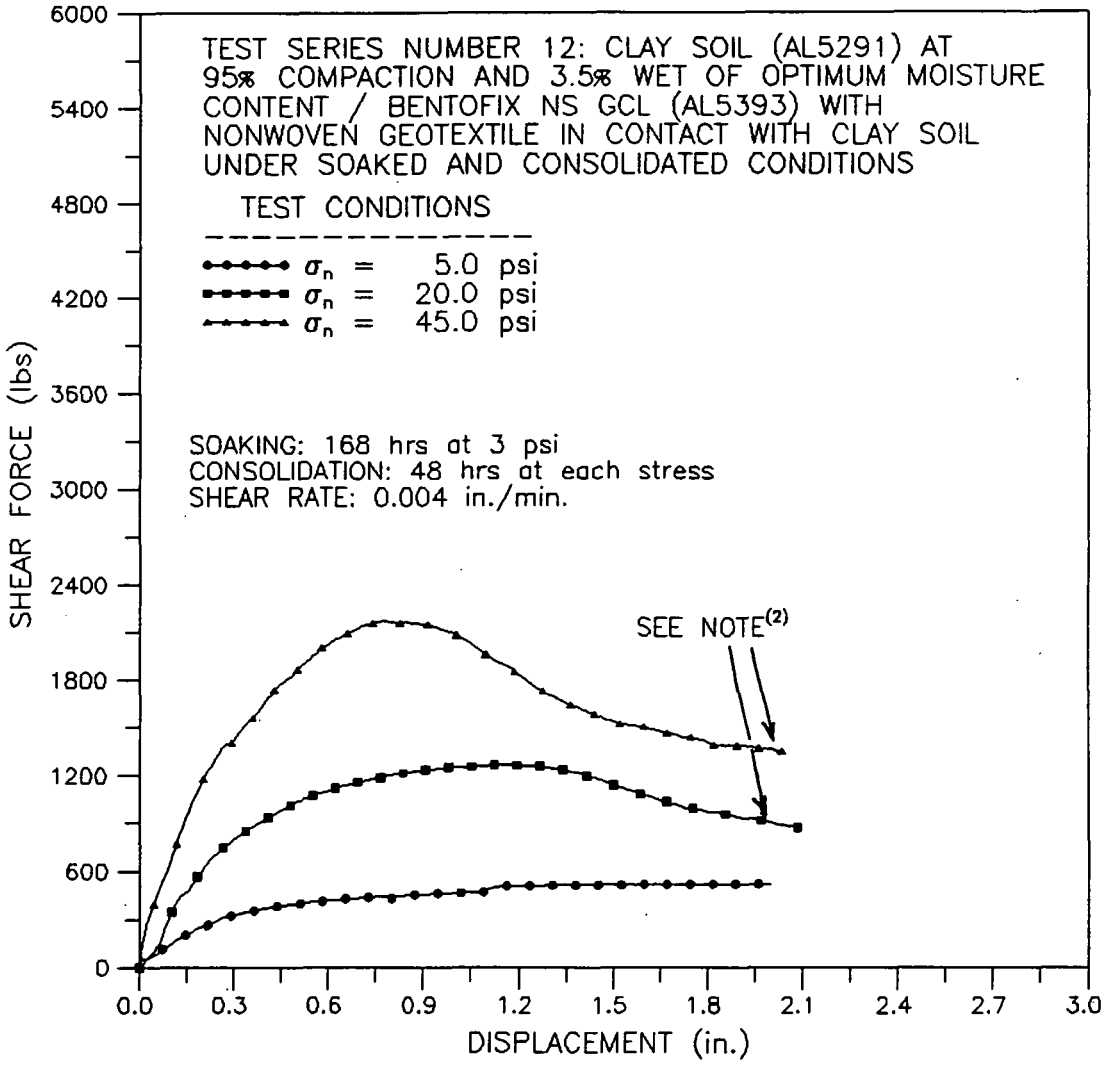
DATE TESTED: 30 JANUARY TO 11 FEBRUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-26
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTES: (1) The shear box size was 12 in. by 12 in. (300 mm by 300 mm), and the contact area remained constant throughout the entire test.

(2) Sliding (i.e., shear failure) was observed to occur within the GCL rather than the intended interface.

000103

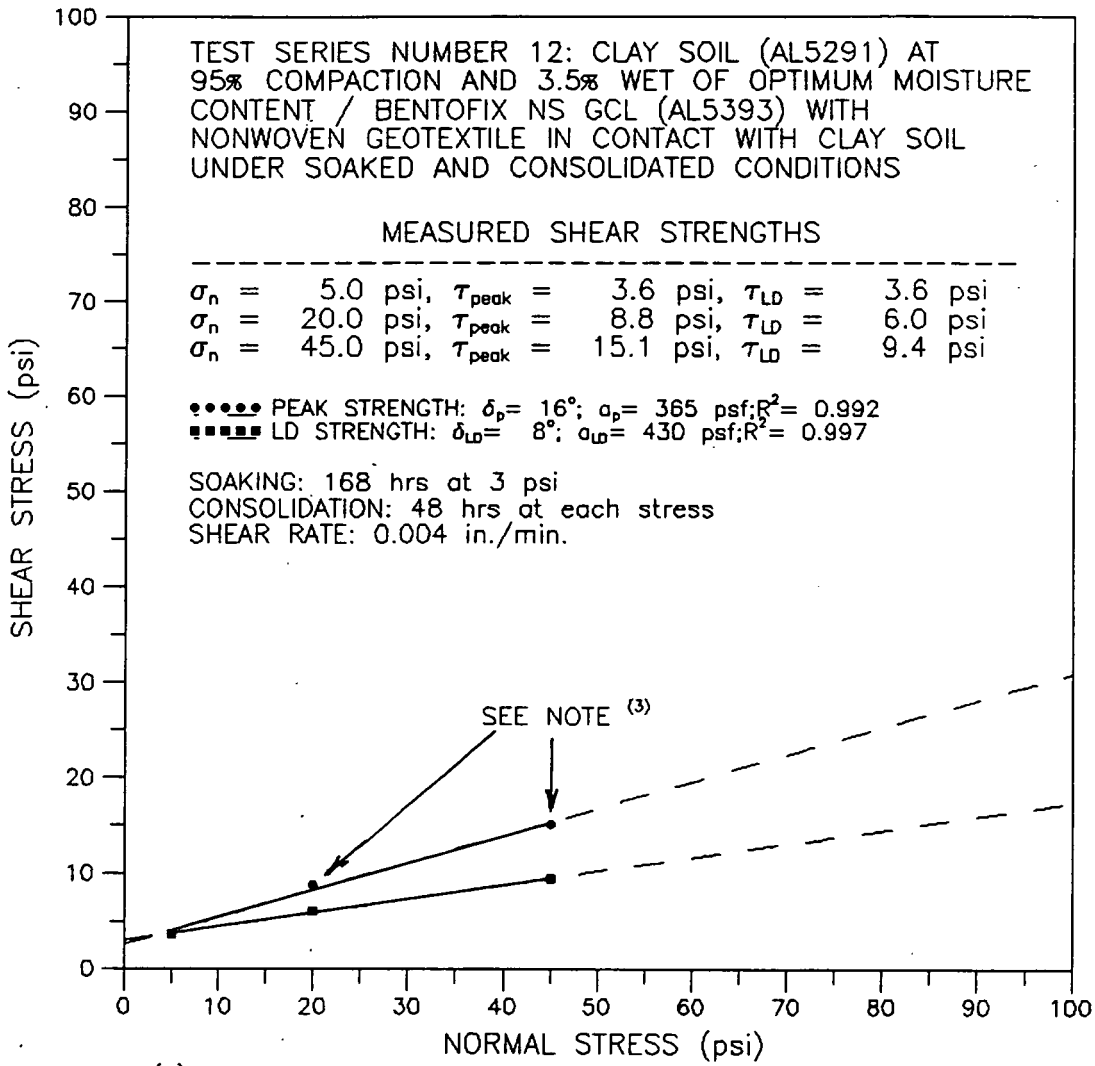
DATE TESTED: 2 TO 12 FEBRUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-27
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTES: (1) The reported total-stress shear strength parameters of friction angle and adhesion may not reflect the true shear strength of the interface, and caution should be exercised in using these shear strength parameters for applications involving normal stresses outside the range of stresses covered by the test.

(2) The large displacement shear strength (τ_{LD}) was calculated using the post-peak shear force measured at the end of each test.

(3) Sliding (i.e., shear failure) was observed to occur within the GCL rather that at the intended interface.

000104

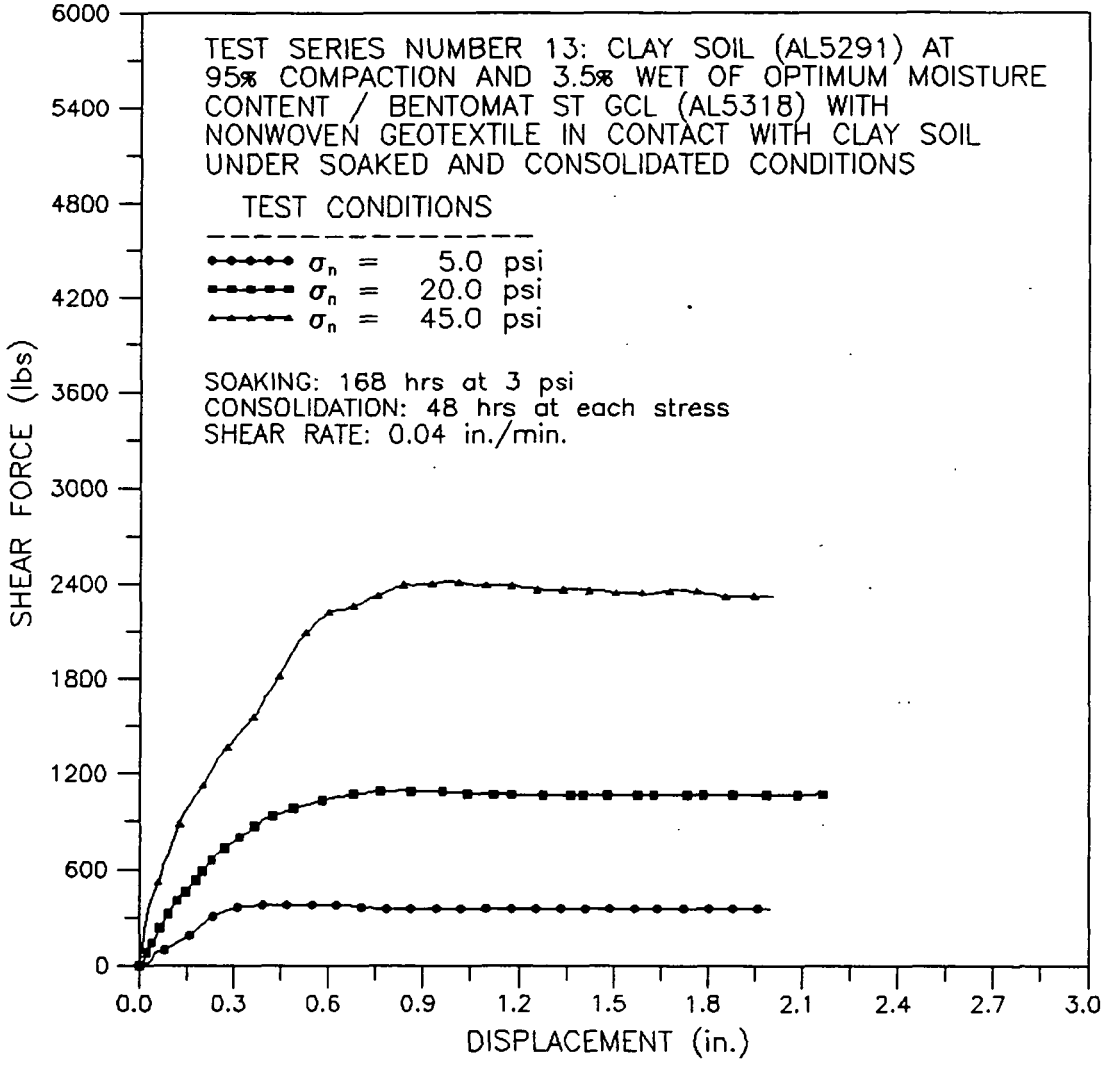
DATE TESTED: 2 TO 12 FEBRUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-28
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTE: The shear box size was 12 in. by 12 in. (300 mm by 300 mm), and the contact area remained constant throughout the entire test.

000105

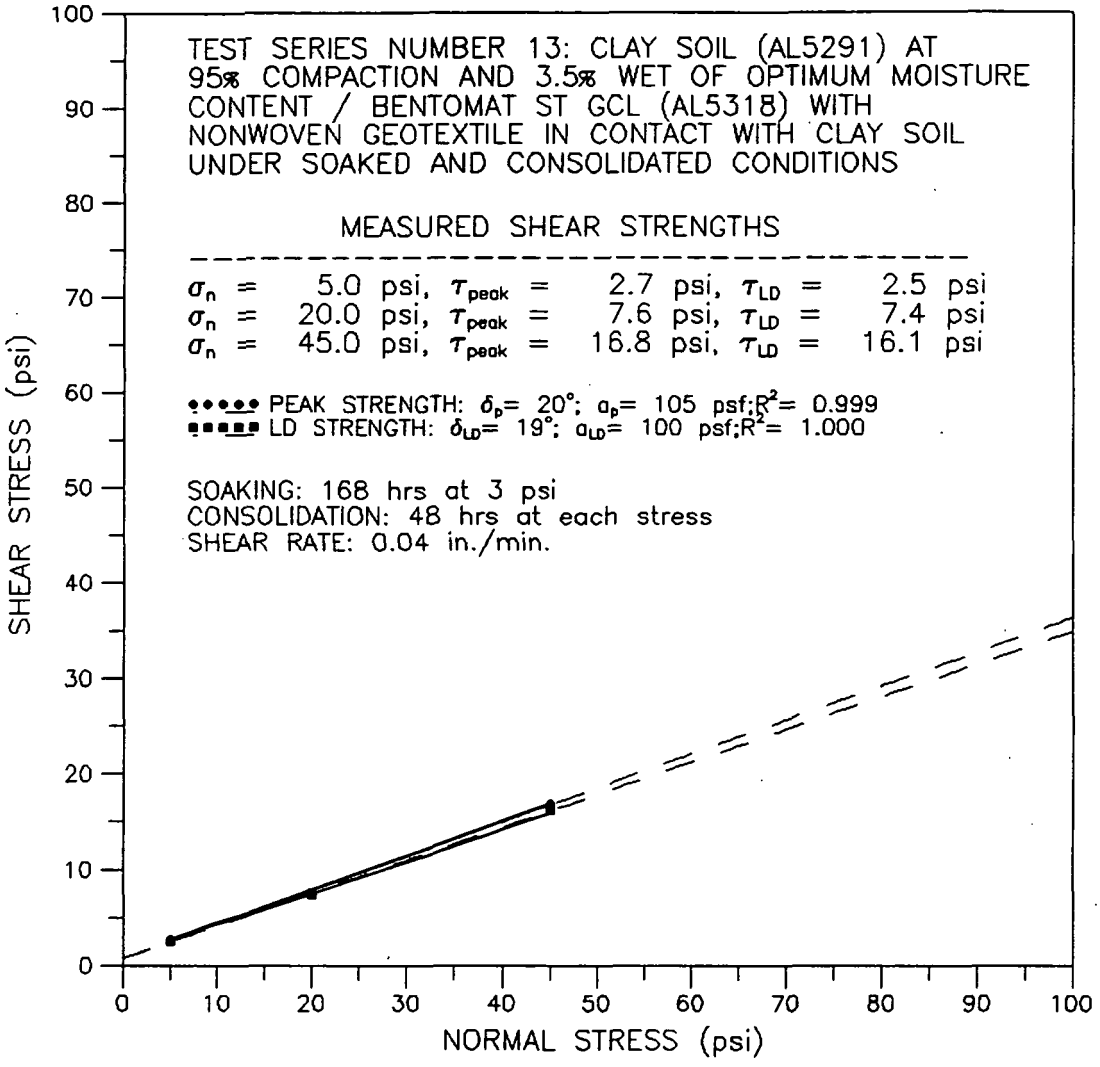
DATE TESTED: 4 TO 14 FEBRUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-29
PROJECT NO.	GE3900-9.2
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTES: (1) The reported total-stress shear strength parameters of friction angle and adhesion may not reflect the true shear strength of the interface, and caution should be exercised in using these shear strength parameters for applications involving normal stresses outside the range of stresses covered by the test.

(2) The large displacement shear strength (τ_{LD}) was calculated using the post-peak shear force measured at the end of each test.

000106

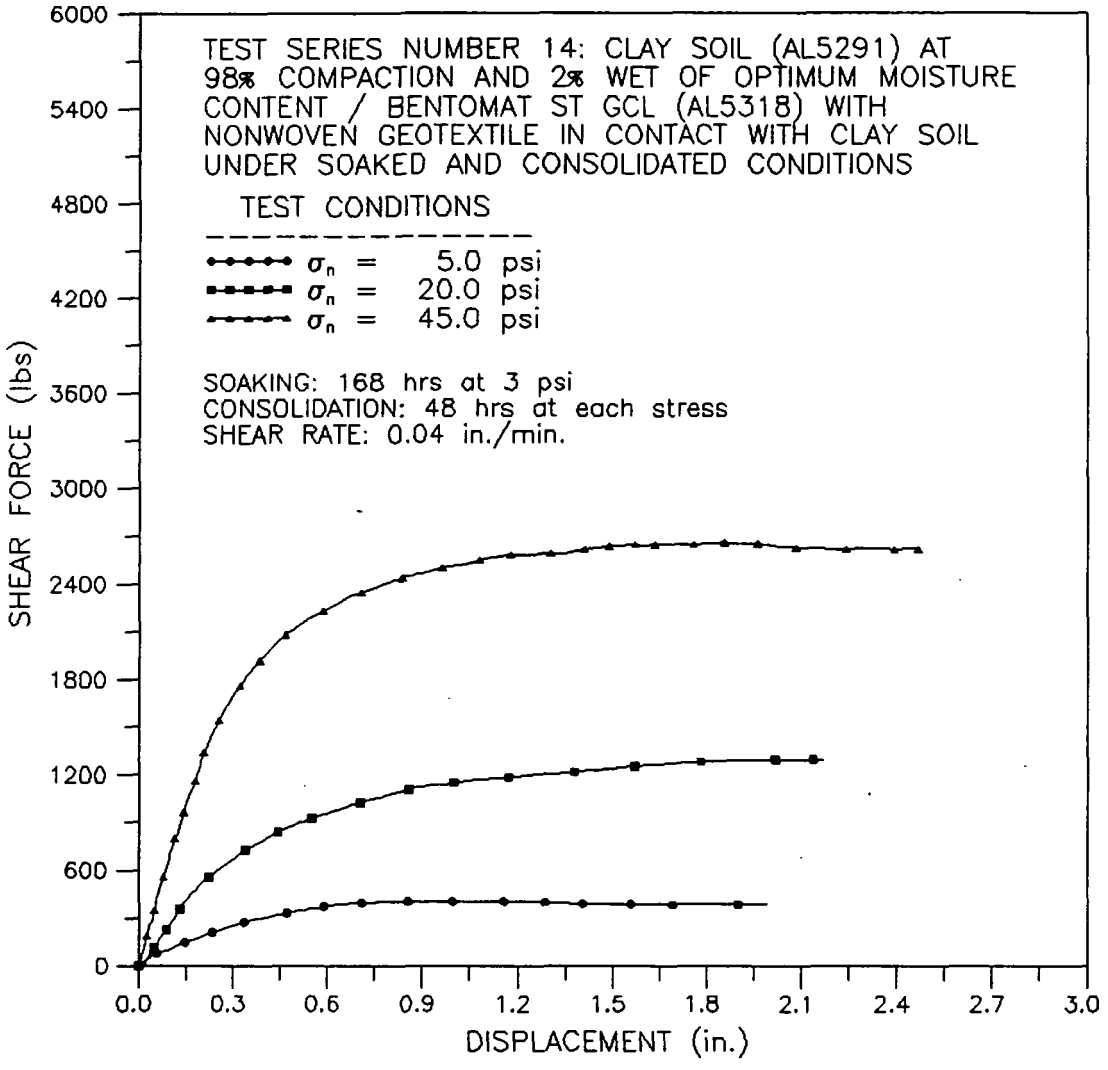
DATE TESTED: 4 TO 14 FEBRUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-30
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTE: A constant area of 1 ft^2 was assumed when computing normal and shear stresses.

000107

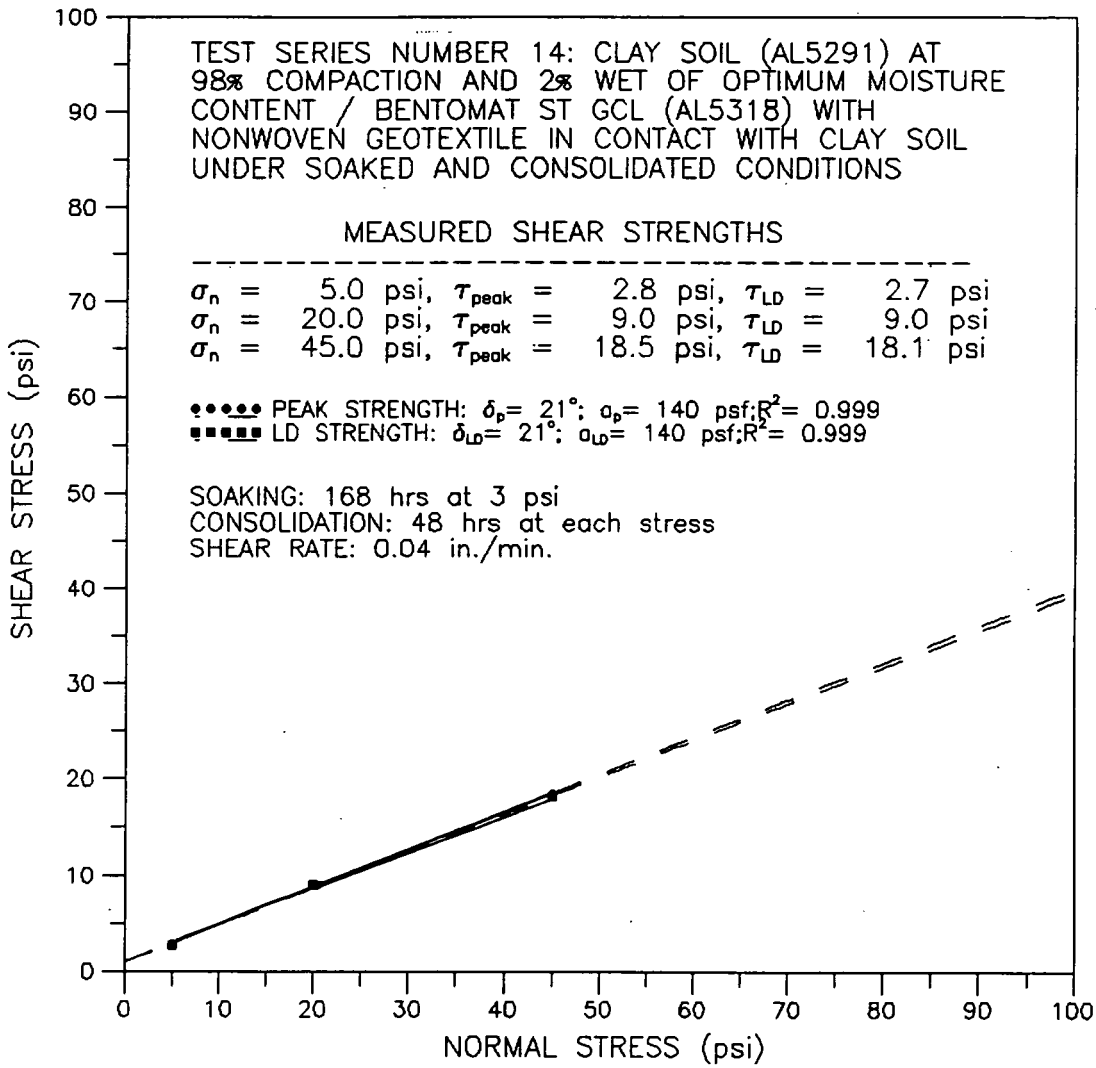
DATE TESTED: 6 TO 16 FEBRUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-31
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTES: (1) The reported total-stress shear strength parameters of friction angle and adhesion may not reflect the true shear strength of the interface, and caution should be exercised in using these shear strength parameters for applications involving normal stresses outside the range of stresses covered by the test.

(2) The large displacement shear strength (τ_{LD}) was calculated using the post-peak shear force measured at the end of each test.

000108

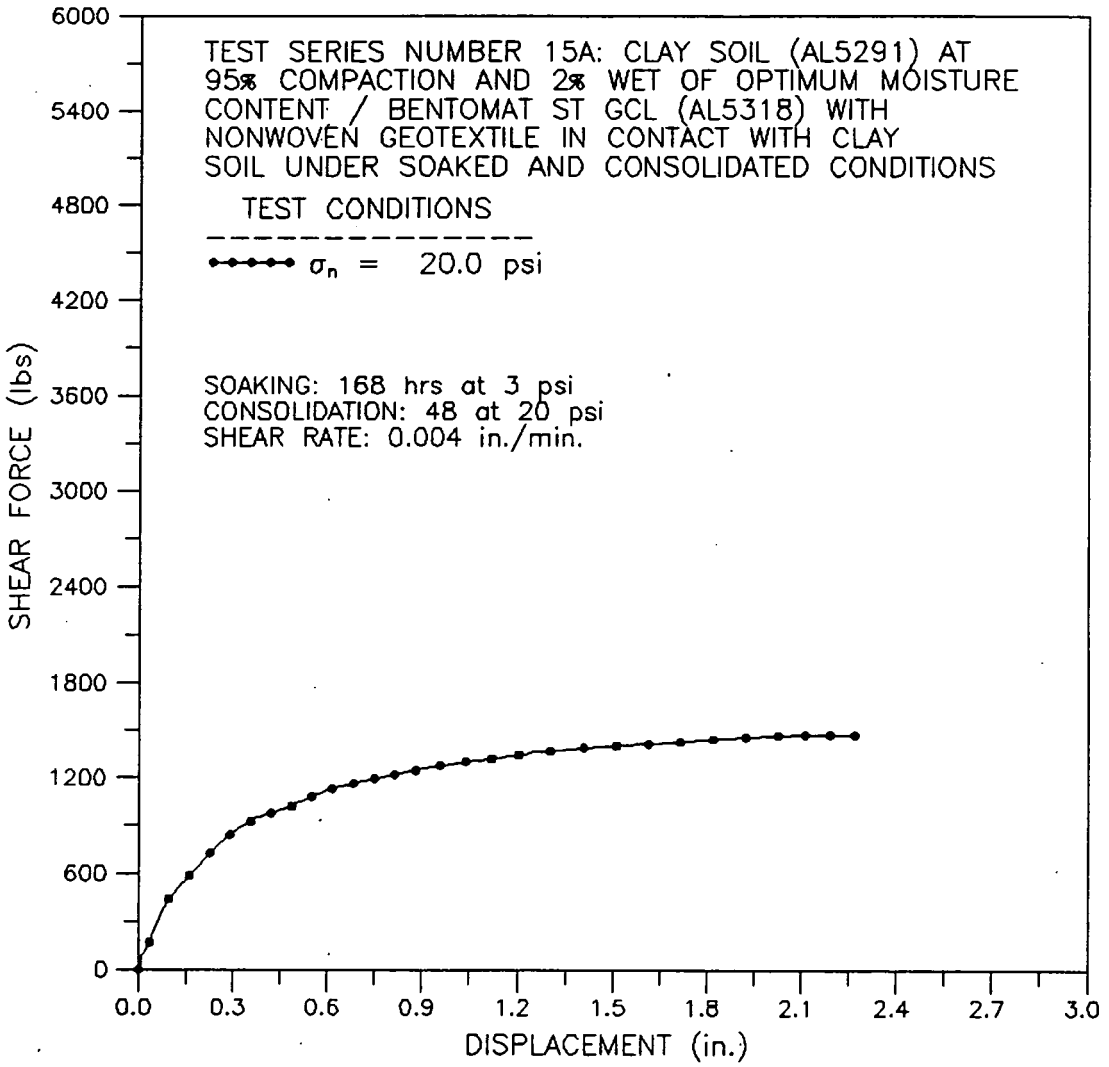
DATE TESTED: 6 TO 16 FEBRUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-32
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTE: The shear box size was 12 in. by 12 in. (300 mm by 300 mm), and the contact area remained constant throughout the entire test.

000109

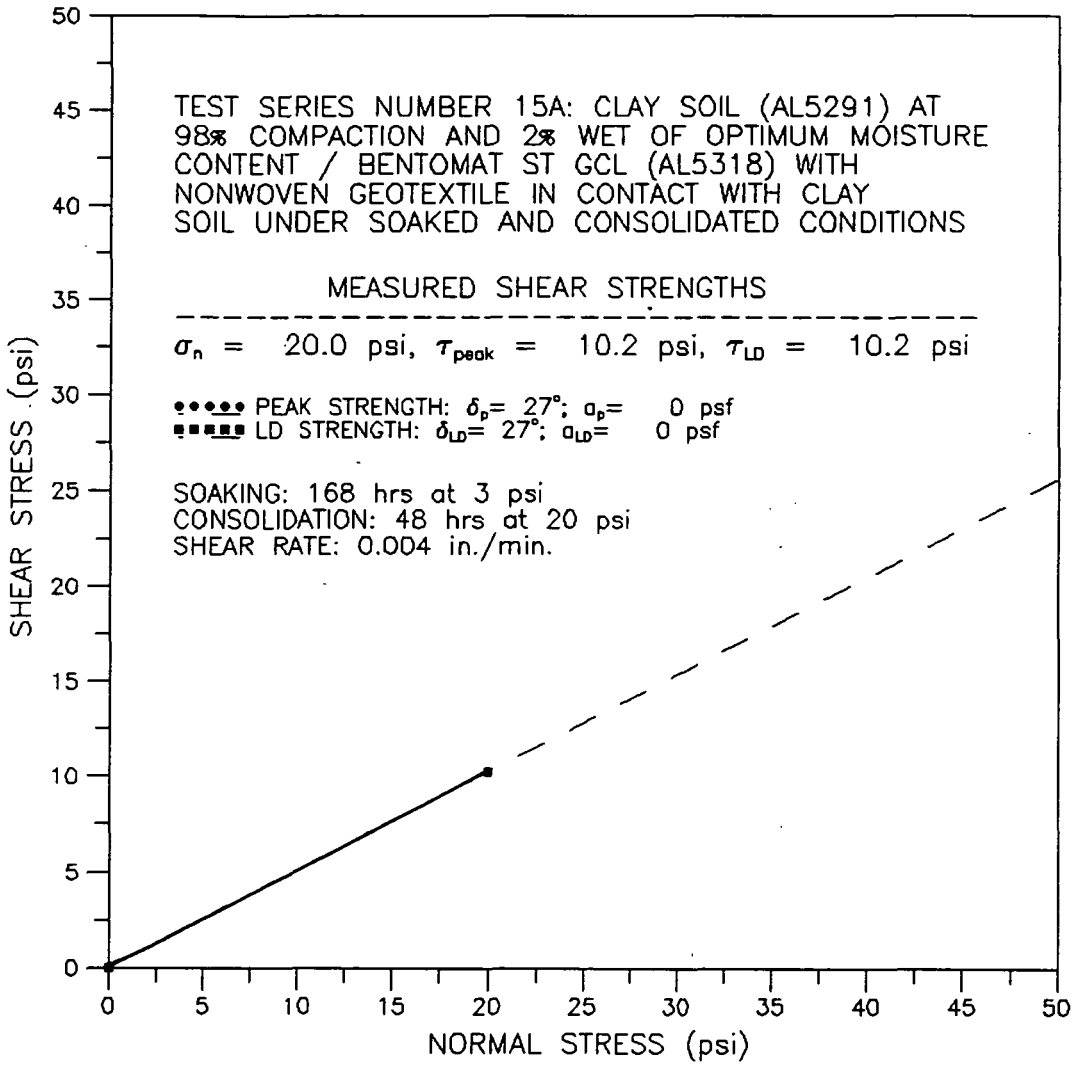
DATE TESTED: 13 TO 23 FEBRUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-33
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTE: The large displacement shear strength (τ_{LD}) was calculated using the post-peak shear force measured at the end of each test.

000110

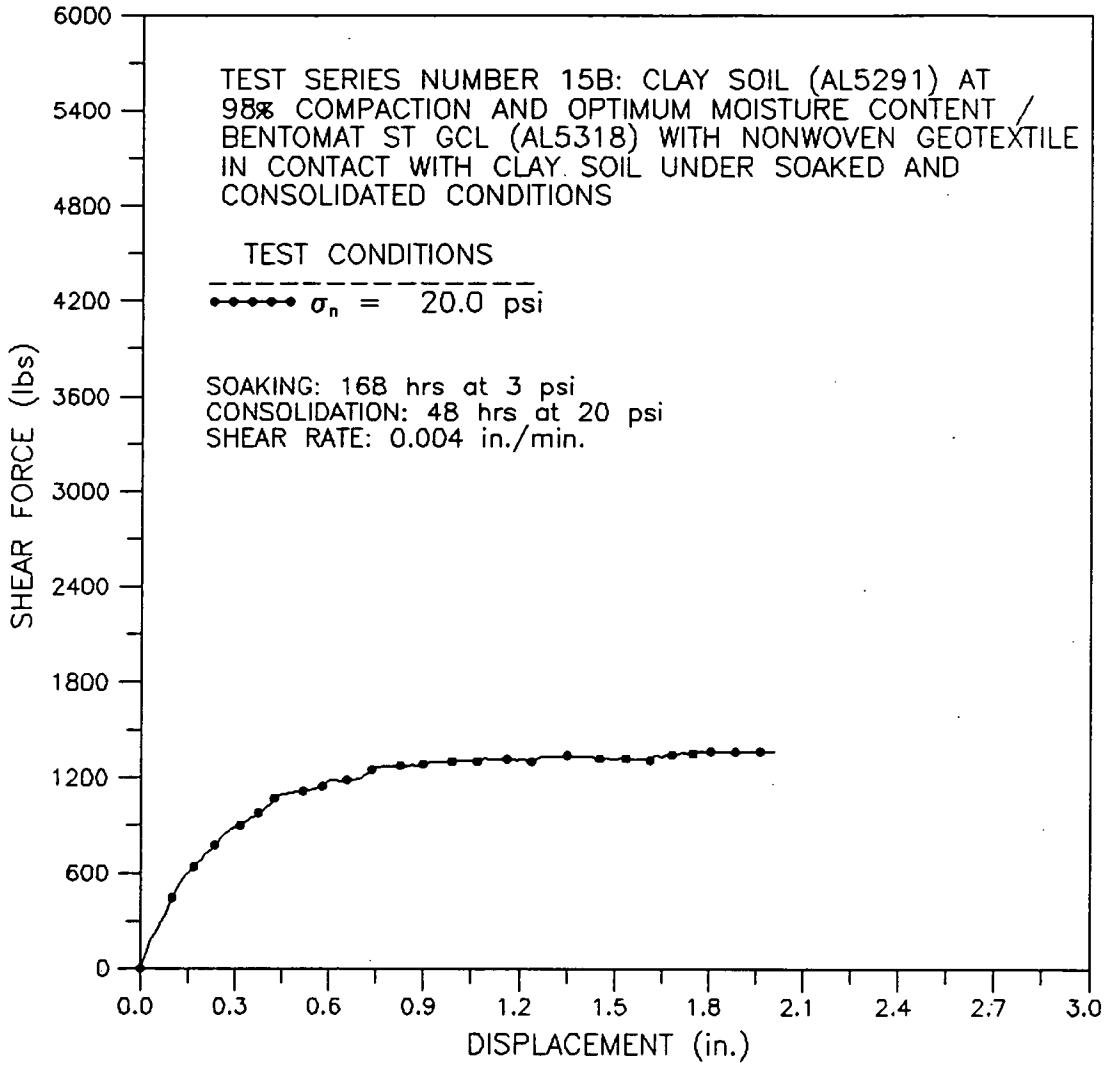
DATE TESTED: 13 TO 23 FEBRUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-34
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTE: The shear box size was 12 in. by 12 in. (300 mm by 300 mm), and the contact area remained constant throughout the entire test.

000111

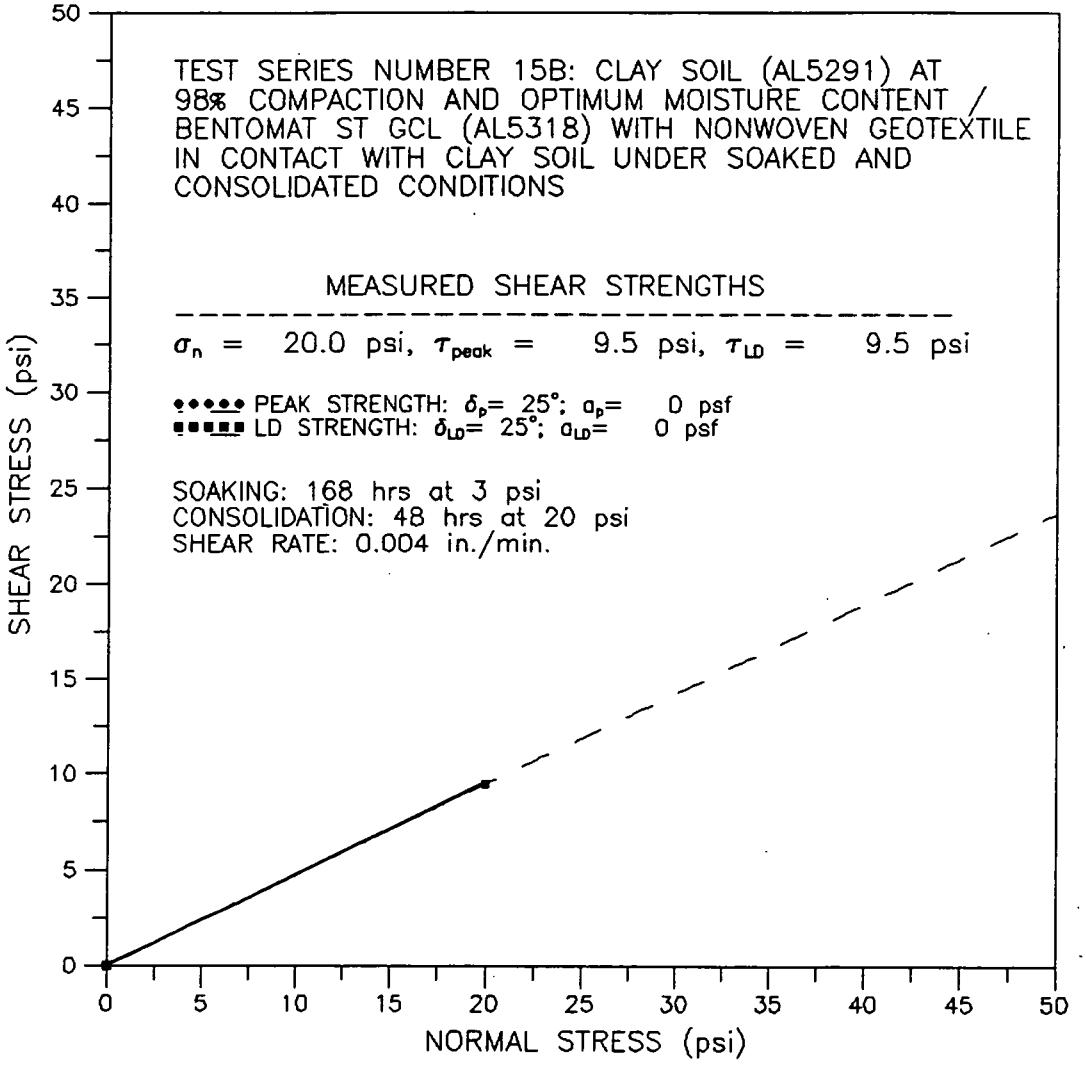
DATE TESTED: 13 TO 23 FEBRUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-35
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTES: The large displacement shear strength (τ_{LD}) was calculated using the post-peak shear force measured at the end of each test.

000112

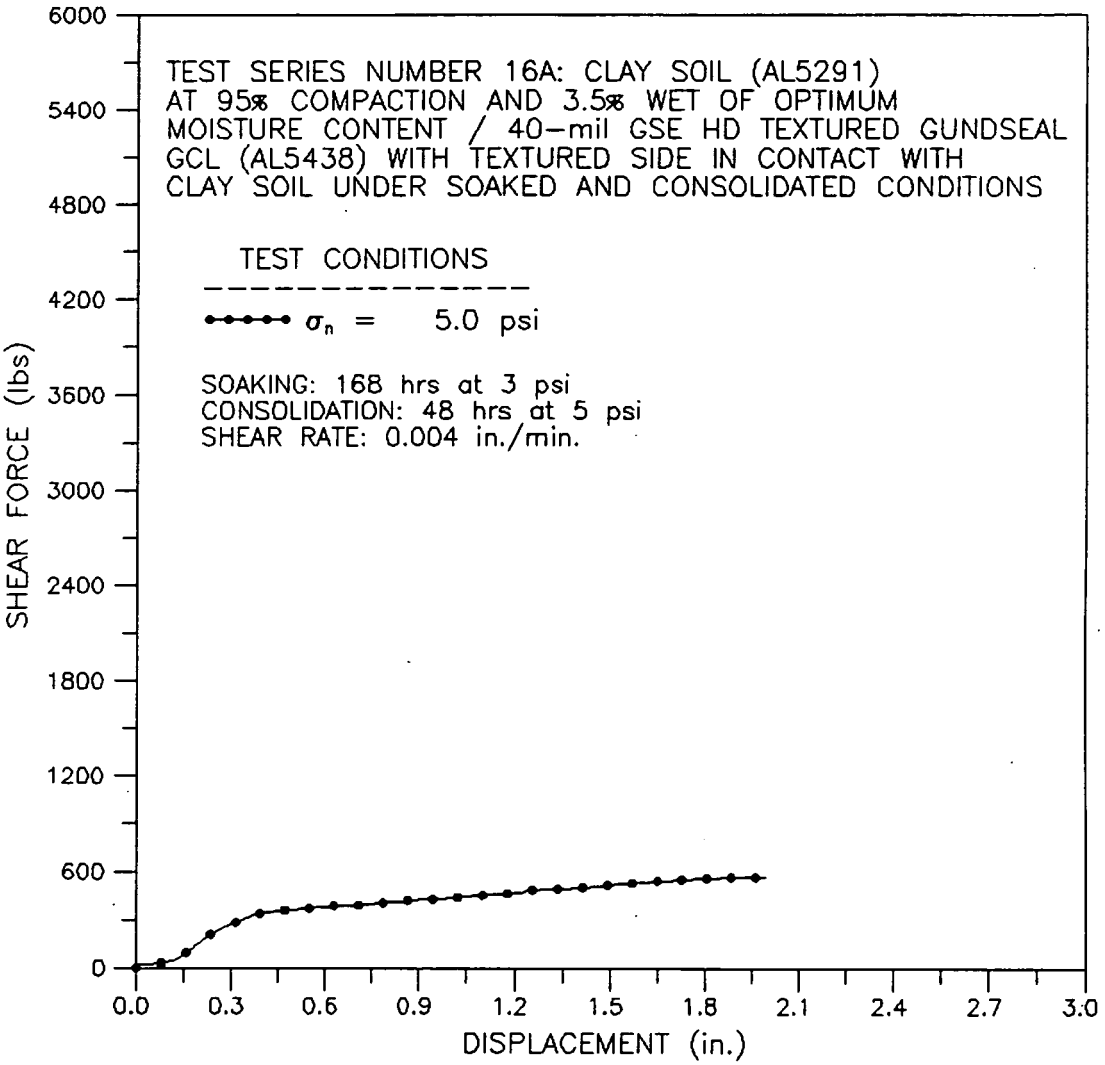
DATE TESTED: 13 TO 23 FEBRUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-36
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTE: The shear box size was 12 in. by 12 in. (300 mm by 300 mm), and the contact area remained constant throughout the entire test.

000113

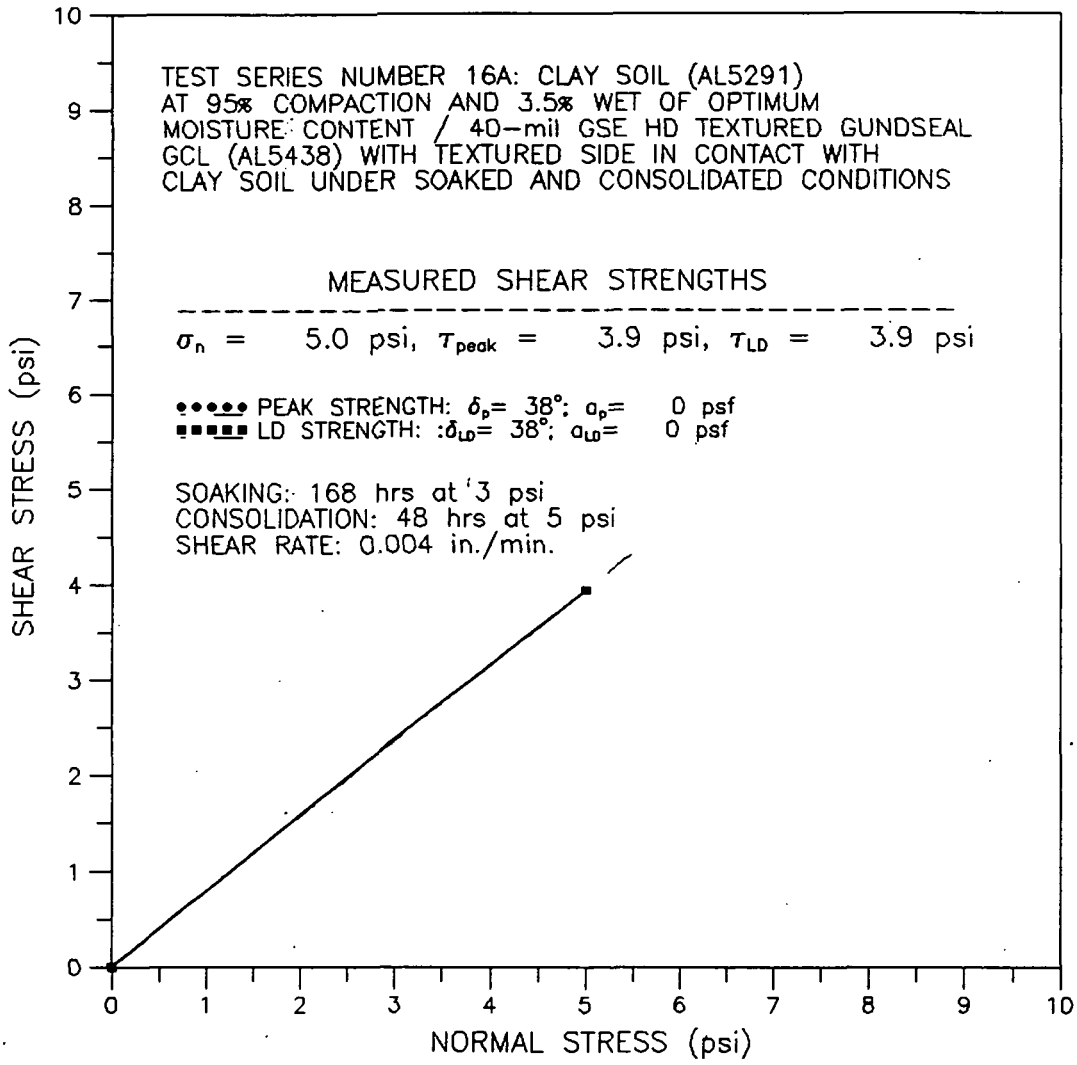
DATE TESTED: 13 TO 23 FEBRUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-37
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTE: The large displacement shear strength (τ_{LD}) was calculated using the post-peak shear force measured at the end of each test.

000114

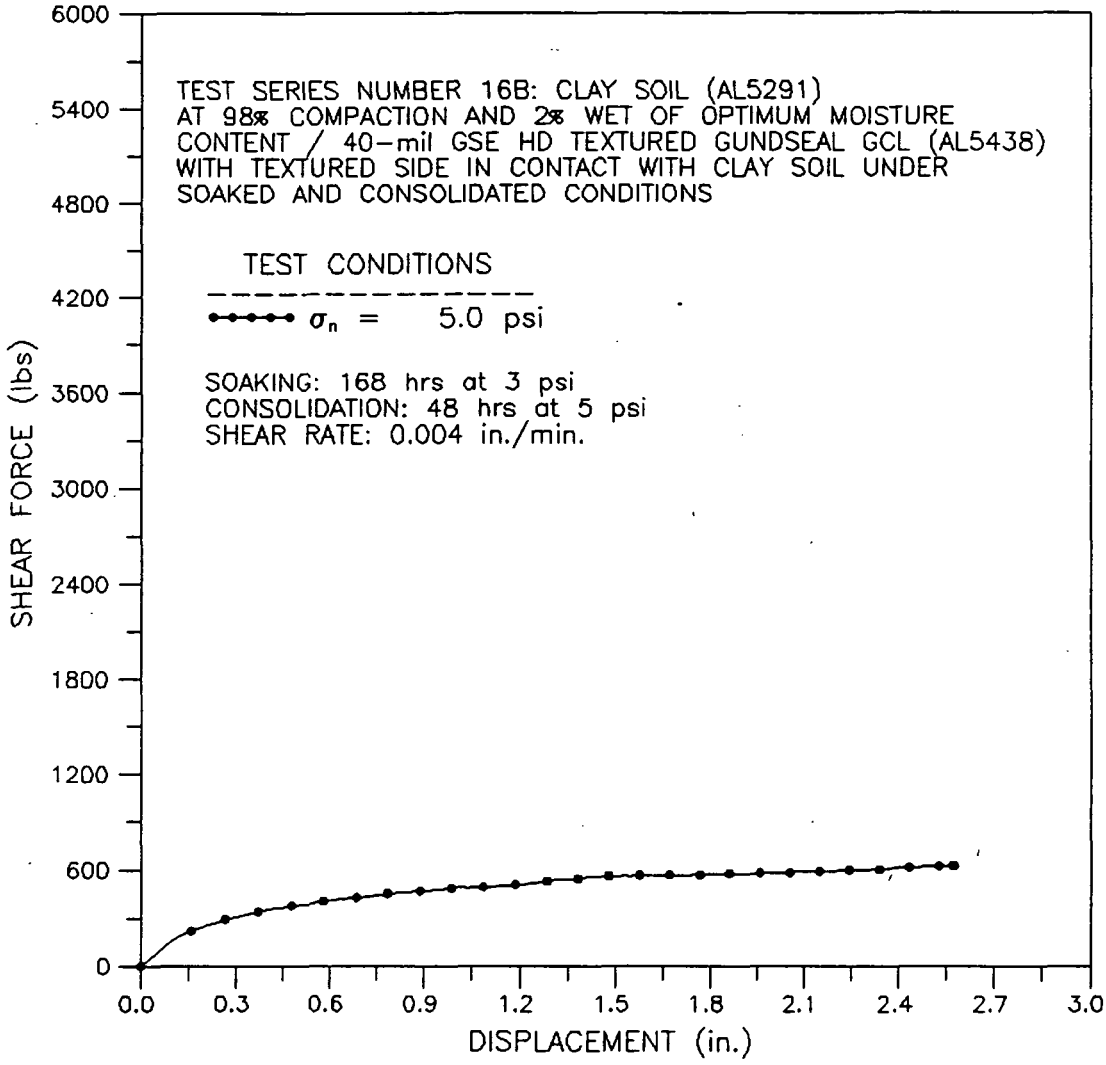
DATE TESTED: 13 TO 23 FEBRUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-38
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTE: The shear box size was 12 in. by 12 in. (300 mm by 300 mm), and the contact area remained constant throughout the entire test.

000115

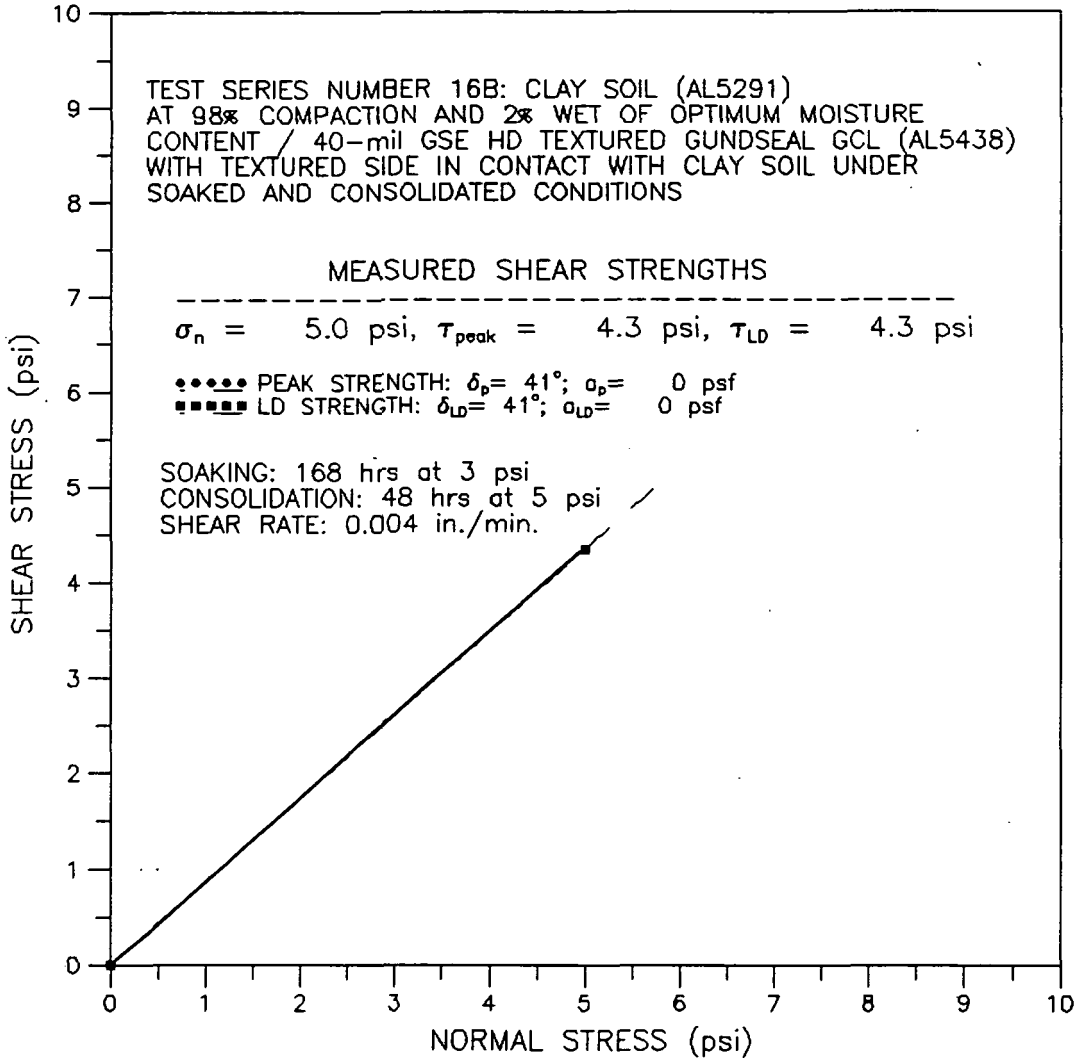
DATE TESTED: 13 TO 23 FEBRUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-39
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTE: The large displacement shear strength (τ_{LD}) was calculated using the post-peak shear force measured at the end of each test.

DATE TESTED: 13 TO 23 FEBRUARY 1996

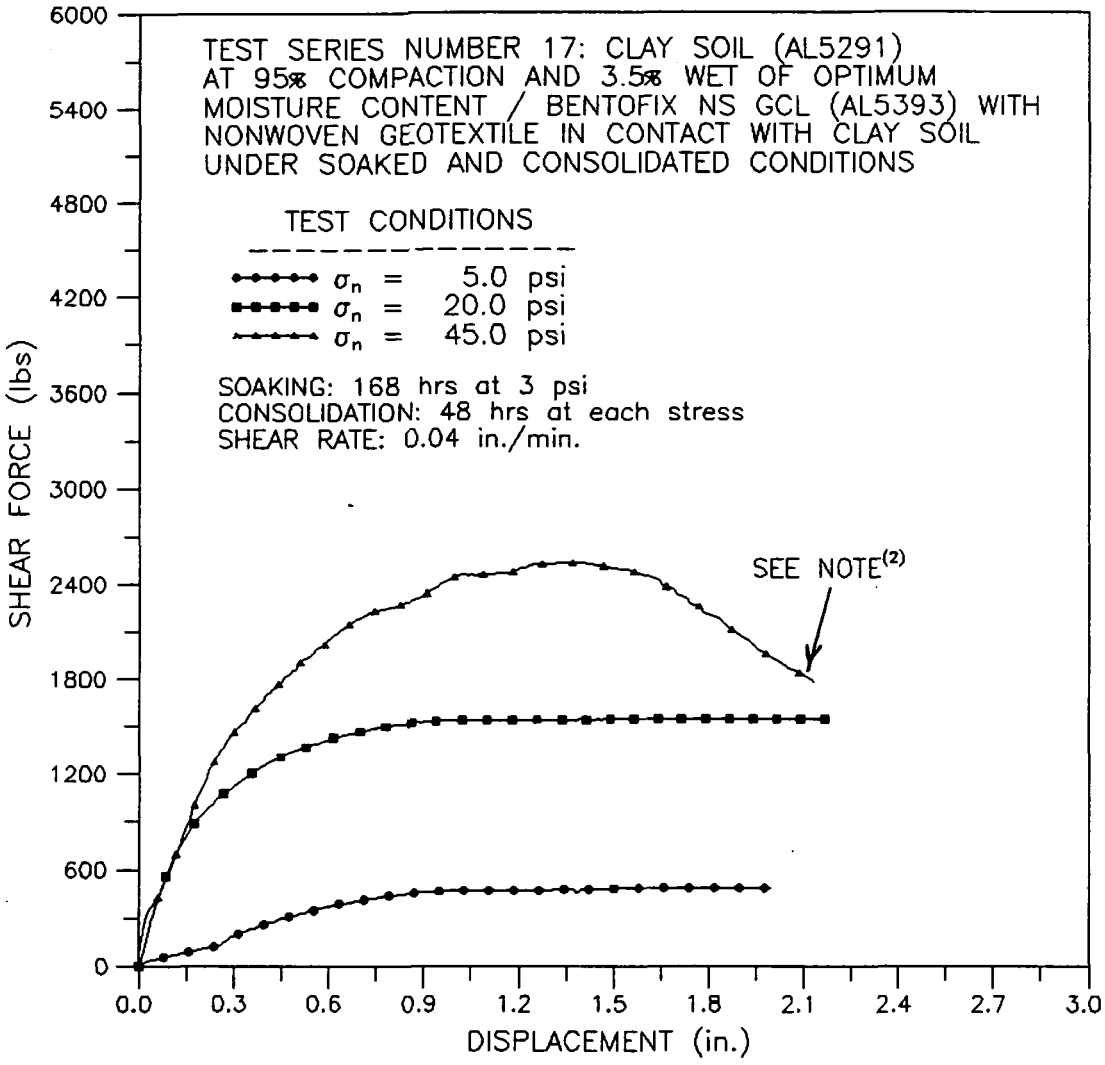
000116

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-40
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTE: (1) The shear box size was 12 in. by 12 in. (300 mm by 300 mm), and the contact area remained constant throughout the entire test.

(2) Sliding (i.e., shear failure) was observed to occur within the GCL rather than at the intended interface.

DATE TESTED: 16 TO 26 FEBRUARY 1996

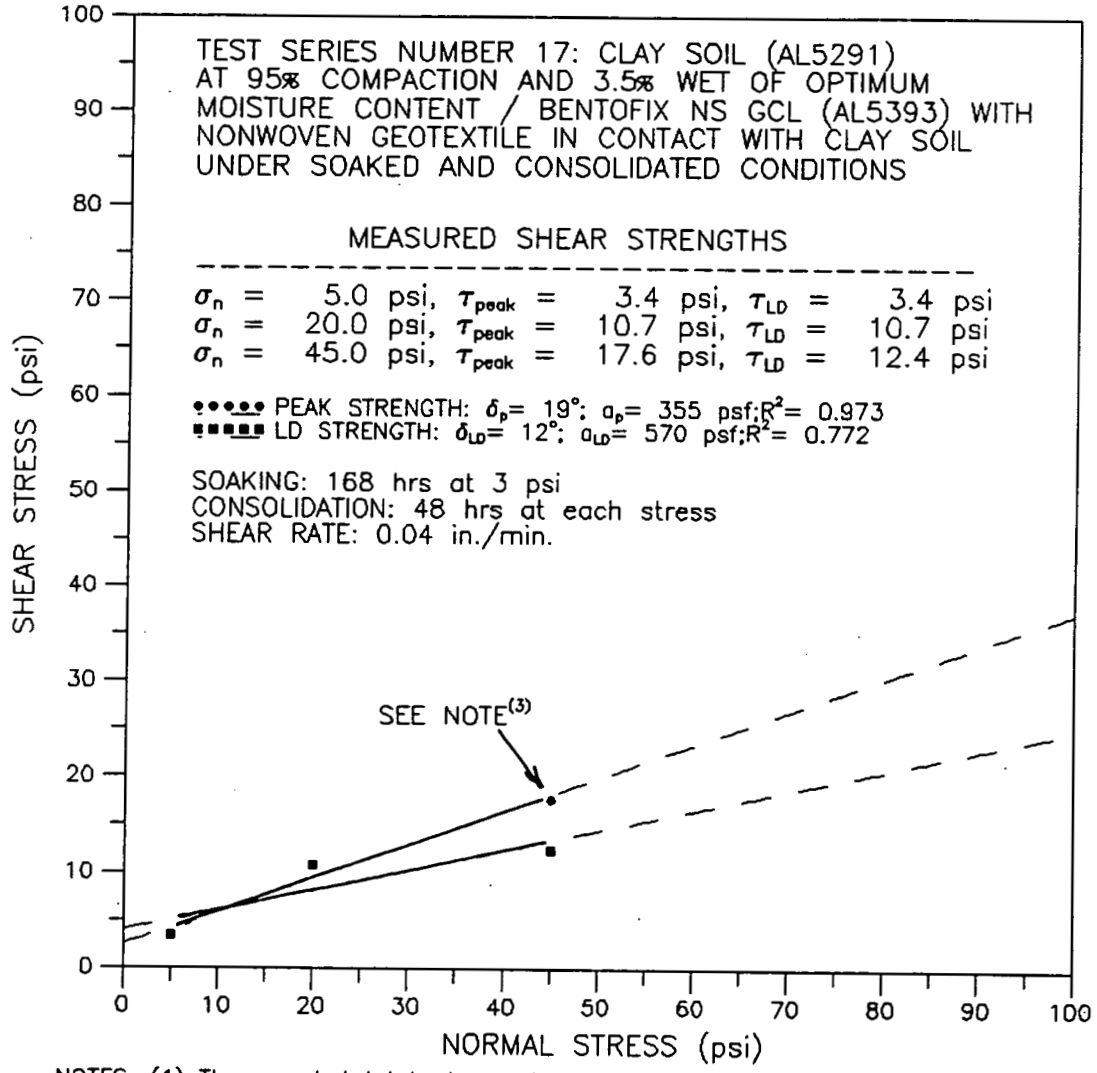
000117

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-41
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTES: (1) The reported total-stress shear strength parameters of friction angle and adhesion may not reflect the true shear strength of the interface, and caution should be exercised in using these shear strength parameters for applications involving normal stresses outside the range of stresses covered by the test.

(2) The large displacement shear strength (τ_{LD}) was calculated using the post-peak shear force measured at the end of each test.

(3) Sliding (i.e., shear failure) was observed to occur within the GCL rather that at the intended interface.

000118

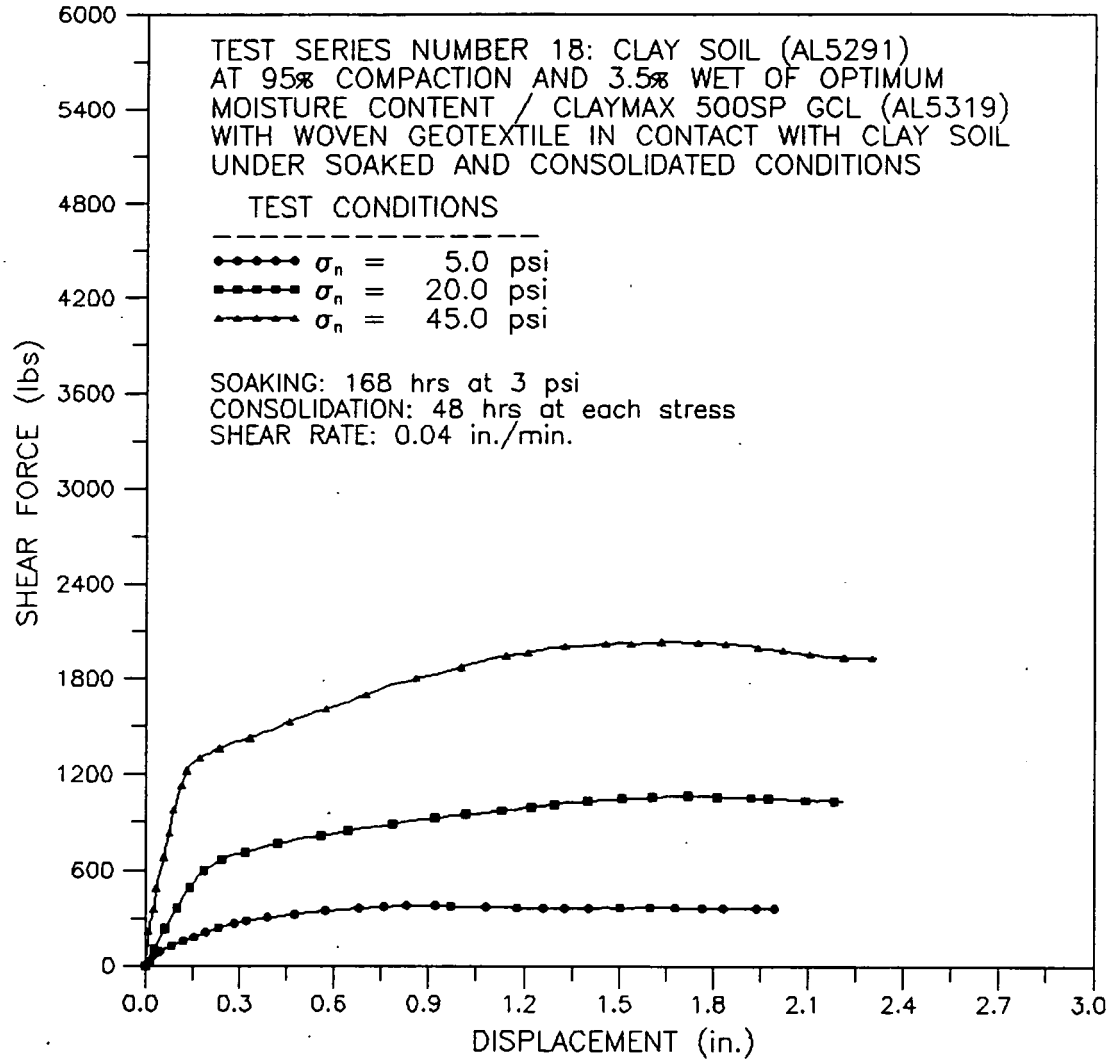
DATE TESTED: 16 TO 26 FEBRUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-42
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTE: The shear box size was 12 in. by 12 in. (300 mm by 300 mm), and the contact area remained constant throughout the entire test.

000119

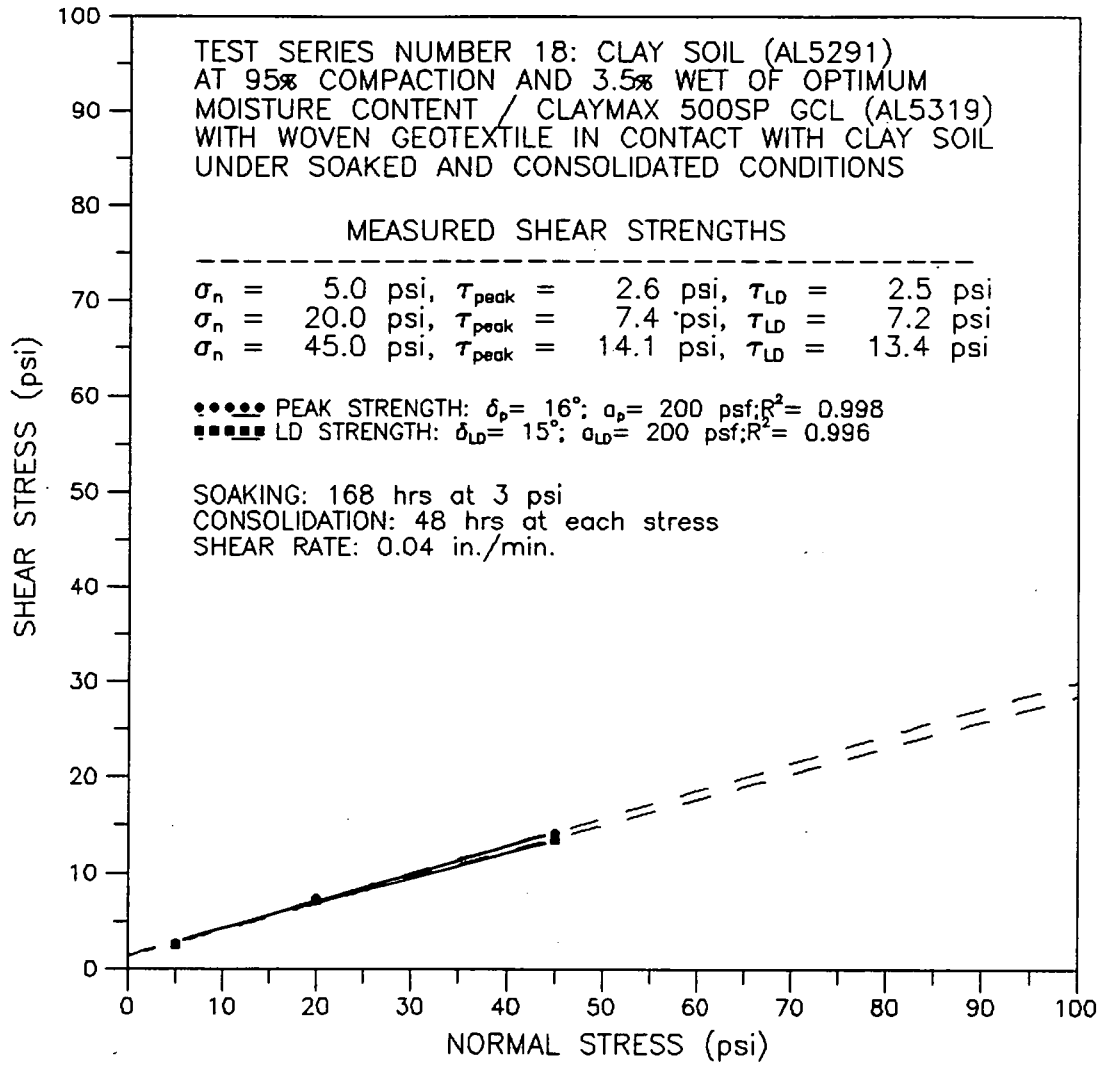
DATE TESTED: 18 TO 28 FEBRUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-43
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTES: (1) The reported total-stress shear strength parameters of friction angle and adhesion may not reflect the true shear strength of the interface, and caution should be exercised in using these shear strength parameters for applications involving normal stresses outside the range of stresses covered by the test.

(2) The large displacement shear strength (τ_{LD}) was calculated using the post-peak shear force measured at the end of each test.

000120

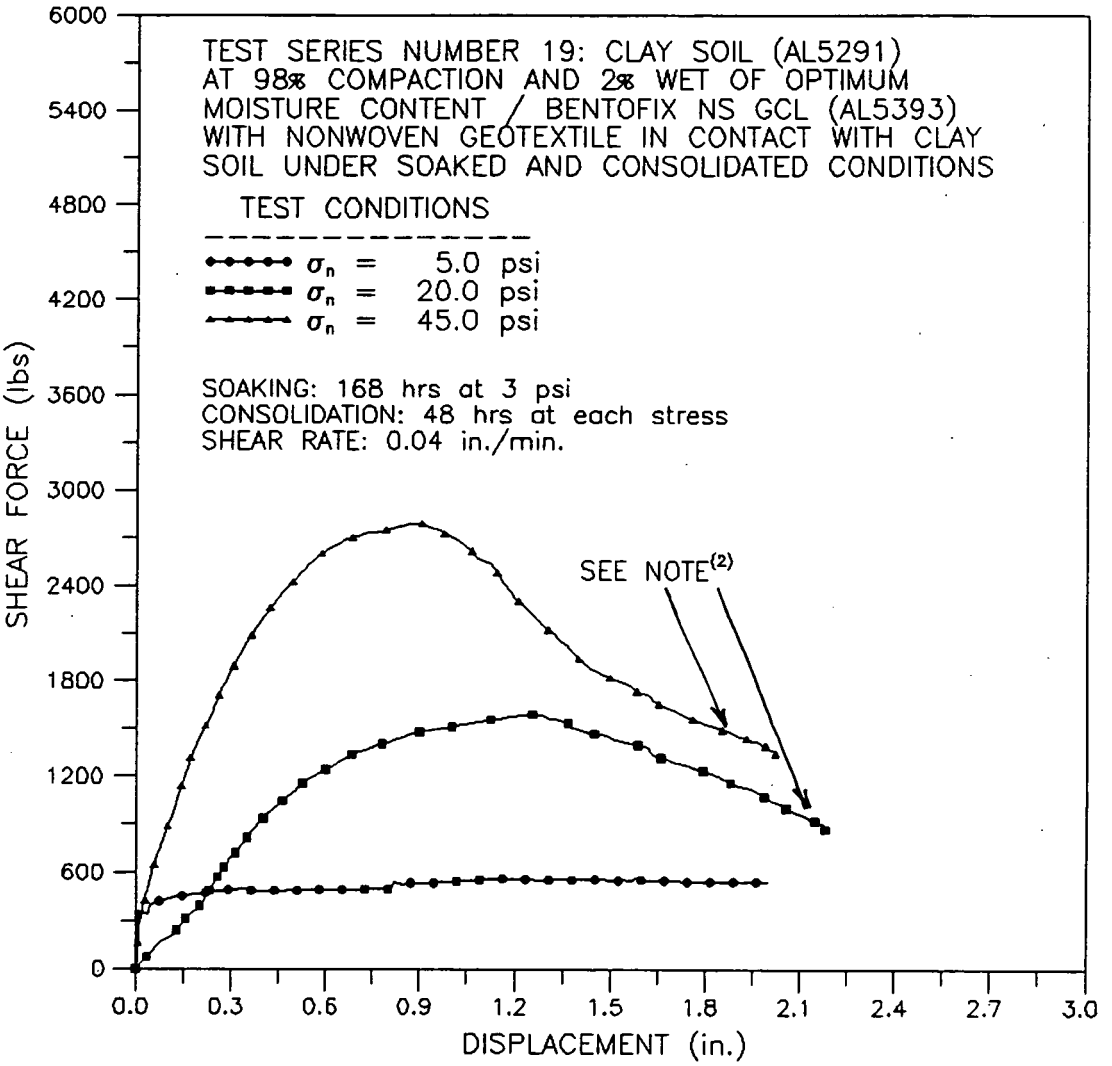
DATE TESTED: 18 TO 28 FEBRUARY 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-44
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTE: (1) The shear box size was 12 in. by 12 in. (300 mm by 300 mm), and the contact area remained constant throughout the entire test.

(2) Sliding (i.e., shear failure) was observed to occur within the GCL rather than at the intended interface.

000121

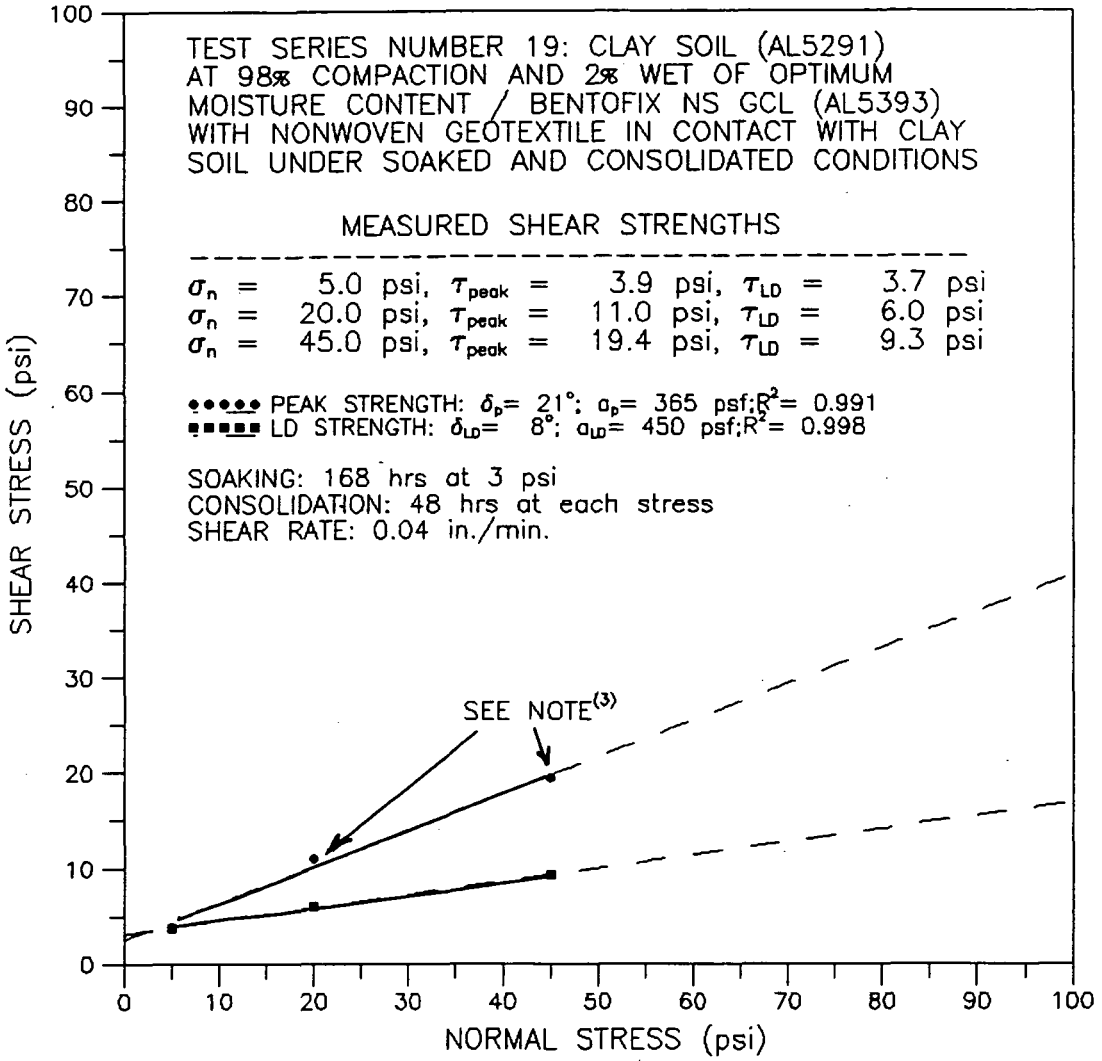
DATE TESTED: 25 FEBRUARY TO 6 MARCH 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-45
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTES: (1) The reported total-stress shear strength parameters of friction angle and adhesion may not reflect the true shear strength of the interface, and caution should be exercised in using these shear strength parameters for applications involving normal stresses outside the range of stresses covered by the test.

(2) The large displacement shear strength (τ_{LD}) was calculated using the post-peak shear force measured at the end of each test.

(3) Sliding (i.e., shear failure) was observed to occur within the GCL rather that at the intended interface.

000122

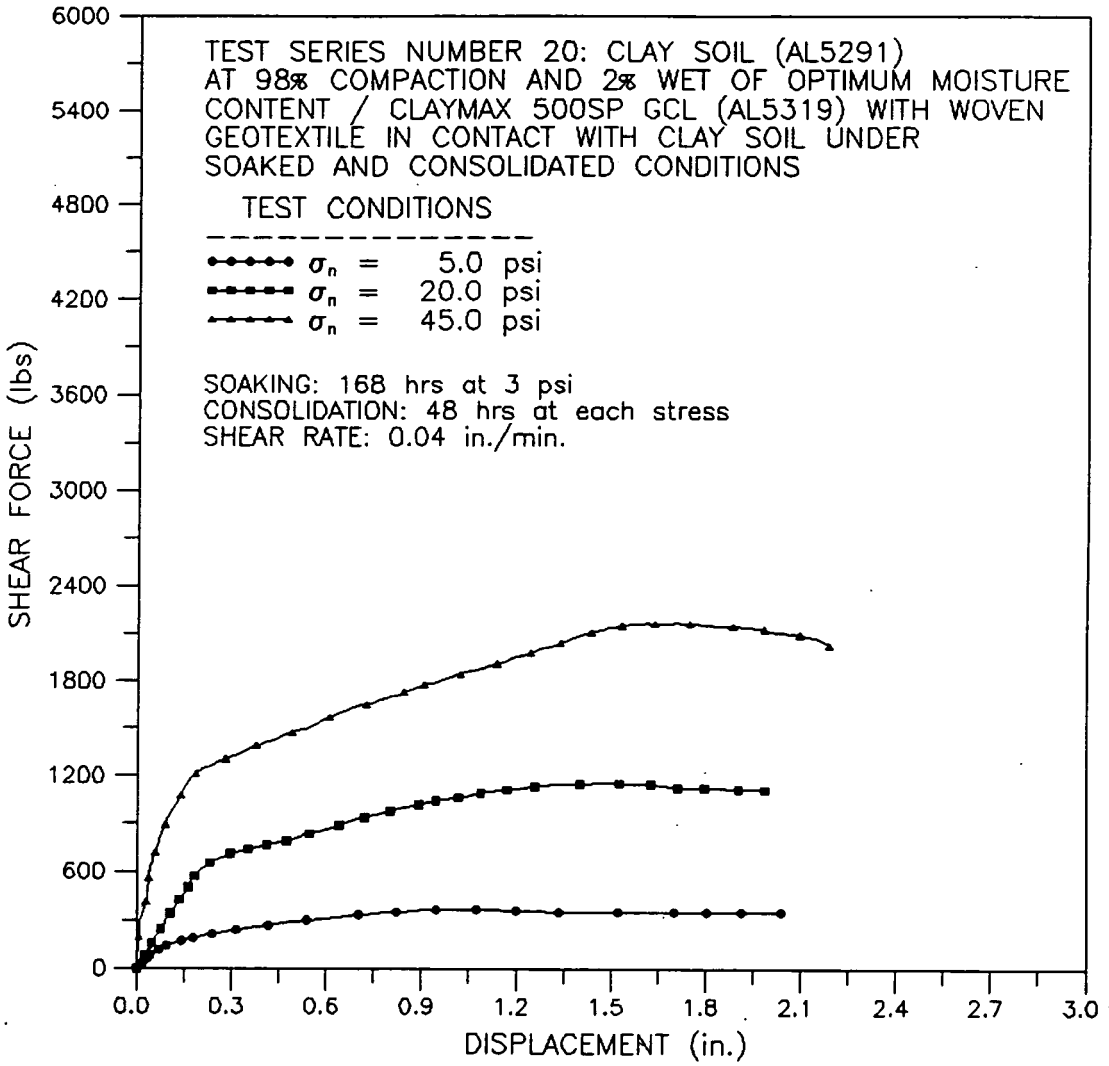
DATE TESTED: 25 FEBRUARY TO 6 MARCH 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-46
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTE: The shear box size was 12 in. by 12 in. (300 mm by 300 mm), and the contact area remained constant throughout the entire test.

000123

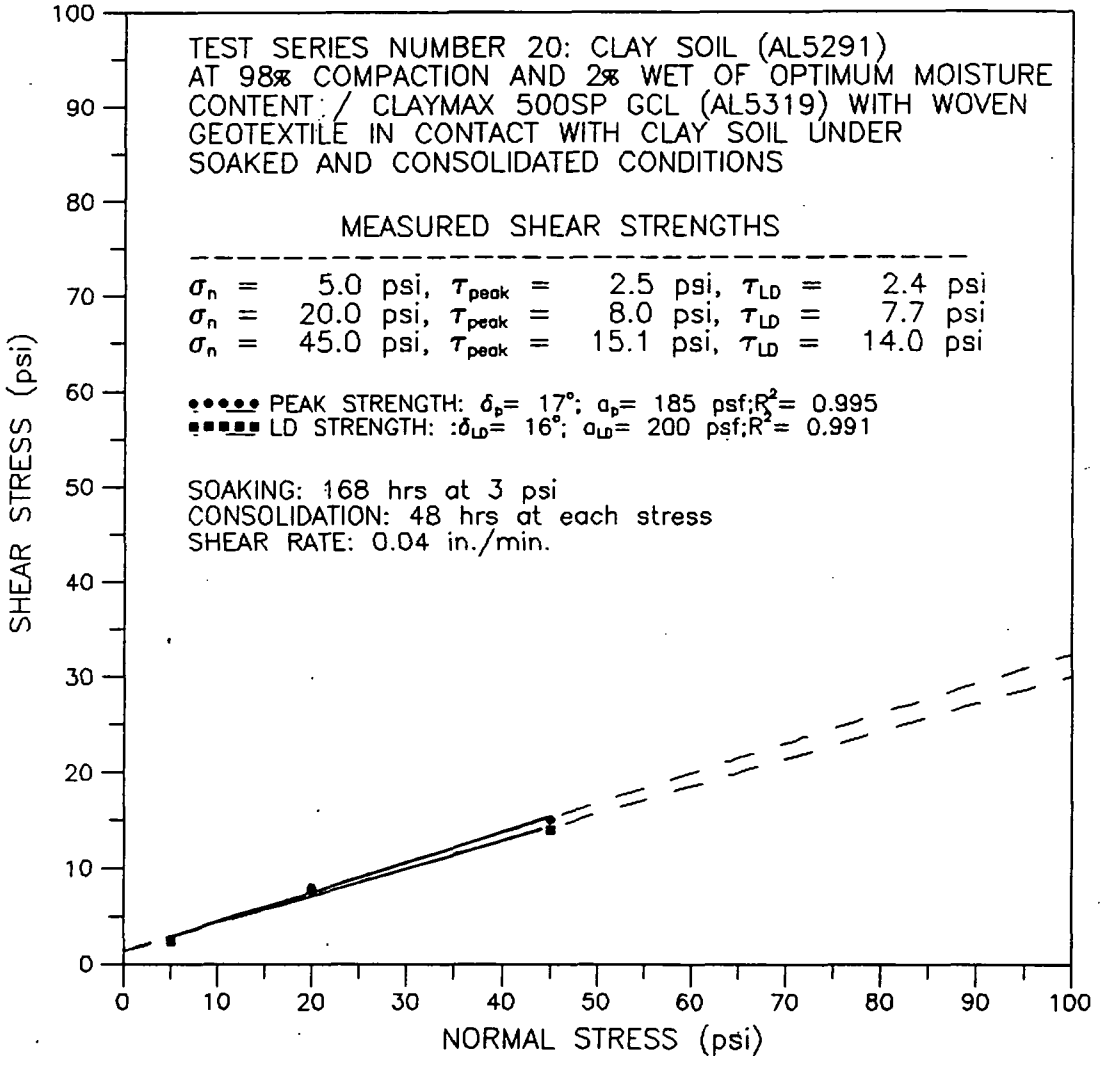
DATE TESTED: 27 FEBRUARY TO 8 MARCH 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-47
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTES: (1) The reported total-stress shear strength parameters of friction angle and adhesion may not reflect the true shear strength of the interface, and caution should be exercised in using these shear strength parameters for applications involving normal stresses outside the range of stresses covered by the test.

(2) The large displacement shear strength (τ_{LD}) was calculated using the post-peak shear force measured at the end of each test.

000124

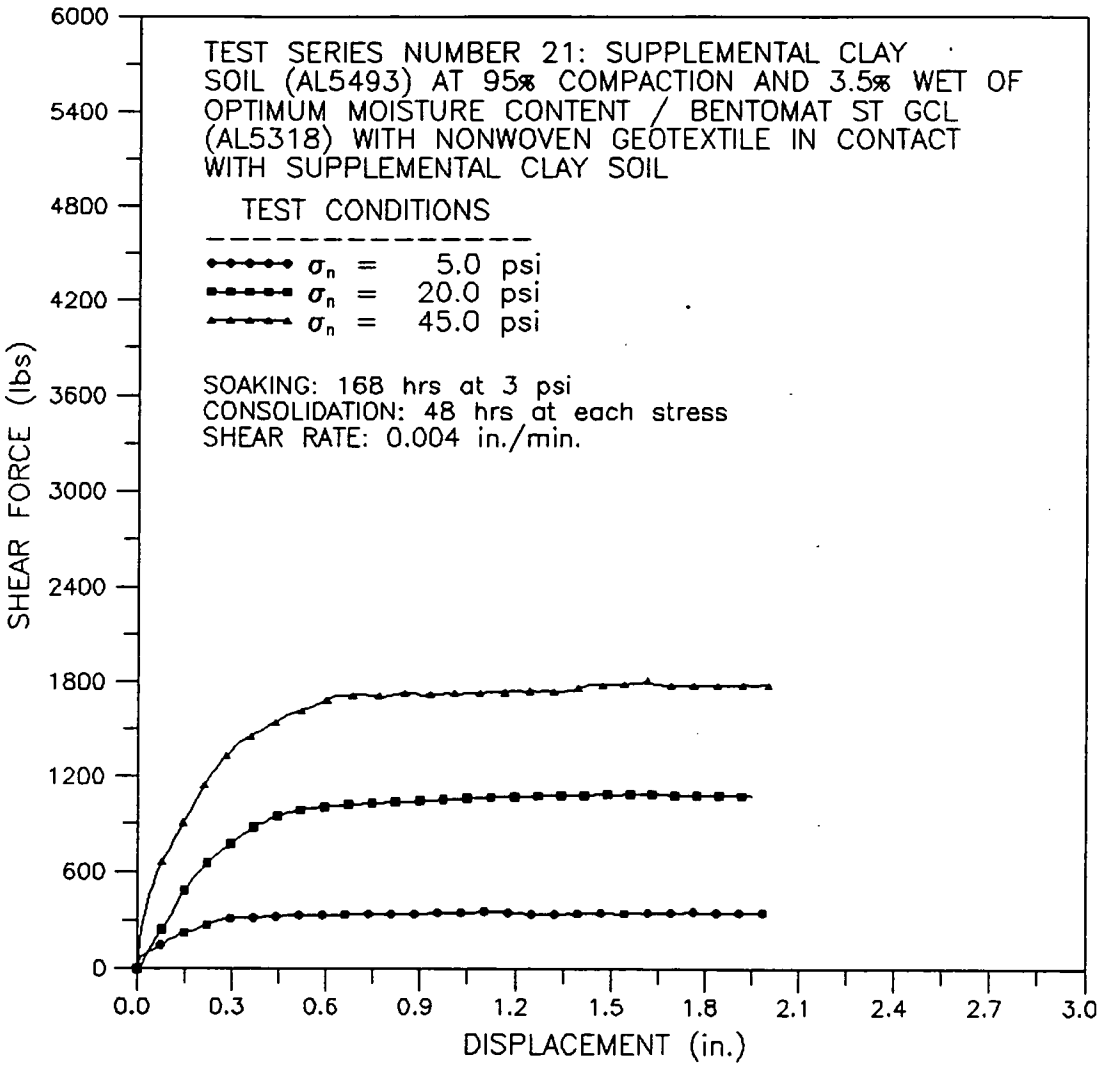
DATE TESTED: 27 FEBRUARY TO 8 MARCH 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-48
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTE: The shear box size was 12 in. by 12 in. (300 mm by 300 mm), and the contact area remained constant throughout the entire test.

000125

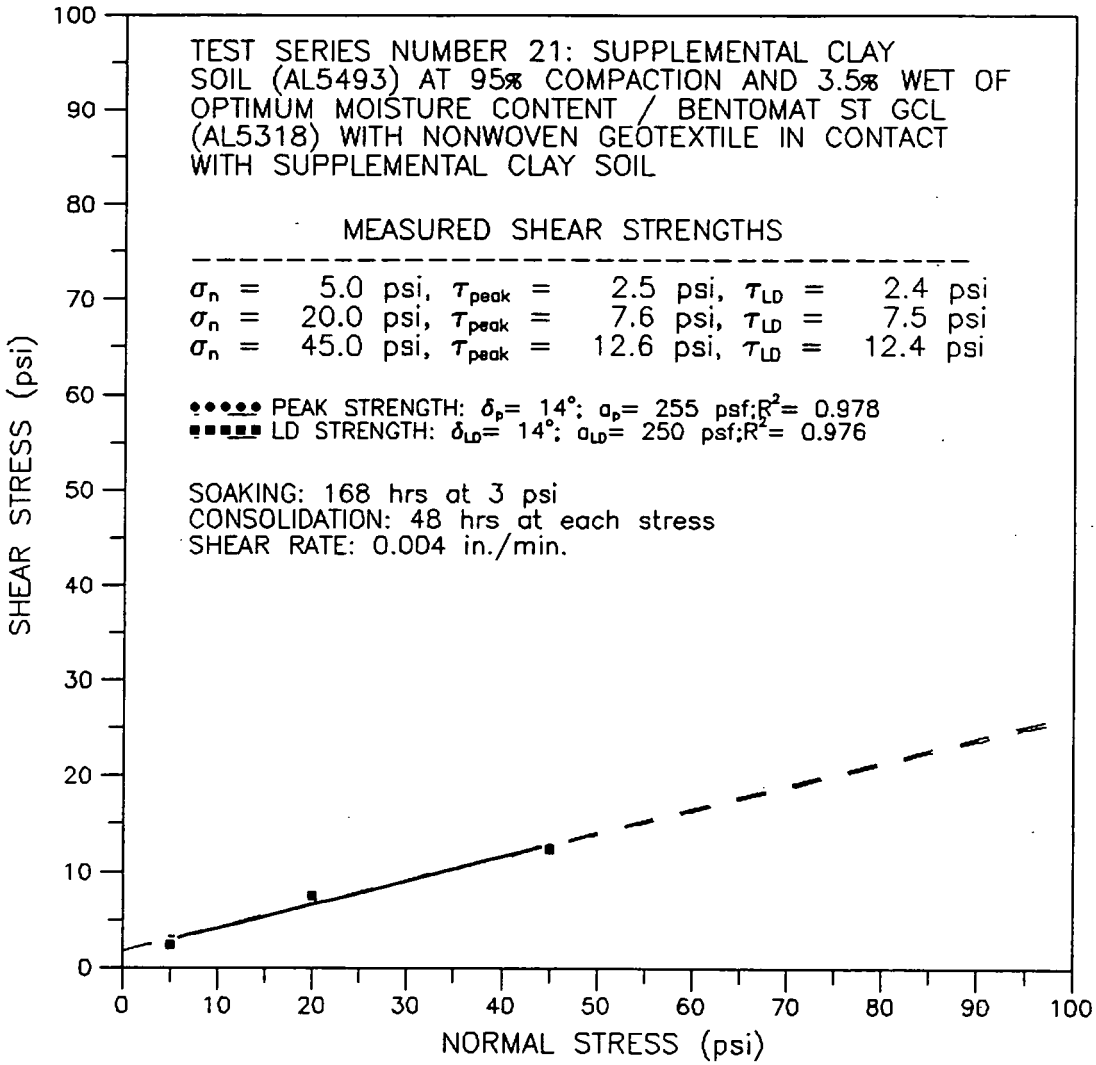
DATE TESTED: 5 TO 15 MARCH 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-49
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTES: (1) The reported total-stress shear strength parameters of friction angle and adhesion may not reflect the true shear strength of the interface, and caution should be exercised in using these shear strength parameters for applications involving normal stresses outside the range of stresses covered by the test.

(2) The large displacement shear strength (τ_{LD}) was calculated using the stabilized post-peak shear force measured at the end

000126

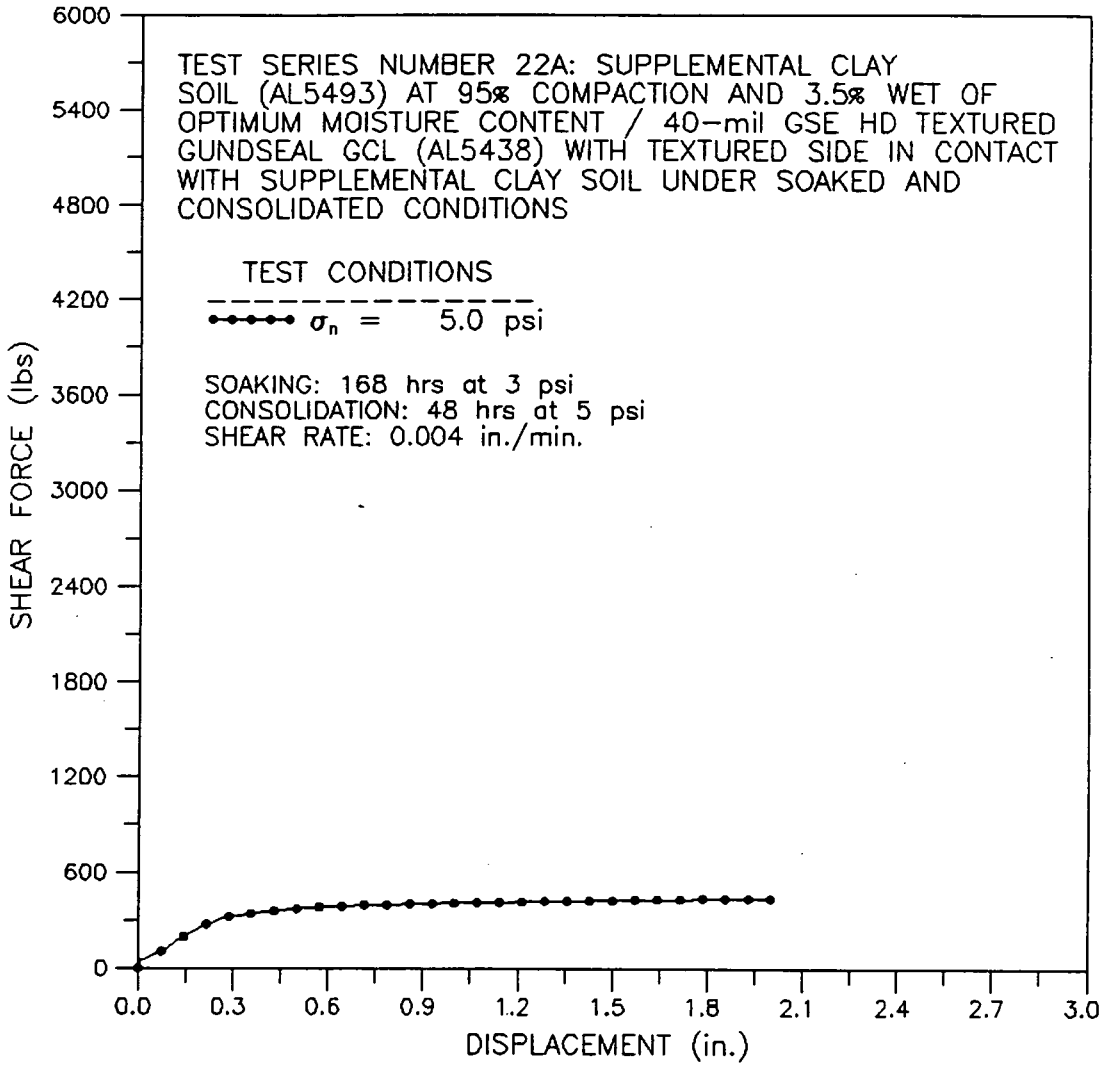
DATE TESTED: 5 TO 15 MARCH 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-50
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTE: The shear box size was 12 in. by 12 in. (300 mm by 300 mm), and the contact area remained constant throughout the entire test.

000127

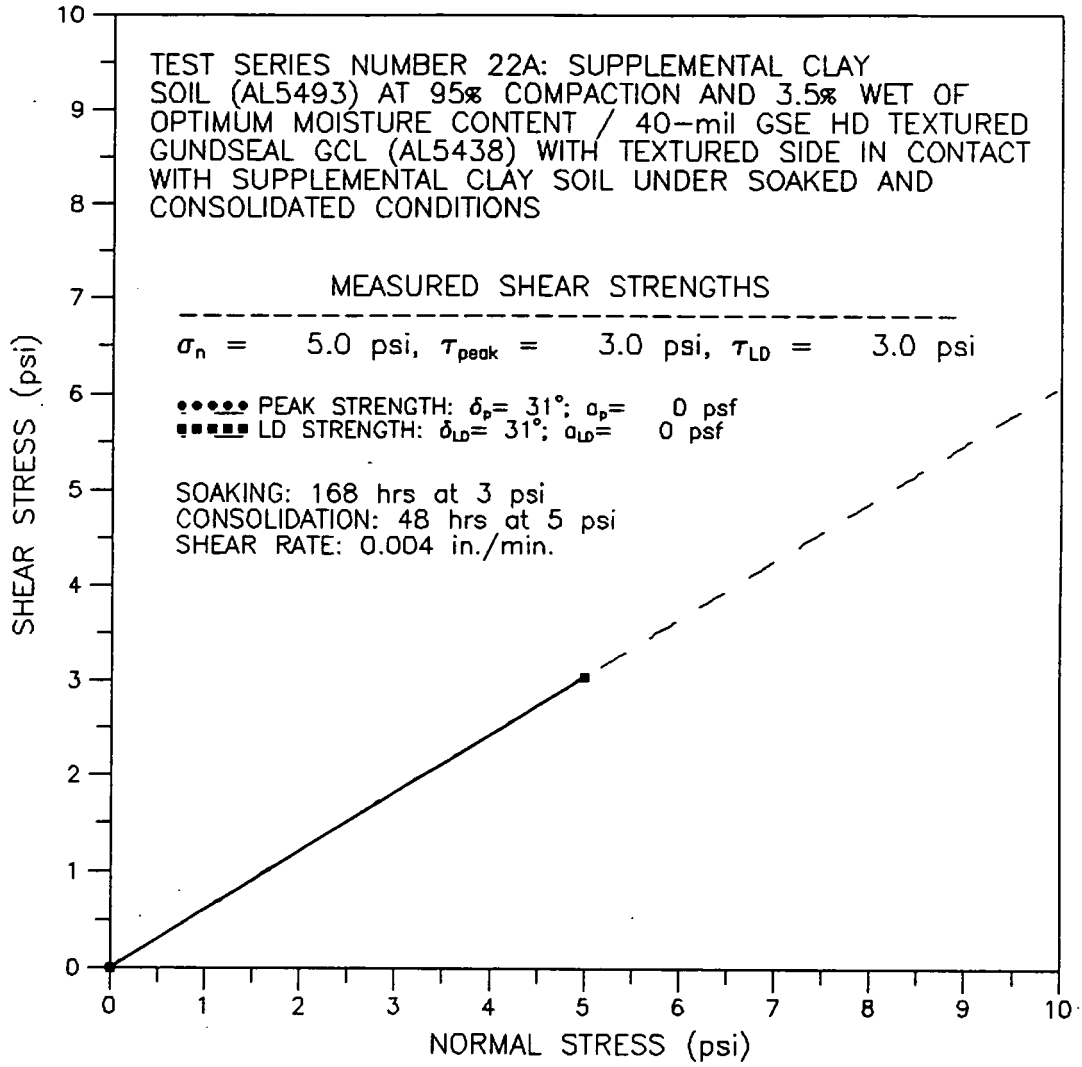
DATE TESTED: 8 TO 18 MARCH 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-51
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTE: The large displacement shear strength (τ_{LD}) was calculated using the post-peak shear force measured at the end of each test.

000128

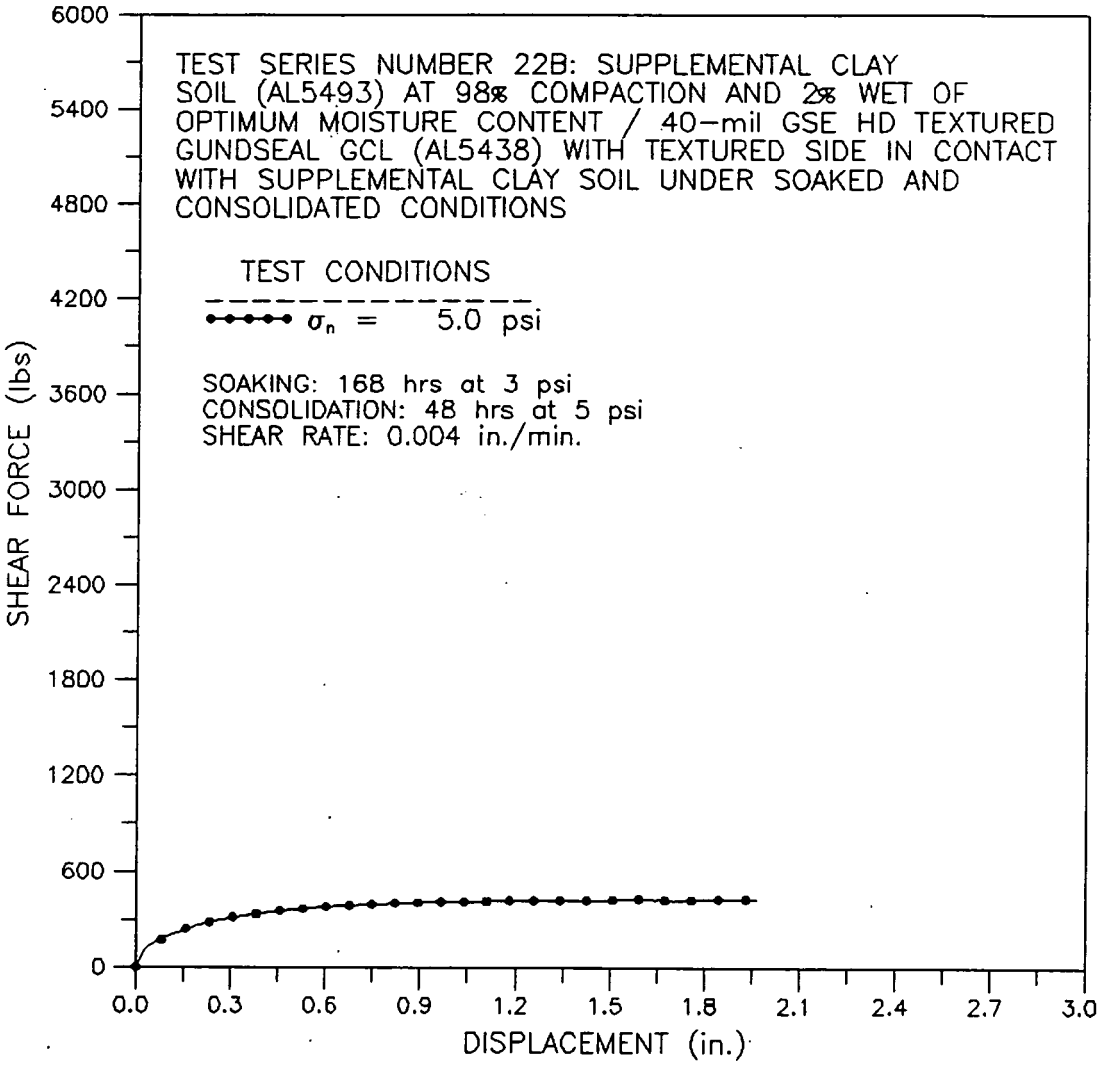
DATE TESTED: 8 TO 18 MARCH 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-52
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTE: The shear box size was 12 in. by 12 in. (300 mm by 300 mm), and the contact area remained constant throughout the entire test.

000129

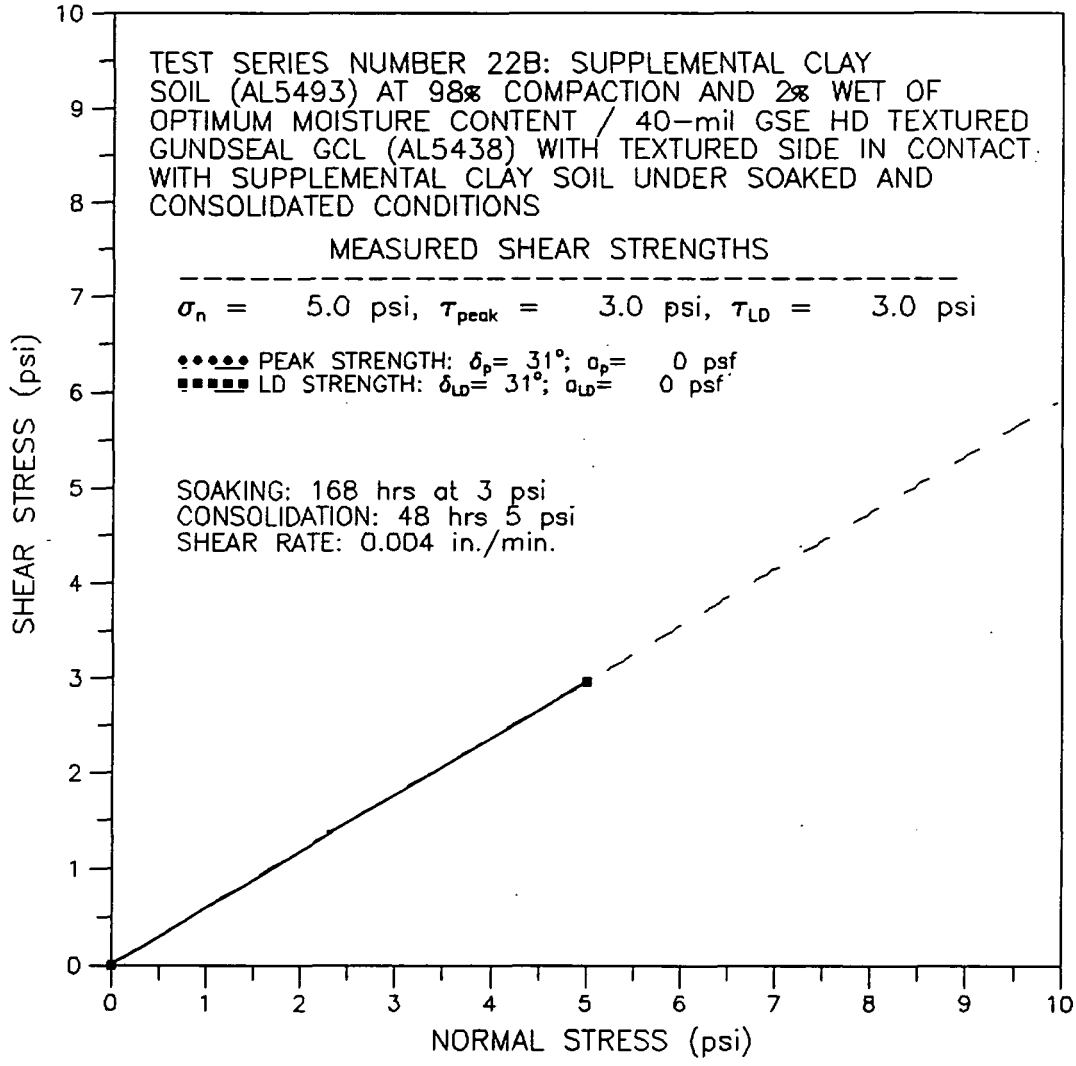
DATE TESTED: 8 TO 18 MARCH 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-53
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
ON-SITE DISPOSAL FACILITY
INTERFACE DIRECT SHEAR TESTING



NOTE: The large displacement shear strength (τ_{LD}) was calculated using the post-peak shear force measured at the end of each test.

000130

DATE TESTED: 8 TO 18 MARCH 1996

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	B-54
PROJECT NO.	GE3900-9.3
DOCUMENT NO.	F964S006
FILE NO.	