BENTOMAT® DN GCL CREEP SHEAR TESTING

Commercially available geosynthetic clay liners (GCLs) consist of bentonite that is either sandwiched between two geotextiles or is bonded to a single geomembrane. GCLs may be further categorized as *unreinforced* or *reinforced*. Unreinforced GCLs have no internal reinforcement and thus possess relatively low shear strength. Reinforced GCLs, by means of needlepunching, are designed to carry and transmit shear loads within their structure and are typically used on slopes greater than 10H:1V.

The creep shear strength behavior of Bentomat ST was previously detailed by Trauger, et.al. (1997) (see TR-217). Bentomat ST is a GCL consisting of a woven geotextile on one side of the bentonite component and a nonwoven geotextile on the other side, reinforced with needlepunched fibers. Two large-scale constant-load (creep) shear testing devices were developed to evaluate the long-term shearing behavior of the GCL. One device was designed to simulate loading conditions that typically occur on a GCL deployed as a cover system. The other device was designed to simulate loading conditions that typically occur on a GCL used in a lining system. The results showed that Bentomat ST had undergone relatively small shear displacements and that the shear displacement rates within the GCL and/or the test interface were continuously decreasing with time.

This program tested Bentomat DN, a GCL consisting of bentonite between two nonwoven geotextiles, reinforced with needlepunched fibers. Once again two large-scale constant-load shear-testing devices were utilized. High normal load testing is being performed on a sample initially hydrated in tap water for 120 hours under a normal load of 400 psf. Then the sample was consolidated and sheared at incrementally increased normal load and constant shear stresses while interfaced with a textured geomembrane. Low normal load testing was performed at a normal stress of 500 psf (24 kPa) and a constant shear load of 250 lbs. (110 kg). The entire test specimen was soaked in tap water for 120 hours under the normal load prior to applying the constant shear load. The entire specimen remained submerged throughout the entire test duration.

The Bentomat DN high normal load shear testing reached the 5,600-hour mark before a mechanical failure (ruptured air bladder) ended the test. For the high normal load study, the total displacement at 5,600 hours was 0.329 in. (8.4 mm) and the displacement rate decreased over time to approximately 1.47×10^{-7} in/min. (3.8×10^{-6} mm/min). The Bentomat DN total displacement and displacement rate are very close to those experienced by Bentomat ST at the same time of its high normal load creep test.

The Bentomat DN creep shear low normal load testing has passed the 10,000-hour mark. For the low normal load study, the total displacement at 10,000 hours was approximately 0.067 in. (1.7 mm) and the displacement rate decreased over time to approximately 2.7×10^{-8} in/min. (6.9×10^{-7} mm/min). Again, the Bentomat DN total displacement and displacement rate are very close to those experienced by Bentomat ST at the 10,000-hour mark of its low normal load creep test. The displacement at peak internal shear strength for Bentomat DN at this low normal load is typically between 0.75 to 1 inch. Thus, Bentomat DN appears to be quite stable with respect to constant-load creep shear.

800.527.9948 Fax 847.577.5566

References

Trauger R.J., Swan R.H. and Yuan Z., "Long-Term Shear Strength Behavior of a Needlepunched Geosynthetic Clay Liner", *Testing and Acceptance Criteria for Geosynthetic Clay Liners,* ASTM STP 1308, American Society for Testing and Materials, W. Conshohocken, PA, 1997.

Geosyntec Consultants, Atlanta,GA, "Final Report – 10,000 hour Constant-Load (Creep) Shear Testing: Bentomat DN GCL Landfill Cover System Evaluation", Project No. GLI3545, February 1, 2001.

Geosyntec Consultants, Atlanta,GA, "Interim Report – Multi-Step Constant-Load (Creep) Shear Testing: Bentomat DN GCL Landfill Lining System Evaluation", Project No. GLI3545, February 1, 2001.

Prepared for:

CETCO
Lining Technologies Group

1500 West Shure Drive
Arlington Heights, Illinois 60004-1440

FINAL REPORT
10,000-HOUR CONSTANT-LOAD (CREEP) SHEAR TESTING

BENTOMAT DN GCL
LANDFILL COVER SYSTEM EVALUATION

Prepared by:

GeoSyntec Consultants
Soil-Geosynthetic Interaction Testing Laboratory
5775 Peachtree Dunwoody Road, Suite 11D
Atlanta, Georgia 30342

Project Number GLI3545

1 February 2001

CAVEAT

The reported results apply only to the materials and test conditions used in the laboratory testing program. The results do not necessarily apply to other materials or test conditions. The test results should not be used in engineering analysis unless the test conditions model the anticipated field conditions. The testing was performed in accordance with general engineering testing standards and requirements. This testing report is submitted for the exclusive use of the client to whom it is addressed.

1. INTRODUCTION

The details of samples submitted for testing to GeoSyntec Consultants' Soil-Geosynthetic Interaction Testing Laboratory (GeoSyntec-SGI®), 5775 Peachtree Dunwoody Road, Suite 11D, Atlanta, Georgia 30342, are as follows:

Submitted by: Mr. James Olsta, P.E.

Client: Colloid Environmental Technologies Company

Address: 1500 West Shure Drive
Arlington Heights, Illinois 60004-1440

Materials tested: Bentomat DN GCL consisting of a nonwoven geotextile on each side of the bentonite component. The GCL was needlepunched together to form the finished product.

2. TEST PROGRAM

The test procedures and results are described in the following appendices:
Appendix A: Summary of Test Procedures
Appendix B: Summary of Test Results
Appendix C: Creep Shear Test Data

3. STORAGE AND DISPOSAL OF MATERIALS

Samples will be stored for 30 days from the date of this report and then discarded unless GeoSyntec-SGI® is informed otherwise.

* * * * *

REPORT REVIEW

REPORT PREPARATION BY:

Zehong Yuan, Ph.D., P.E.
Program Manager

TECHNICAL REVIEW BY:

Robert H. Swan, Jr.
Laboratory Manager

APPENDIX A

SUMMARY OF TEST PROCEDURES

SUMMARY OF TEST PROCEDURES

CONSTANT LOAD (CREEP) SHEAR TESTING

Test Method

The creep shear test was performed in accordance with the American Society for Testing and Materials (ASTM) Standard Test Method D 6243, "*Determining the Internal and Interface Shear Resistance of Geosynthetic Clay Liner by the Direct Shear Method*". The test was conducted in a specifically designed large direct shear device consisting of five major components, as shown in Figure 1 of Appendix A:

- a rigid supporting table;
- a upper shear box measuring 12 in. by 12 in. in plan and 3 in. in depth and a lower shear box measuring 14 in. by 12 in. in plan and 3 in. in depth;
- a waterproof containment box to allow the test specimen to be tested under fully submerged conditions;
- a dead weight loading system for applying normal loads to the test specimen; and
- a dead weight loading system for applying constant shear load to the test specimen.

Sample Description and Test Configuration

The creep shear test was conducted on the Bentomat DN GCL. The configuration of the test specimen used in the creep shear test, from top to bottom, consisted of:

- rigid substrate with textured steel gripping surface;
- Bentomat DN GCL; and
- rigid substrate with textured steel gripping surface.

A bulk sample of the GCL material was provided to GeoSyntec by CETCO.

Test Procedures

For the creep shear test, the entire test specimen was constructed and tested under the same conditions as described below:

- Test Atmosphere: the test was conducted in a controlled atmosphere where the air was maintained at a relative humidity of 50 to 70 percent and a temperature of 70 +/- 4° F (21 +/- 2°C); both relative humidity and temperature were monitored on a regular basis.

- A fresh GCL specimen was trimmed from the bulk sample of the GCL and placed between two rigid wooden substrates with 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 2 of Appendix A. The entire test specimen was then placed in the shear box to provide confinement for the exposed bentonite component. The textured steel gripping surfaces were employed to minimize slippage between each geotextile component of the GCL and rigid wood substrate, therefore providing a relatively uniform transfer of shear load onto the GCL specimen.

- Soaking Conditions: the entire test specimen was soaked in tap water for 120 hours under a normal stress of 500 psf. The soaking normal stress was applied to the test specimen with the use of dead weight prior to immersion. The entire test specimen remained submerged throughout the entire test duration.

- Loading Conditions: after the 120-hour soaking period, a constant shear stress of 250 psf was applied to the test specimen within 3 to 5 seconds in a controlled manner without disruption of the soaking normal stress. The constant shear stress was applied to the test specimen through the use of the dead weight loading system and monitored on a regular basis.

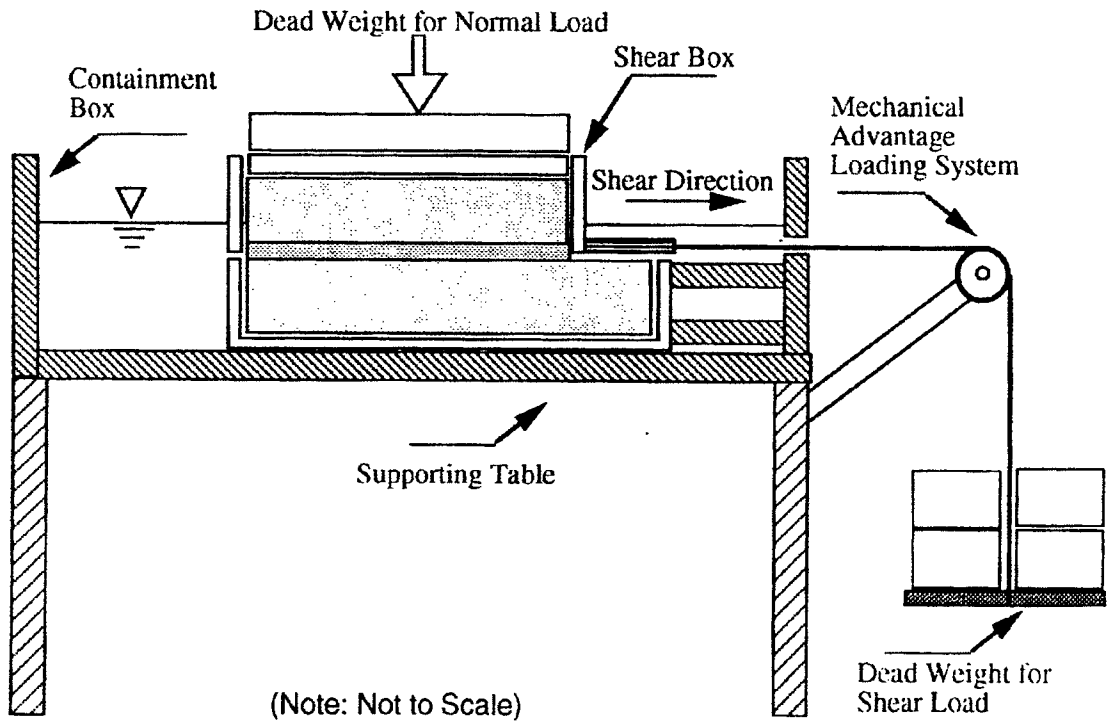
- Monitoring: vertical displacements (i.e., swelling or compression) of the GCL specimen during the entire test were monitored with the use of dial gages. Shear displacements were monitored by using a dial gage attached to a "tell-tail" wire, which was connected to the upper shear box. Both the vertical and horizontal

displacements were monitored on a regular basis.

Test Data Presentation

The creep shear test is being conducted to evaluate the behavior of the Bentomat DN GCL under constant-load conditions. The creep shear test is currently ongoing. The total duration of the shear phase at the time of this report is approximately 13,100 hours. For the test, measured vertical displacements during the initial soaking phase were plotted on a graph of vertical displacement versus logarithm of time. Measured vertical and shear displacements during the constant-load shear phase were plotted on a graph of vertical and shear displacement versus logarithm of time. Incremental shear displacement rates were calculated using the measured shear displacement data and plotted on a graph of logarithm of displacement rate versus shear displacement and a graph of logarithm of displacement rate versus logarithm of time. The results of the creep shear test are presented graphically in Appendix C.

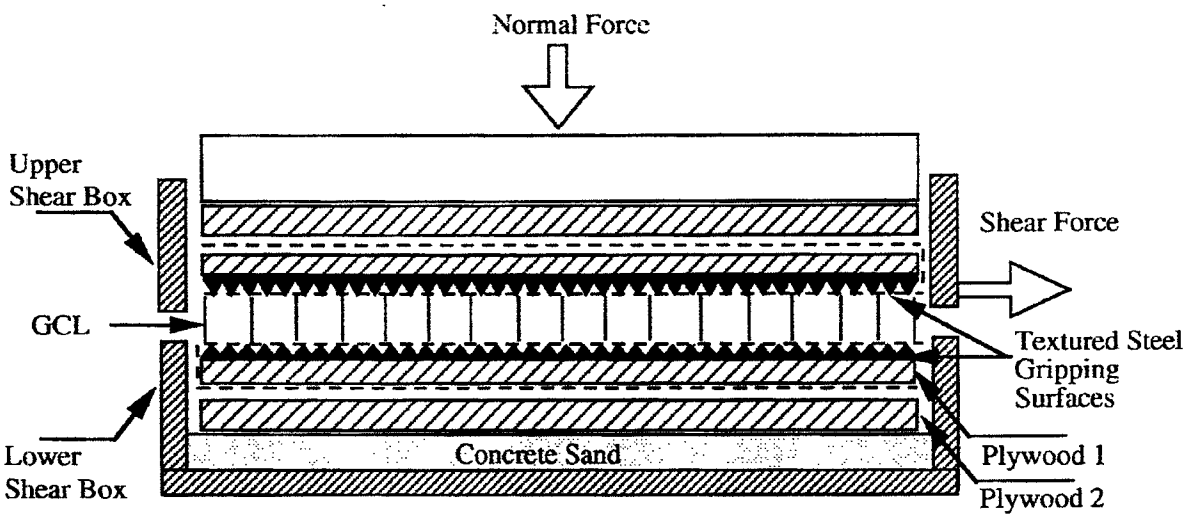
A summary of the creep shear test results is presented in Table 1 of Appendix B. This table presents the total shear displacement and incremental shear displacement rate at 1, 10, 100, 500, 1000, 5000, and 10,000 hours of elapsed time for the GCL specimen. It is noted that the values of displacement and displacement rates at these selected times presented in Table 1 may have been derived by linear interpolation between the actually measured data points at the specific time period of interest.



GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	1
PROJECT NO.	GLI3545
DOCUMENT NO.	SGI01013
FILE NO.	

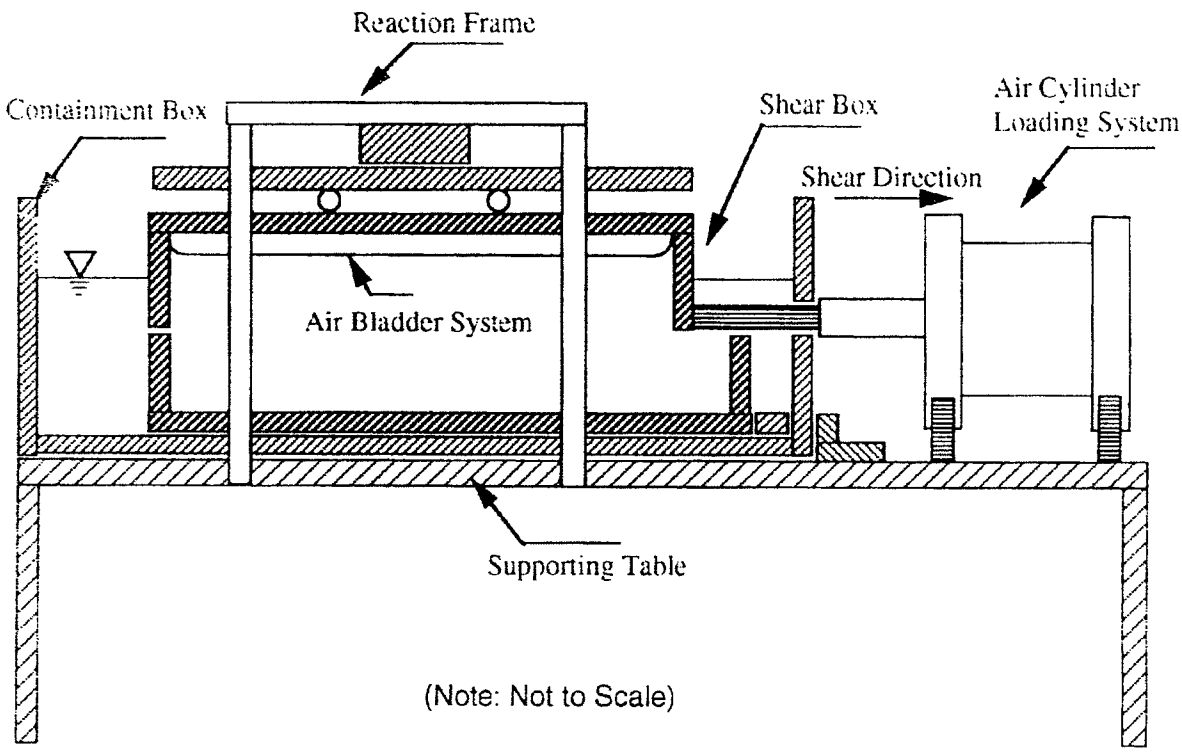


(Note: Not to Scale)

GEOSYNTEC CONSULTANTS

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	2
PROJECT NO.	GLI3545
DOCUMENT NO.	SGI01013
FILE NO.	

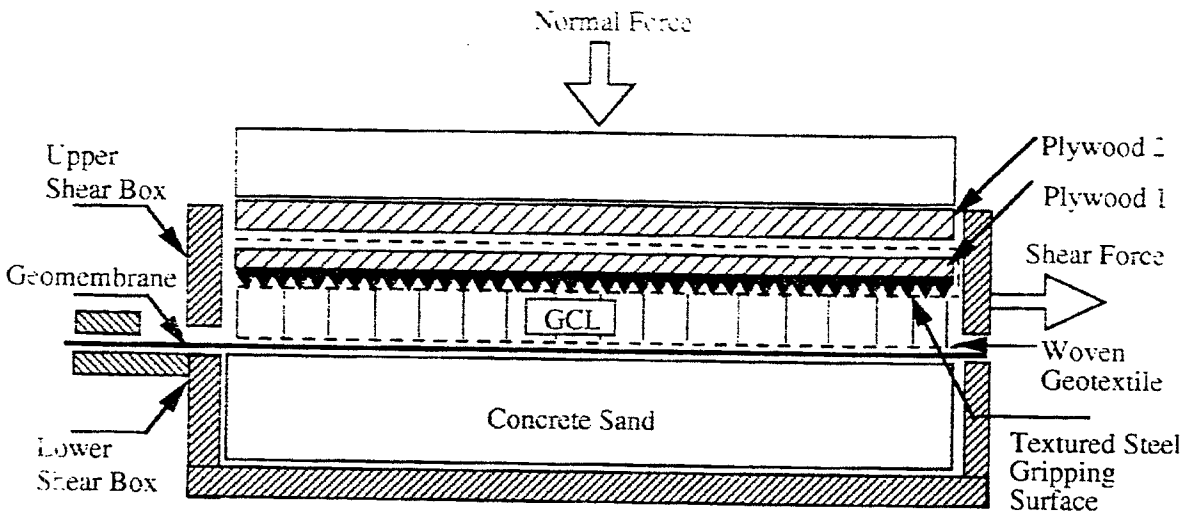


(Note: Not to Scale)

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	1
PROJECT NO.	GLI3545
DOCUMENT NO.	SGI01014
FILE NO.	



(Note: Not to Scale)

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	2
PROJECT NO.	GLI3545
DOCUMENT NO.	SGI01014
FILE NO.	

APPENDIX B

SUMMARY OF TEST RESULTS

TABLE 1

SUMMARY OF CREEP SHEAR TEST RESULTS
COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
BENTOMAT DN GCL
LANDFILL COVER SYSTEM EVALUATION

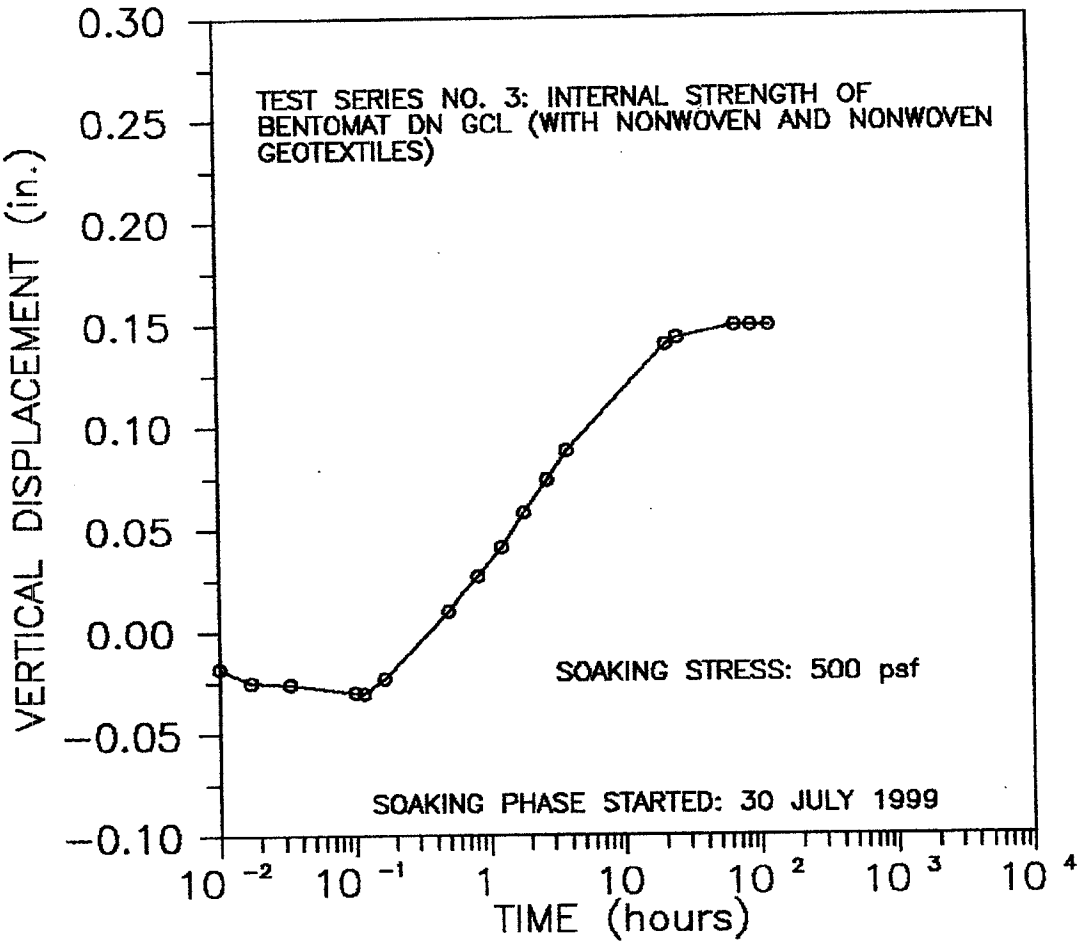
Test Number[1]	1	
Test Specimen	Bentomat DN GCL	
Loading Conditions	Normal Stress: 500 psf Shear Stress: 250 psf	
Elapsed Time (Hours)	Total Shear Displacement (in.)	Incremental Shear Displacement Rate (in./min)
1	0.031	6.78×10^{-5}
10	0.035	6.59×10^{-6}
100	0.038	6.40×10^{-7}
500	0.042	2.90×10^{-7}
1,000	0.046	1.48×10^{-7}
5,000	0.062	5.79×10^{-8}
10,000	0.067	2.66×10^{-8}

NOTE: (1) The GCL specimen was soaked in tap water for 120 hours under a normal stress of 500 psf prior to application of the constant shear load to the GCL specimen. This test is currently ongoing; therefore the total duration of the shear phase at the time of this report is approximately 13,100 hours.

APPENDIX C

CREEP SHEAR TEST DATA

COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
CREEP SHEAR TESTING
SOAKING PHASE



TESTING ATMOSPHERE: AIR MAINTAINED AND REGULARLY MONITORED AT A RELATIVE HUMIDITY OF 50 TO 72 PERCENT AND A TEMPERATURE OF 70 +/− 2 degF(21 +/− 1 degC).

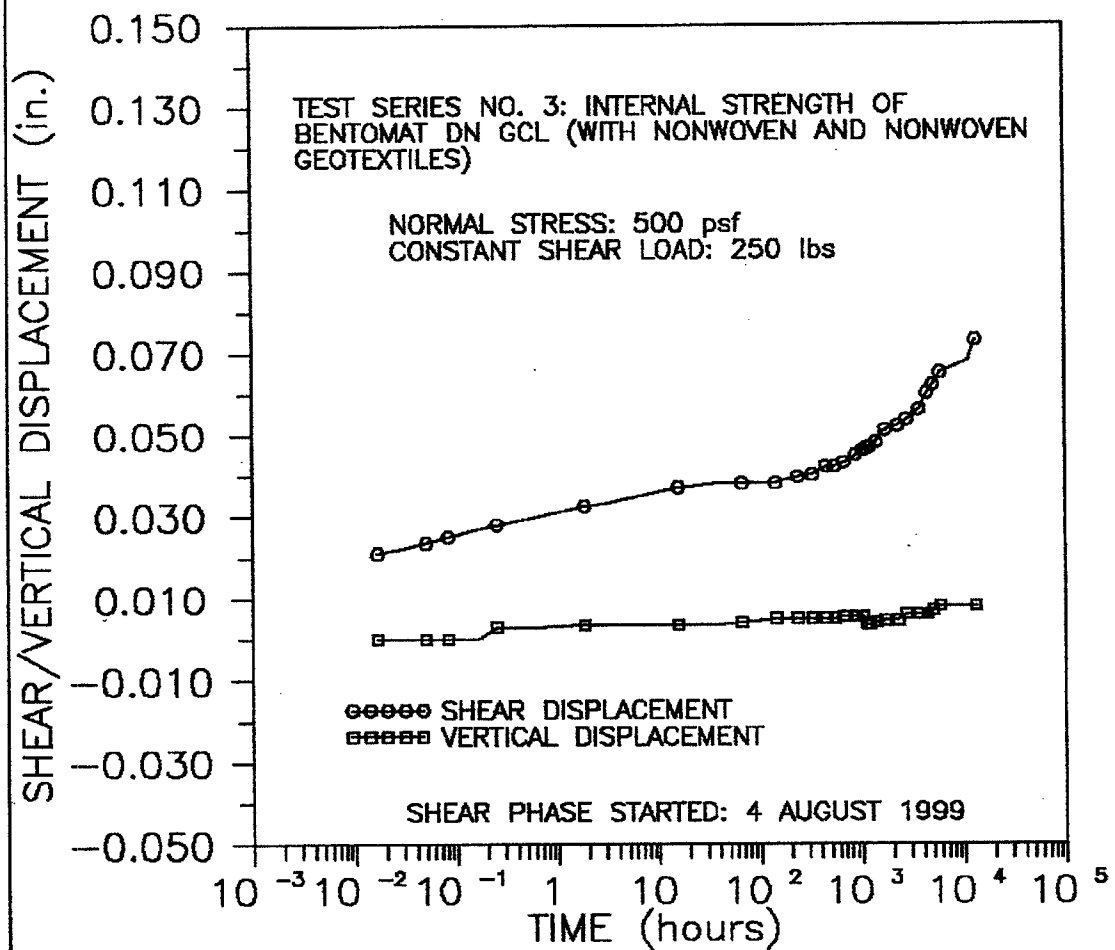
DATE REPORTED: 31 JANUARY 2001

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	3
PROJECT NO.	GLI3545−02
DOCUMENT NO.	SGI99083
FILE NO.	

COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
CREEP SHEAR TESTING
SHEARING PHASE



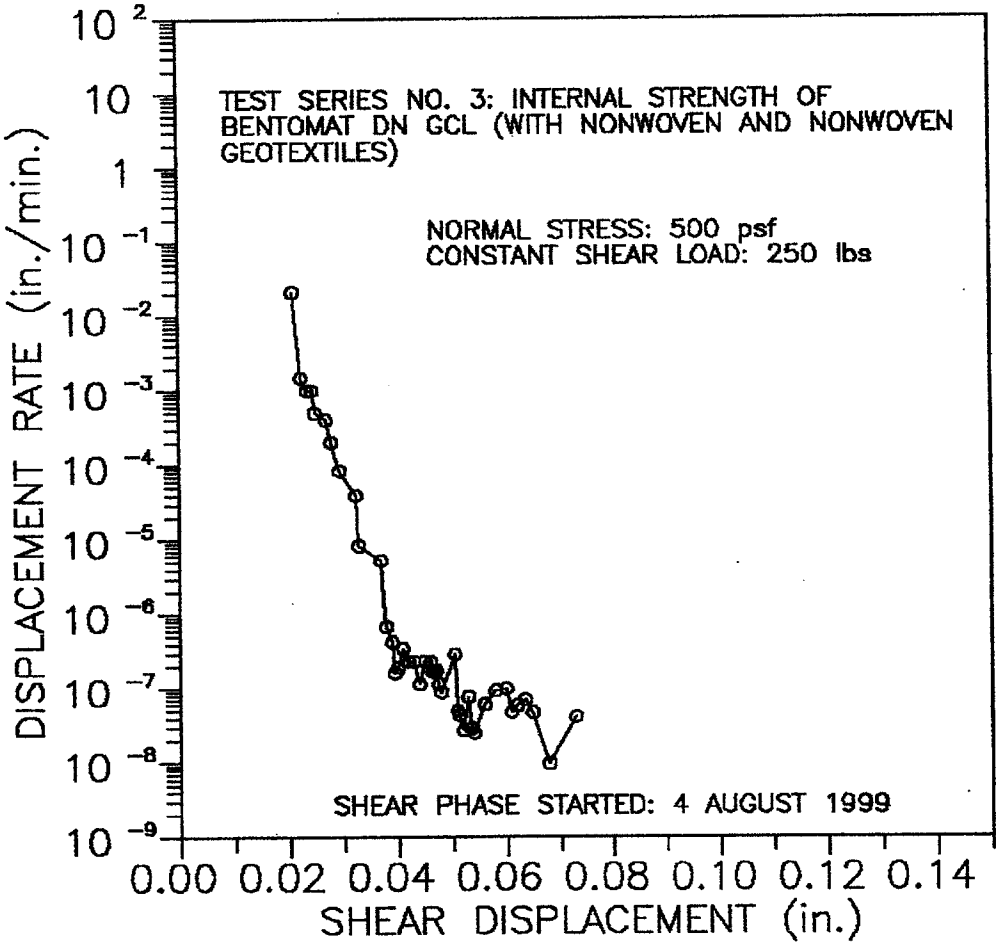
TESTING ATMOSPHERE: AIR MAINTAINED AND REGULARLY MONITORED AT A RELATIVE HUMIDITY OF 50 TO 70 PERCENT AND A TEMPERATURE OF 70 +/− 4 deg F (21 +/− 2 deg C).

DATE REPORTED: 31 JANUARY 2001

GeoSyntec Consultants
SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	4
PROJECT NO.	GLI3545−02
DOCUMENT NO.	SGI99083
FILE NO.	

COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
CREEP SHEAR TESTING
SHEARING PHASE



TESTING ATMOSPHERE: AIR MAINTAINED AND REGULARLY MONITORED AT A RELATIVE HUMIDITY OF 50 TO 72 PERCENT AND A TEMPERATURE OF 70 +/- 2 degF(21 +/- 1 degC).

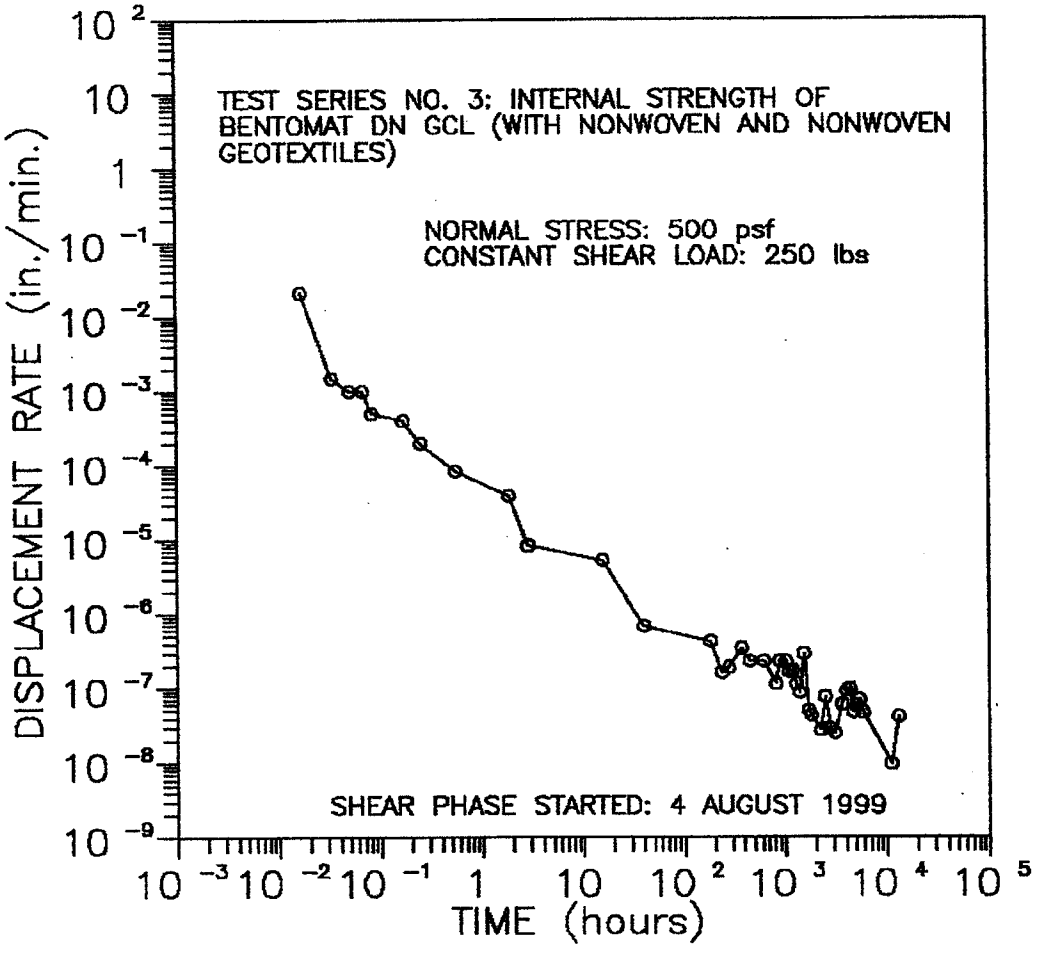
DATE REPORTED: 31 JANUARY 2001

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	5
PROJECT NO.	GLI3545-02
DOCUMENT NO.	SGI99083
FILE NO.	

COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
CREEP SHEAR TESTING
SHEARING PHASE



TESTING ATMOSPHERE: AIR MAINTAINED AND REGULARLY MONITORED AT A RELATIVE HUMIDITY OF 50 TO 72 PERCENT AND A TEMPERATURE OF 70 +/- 2 degF(21 +/- 1 degC).

DATE REPORTED: 31 JANUARY 2001

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	6
PROJECT NO.	GLI3545-02
DOCUMENT NO.	SGI99083
FILE NO.	

Prepared for:

CETCO
Lining Technologies Group

1500 West Shure Drive
Arlington Heights, Illinois 60004-1440

FINAL REPORT
MULTI-STEP CONSTANT-LOAD (CREEP) SHEAR TESTING

BENTOMAT DN GCL / GSE TEXTURED HDPE GEOMEMBRANE LANDFILL LINING SYSTEM EVALUATION

Prepared by:

GeoSyntec Consultants
Soil-Geosynthetic Interaction Testing Laboratory
5775 Peachtree Dunwoody Road, Suite 11D
Atlanta, Georgia 30342

Project Number GLI3545

1 February 2001

CAVEAT

The reported results apply only to the materials and test conditions used in the laboratory testing program. The results do not necessarily apply to other materials or test conditions. The test results should not be used in engineering analysis unless the test conditions model the anticipated field conditions. The testing was performed in accordance with general engineering testing standards and requirements. This testing report is submitted for the exclusive use of the client to whom it is addressed.

1. INTRODUCTION

The details of samples submitted for testing to GeoSyntec Consultants' Soil-Geosynthetic Interaction Testing Laboratory (GeoSyntec-SGI®), 5775 Peachtree Dunwoody Road, Suite 11D, Atlanta, Georgia 30342, are as follows:

Submitted by: Mr. James Olsta, P.E.

Client: Colloid Environmental Technologies Company

Address: 1500 West Shure Drive
Arlington Heights, Illinois 60004-1440

Materials tested: Bentomat DN GCL consisting of a nonwoven geotextile on each side of the bentonite component. The GCL was needlepunched together to form the finished product. 80-mil GSE Lining Technology, Inc. (GSE) textured HDPE geomembrane.

2. TEST PROGRAM

The test procedures and results are described in the following appendices:
Appendix A: Summary of Test Procedures
Appendix B: Summary of Test Results
Appendix C: Creep Shear Test Data

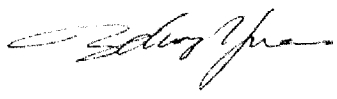
3. STORAGE AND DISPOSAL OF MATERIALS

Samples will be stored for 30 days from the date of this report and then discarded unless GeoSyntec-SGI® is informed otherwise.

* * * * *

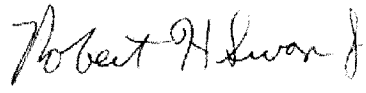
REPORT REVIEW

REPORT PREPARATION BY:



Zehong Yuan, Ph.D., P.E.
Program Manager

TECHNICAL REVIEW BY:



Robert H. Swan, Jr.
Laboratory Manager

APPENDIX A

SUMMARY OF TEST PROCEDURES

SUMMARY OF TEST PROCEDURES

CONSTANT LOAD (CREEP) SHEAR TESTING

Test Method

The creep shear test was performed in accordance with the American Society for Testing and Materials (ASTM) Standard Test Method D 6243, "*Determining the Internal and Interface Shear Resistance of Geosynthetic Clay Liner by the Direct Shear Method*". The test was conducted in a specifically designed large direct shear device consisting of five major components, as shown in Figure 1 of Appendix A:

- a rigid supporting table;
- a upper shear box measuring 12 in. by 12 in. in plan and 3 in. in depth and a lower shear box measuring 14 in. by 12 in. in plan and 3 in. in depth;
- a waterproof containment box to allow the test specimen to be tested under fully submerged conditions;
- an air bladder loading system for applying normal loads to the test specimen; and
- three parallel-connected 6-in. diameter air cylinders for applying constant shear loads to the test specimen.

Sample Description and Test Configuration

The creep shear test was conducted on the Bentomat DN GCL and 80-mil GSE textured HDPE geomembrane. The configuration of the test specimen used in the creep shear test, from top to bottom, consisted of:

- rigid substrate with textured steel gripping surface;
- Bentomat DN GCL (needled side against geomembrane);
- 80-mil GSE textured HDPE geomembrane; and
- dense concrete sand.

The bulk samples of the GCL and geomembrane materials were provided to GeoSyntec by CETCO. The test specimens were setup in such a way that: (i) creep shear failure could occur through the Bentomat DN GCL; (ii) sliding (shear failure) could occur between the Bentomat DN GCL and the GSE textured geomembrane; or (iii) creep shear/sliding failure could be a component of both internal and interface creep shear failure.

Test Procedures

For the creep shear test, the entire test specimen was constructed and tested under the same conditions as described below:

- Test Atmosphere: the test was conducted in a controlled atmosphere where the air was maintained at a relative humidity of 50 to 70 percent and a temperature of 70 +/- 4° F (21 +/- 2° C); both relative humidity and temperature were monitored on a regular basis.

- Concrete sand was compacted into the lower shear box by hand tamping to a relatively dense state under dry conditions. A fresh geomembrane specimen was placed on top of the compacted concrete sand and attached to the lower shear box with mechanical compression clamps. A fresh GCL specimen was trimmed from the bulk sample of the GCL and placed on top of the geomembrane specimen with its needled side in contact with the geomembrane. A rigid wooden substrate with textured steel gripping surface was placed on top of the GCL specimen. The end of the upper geotextile of the GCL was then sandwiched between a second rigid wooden substrate prior to testing as shown in Figure 2 of Appendix A. The textured steel gripping surface was employed to minimize slippage between the geotextile component of the GCL and rigid wood substrate, therefore providing a relatively uniform transfer of shear load onto the GCL specimen.

- Soaking Conditions: the entire test specimen was soaked in tap water for 120 hours under a normal stress of 400 psf. The soaking normal stress was applied to the test specimen with the use of dead weight prior to immersion. The entire test specimen remained submerged throughout the entire test duration.

- Consolidation and Shearing Phase 1: after the 120-hour soaking period, the

entire test specimen was then consolidated for 120 hours under a normal stress of 2000 psf and then subjected to a constant shear stress of 400 psf for approximately 1,000 hours. The constant shear stress was applied to the test specimen through the use of the air cylinder loading system and monitored on a regular basis.

- Consolidation and Shearing Phase 2: the entire test specimen was then consolidated for 120 hours under a normal stress of 4000 psf and then subjected to a constant shear stress of 800 psf for approximately 1,000 hours. The constant shear stress was applied to the test specimen through the use of the air cylinder loading system and monitored on a regular basis.

- Consolidation and Shearing Phase 3: the entire test specimen was then consolidated for 120 hours under a normal stress of 6000 psf and then subjected to a constant shear stress of 1200 psf for approximately 1,000 hours. The constant shear stress was applied to the test specimen through the use of the air cylinder loading system and monitored on a regular basis.

- Consolidation and Shearing Phase 4: the entire test specimen was then consolidated for 120 hours under a normal stress of 8000 psf and then subjected to a constant shear stress of 1600 psf for approximately 1,000 hours. The constant shear stress was applied to the test specimen through the use of the air cylinder loading system and monitored on a regular basis.

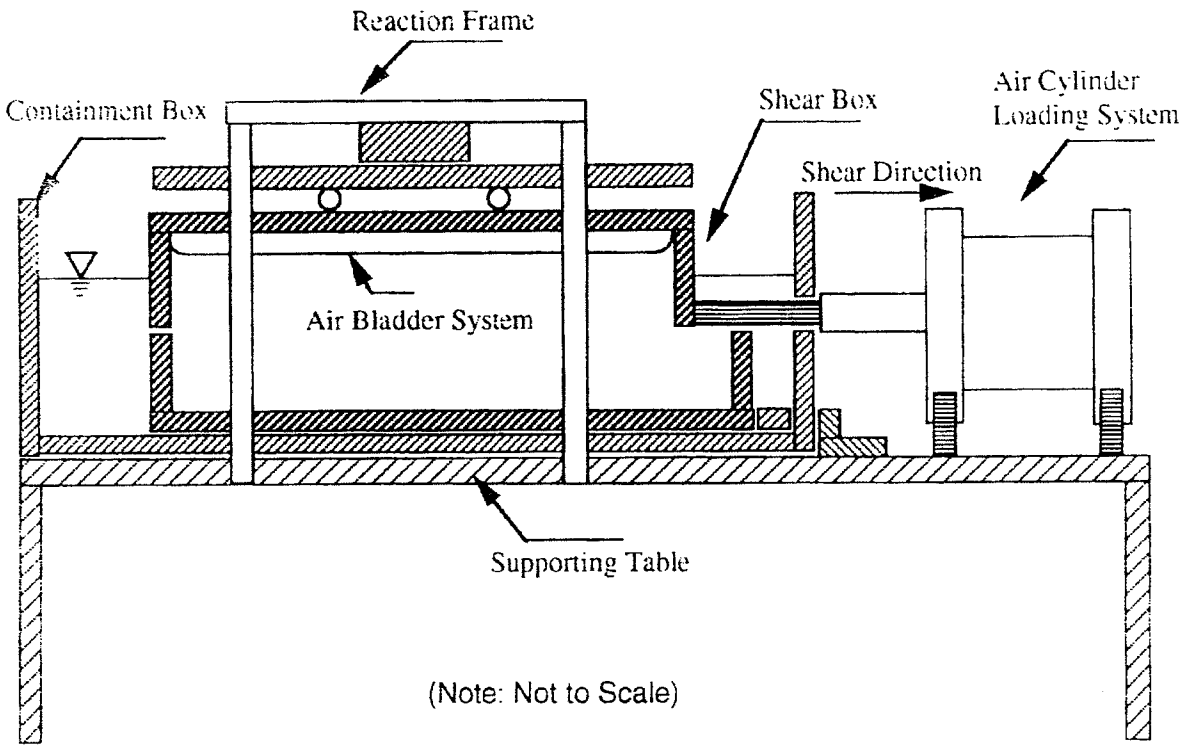
- Consolidation and Shearing Phase 5: the entire test specimen was then consolidated for 120 hours under a normal stress of 10,000 psf and then subjected to a constant shear stress of 2000 psf for approximately 1,000 hours. The constant shear stress was applied to the test specimen through the use of the air cylinder loading system and monitored on a regular basis.

- Monitoring: vertical displacements (i.e., swelling or compression) of the GCL specimen during the entire test were monitored with the use of dial gages. Shear displacements were monitored by using two dial gages, each attached to a "tell-tail" wire. One "tell-tail" wire was connected to the upper shear box and the other "tell-tail" wire was connected to the lower geotextile of the GCL in contact with the geomembrane. Both the vertical and horizontal displacements were monitored on a regular basis.

Test Data Presentation

A creep shear test consisting of five loading increments was conducted to evaluate the behavior of the Bentomat DN GCL against a textured HDPE geomembrane under constant-load conditions. For the test, measured vertical displacements during the initial soaking phase were plotted on a graph of vertical displacement versus logarithm of time. For each loading increment of the test, measured vertical and shear displacements during the consolidation and shear phase were plotted on a graph of vertical and shear displacement versus logarithm of time. Incremental shear displacement rates were calculated using the measured shear displacement data and plotted on a graph of logarithm of displacement rate versus shear displacement and a graph of logarithm of displacement rate versus logarithm of time. The results of the initial soaking phase and the five consolidation/shear phases are presented graphically in Appendix C.

A summary of the creep shear test results for each loading phase are presented in Tables 1 through 5 of Appendix B. Each table presents the total shear displacement and incremental shear displacement rate at 1, 10, 100, 500, and 1000 hours of elapsed time for the GCL /geomembrane specimen. It is noted that the values of displacement and displacement rates at these selected times presented in each table may have been derived by linear interpolation between the actually measured data points at the specific time period of interest.

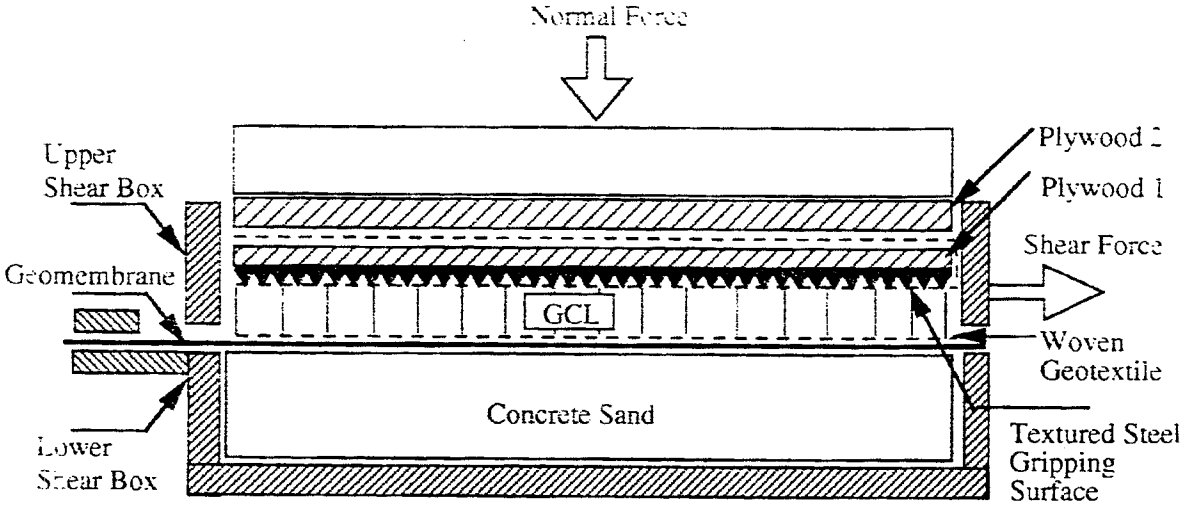


(Note: Not to Scale)

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	1
PROJECT NO.	GLI3545
DOCUMENT NO.	SGI01014
FILE NO.	



(Note: Not to Scale)

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	2
PROJECT NO.	GLI3545
DOCUMENT NO.	SGI01014
FILE NO.	

APPENDIX B

SUMMARY OF TEST RESULTS

TABLE 1

SUMMARY OF CREEP SHEAR TEST RESULTS
COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
BENTOMAT DN GCL WITH NEEDLED SIDE AGAINST GEOMEMBRANE / 80-MIL GSE TEXTURED HDPE GEOMEMBRANE
LANDFILL LINING SYSTEM EVALUATION

Test Phase Number[1]	Phase 1	
Test Specimen	Bentomat DN GCL/80-mil GSE Textured HDPE Geomembrane	
Loading Conditions	Normal Stress: 2000 psf Shear Stress: 400 psf	
Elapsed Time (Hours)	Total Shear Displacement (in.)	Incremental Shear Displacement Rate (in./min)
1	0.116	4.00×10^{-5}
10	0.122	3.65×10^{-6}
100	0.126	3.45×10^{-7}
500	0.132	1.39×10^{-7}
1,000	0.137	2.32×10^{-7}

NOTE: (1) The entire test specimen was soaked in tap water for 120 hours under a normal stress of 400 psf prior to application of the consolidation stress of 2000 psf to the test specimen.

TABLE 2

SUMMARY OF CREEP SHEAR TEST RESULTS
COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
BENTOMAT DN GCL WITH NEEDLED SIDE AGAINST GEOMEMBRANE / 80-MIL GSE TEXTURED HDPE GEOMEMBRANE
LANDFILL LINING SYSTEM EVALUATION

Test Phase Number	Phase 2	
Test Specimen	Bentomat DN GCL/80-mil GSE Textured HDPE Geomembrane	
Loading Conditions	Normal Stress: 4000 psf Shear Stress: 800 psf	
Elapsed Time (Hours)	Total Shear Displacement (in.)	Incremental Shear Displacement Rate (in./min)
1	0.187	1.72×10^{-5}
10	0.192	2.63×10^{-6}
100	0.195	6.46×10^{-7}
500	0.204	7.52×10^{-8}
1,000	0.206	4.73×10^{-8}

TABLE 3

SUMMARY OF CREEP SHEAR TEST RESULTS
COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
BENTOMAT DN GCL WITH NEEDLED SIDE AGAINST GEOMEMBRANE / 80-MIL GSE TEXTURED HDPE GEOMEMBRANE
LANDFILL LINING SYSTEM EVALUATION

Test Phase Number	Phase 3	
Test Specimen	Bentomat DN GCL/80-mil GSE Textured HDPE Geomembrane	
Loading Conditions	Normal Stress: 6000 psf Shear Stress: 1200 psf	
Elapsed Time (Hours)	Total Shear Displacement (in.)	Incremental Shear Displacement Rate (in./min)
1	0.233	2.00×10^{-5}
10	0.235	2.93×10^{-6}
100	0.239	1.75×10^{-7}
500	0.245	1.74×10^{-7}
1,000	0.247	2.82×10^{-8}

TABLE 4

SUMMARY OF CREEP SHEAR TEST RESULTS
COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
BENTOMAT DN GCL WITH NEEDLED SIDE AGAINST GEOMEMBRANE / 80-MIL GSE
TEXTURED HDPE GEOMEMBRANE
LANDFILL LINING SYSTEM EVALUATION

Test Phase Number	**Phase 4**	
Test Specimen	**Bentomat DN GCL/80-mil GSE Textured HDPE Geomembrane**	
Loading Conditions	**Normal Stress: 8000 psf** **Shear Stress: 1600 psf**	
Elapsed Time **(Hours)**	**Total Shear Displacement** **(in.)**	**Incremental Shear Displacement Rate** **(in./min)**
1	0.271	1.25×10^{-5}
10	0.274	3.26×10^{-6}
100	0.276	7.17×10^{-7}
500	0.277	5.80×10^{-8}
1,000	0.279	3.58×10^{-8}

TABLE 5

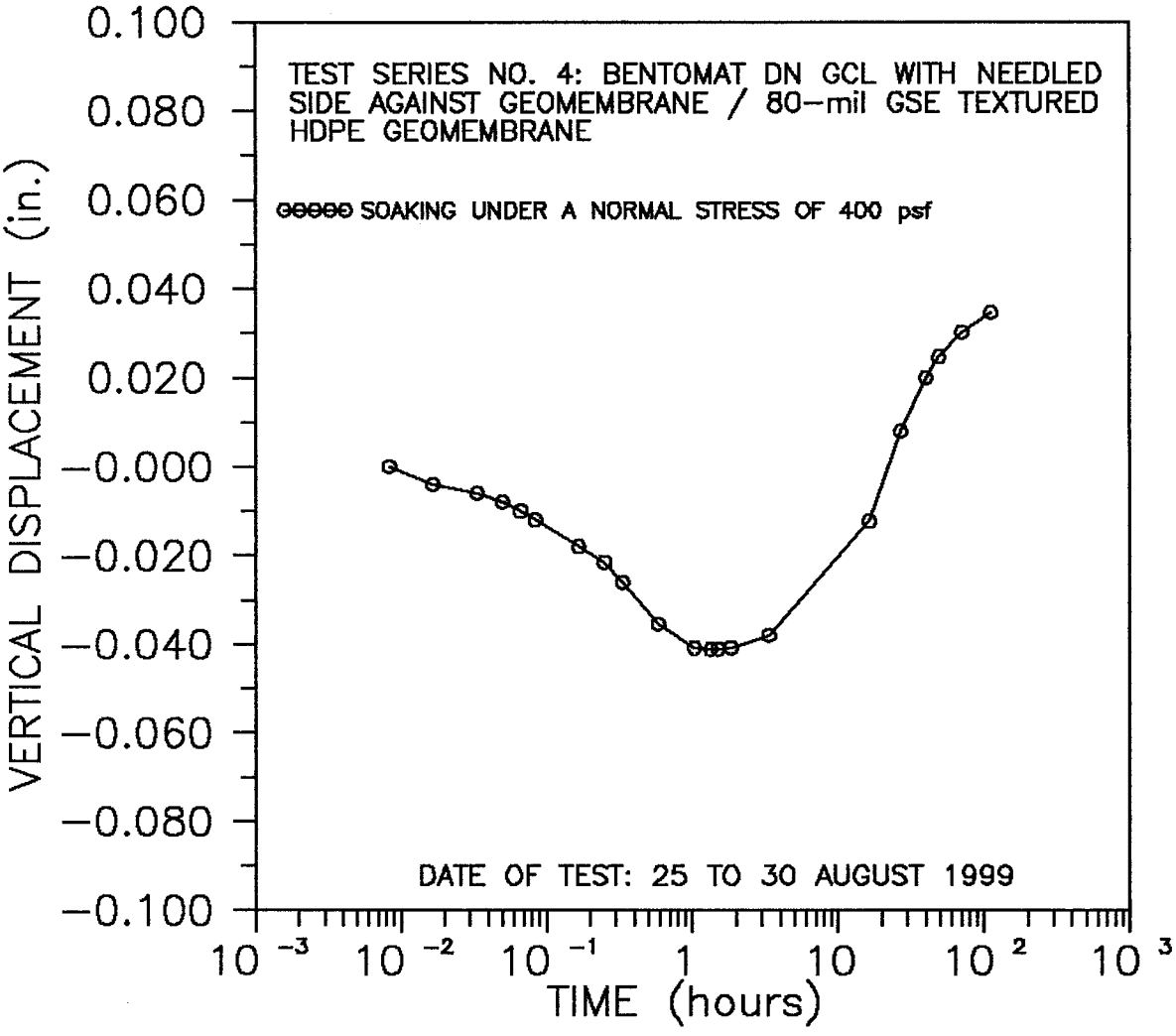
SUMMARY OF CREEP SHEAR TEST RESULTS
COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
BENTOMAT DN GCL WITH NEEDLED SIDE AGAINST GEOMEMBRANE / 80-MIL GSE TEXTURED HDPE GEOMEMBRANE
LANDFILL LINING SYSTEM EVALUATION

Test Phase Number	Phase 5	
Test Specimen	Bentomat DN GCL/80-mil GSE Textured HDPE Geomembrane	
Loading Conditions	Normal Stress: 10000 psf Shear Stress: 2000 psf	
Elapsed Time (Hours)	Total Shear Displacement (in.)	Incremental Shear Displacement Rate (in./min)
1	0.315	1.00×10^{-5}
10	0.317	2.77×10^{-6}
100	0.319	5.26×10^{-7}
500	0.322	9.97×10^{-8}
1,000	0.326	1.55×10^{-7}
1,600	0.329	1.47×10^{-7}

APPENDIX C

CREEP SHEAR TEST DATA

COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
CREEP SHEAR TESTING
SOAKING PHASE



TESTING ATMOSPHERE: AIR MAINTAINED AND REGULARLY MONITORED AT A RELATIVE HUMIDITY OF 50 TO 72 PERCENT AND A TEMPERATURE OF 70 +/− 2 degF(21 +/− 1 degC).

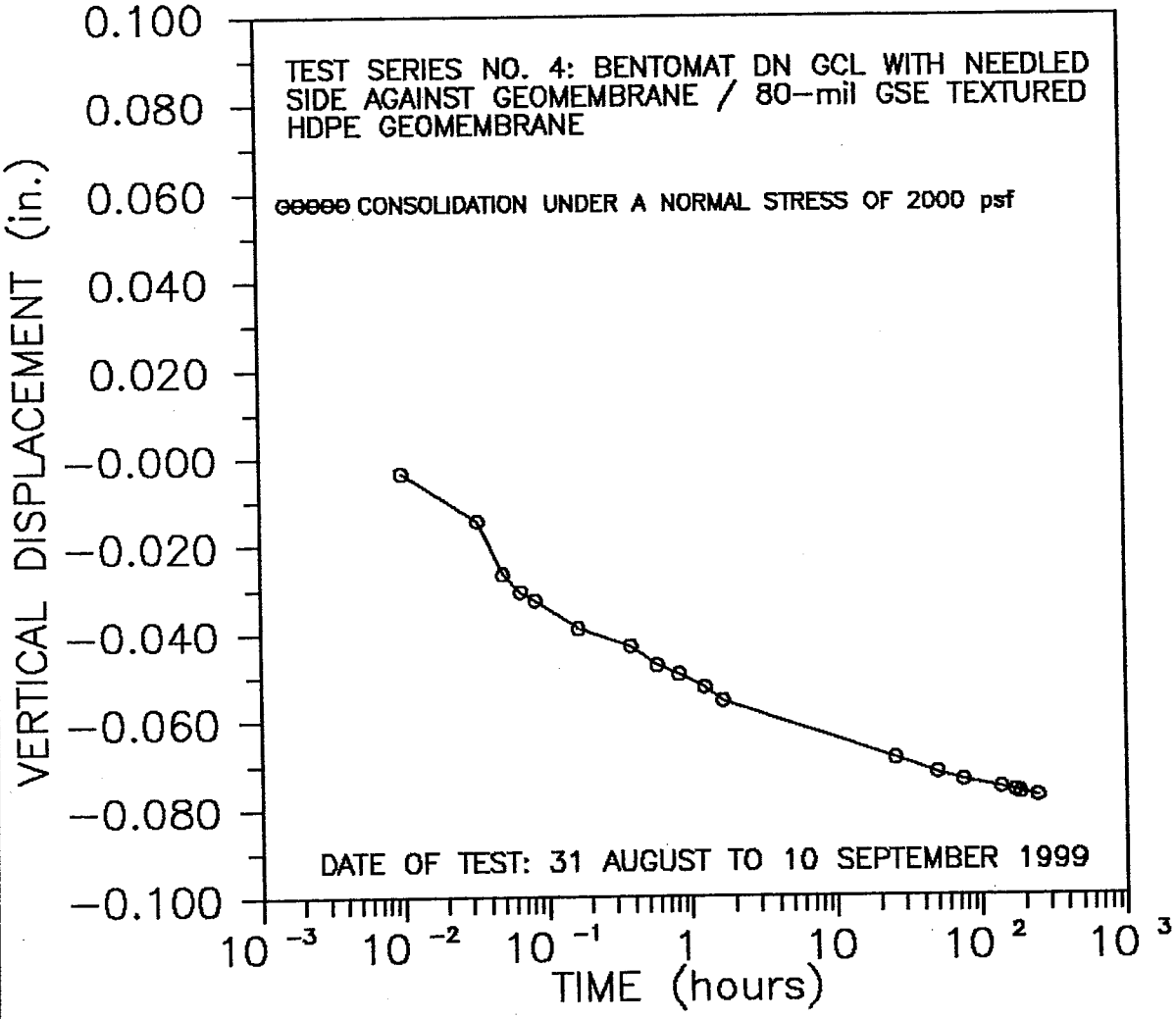
DATE REPORTED: 16 FEBRUARY 2000

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	
PROJECT NO.	GLI3545-02
DOCUMENT NO.	
FILE NO.	

COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
CREEP SHEAR TESTING
CONSOLIDATION PHASE 1



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SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

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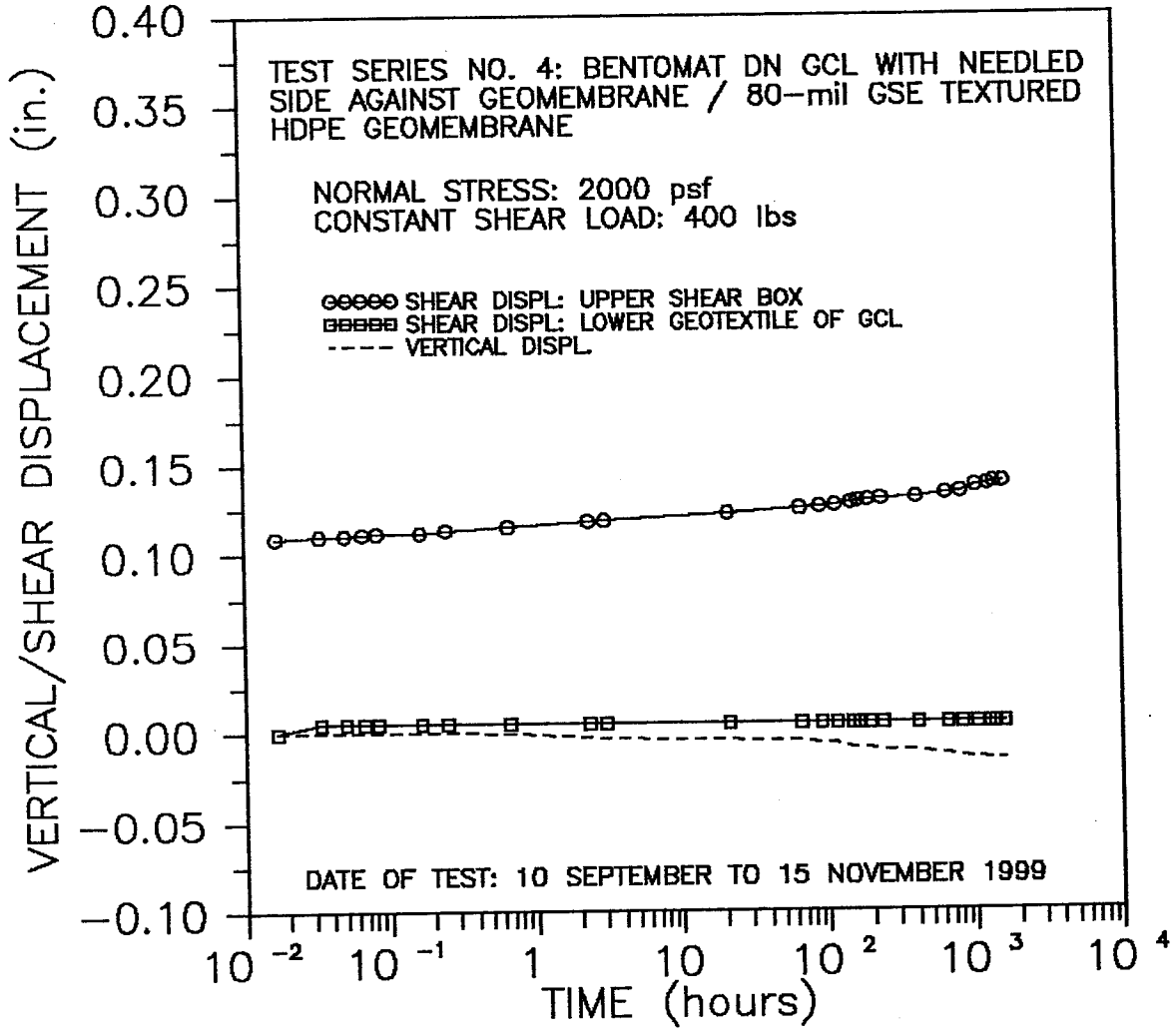
PROJECT NO.	GLI3545-02
DOCUMENT NO.	
FILE NO.	

COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
CREEP SHEAR TESTING
SHEARING PHASE 1



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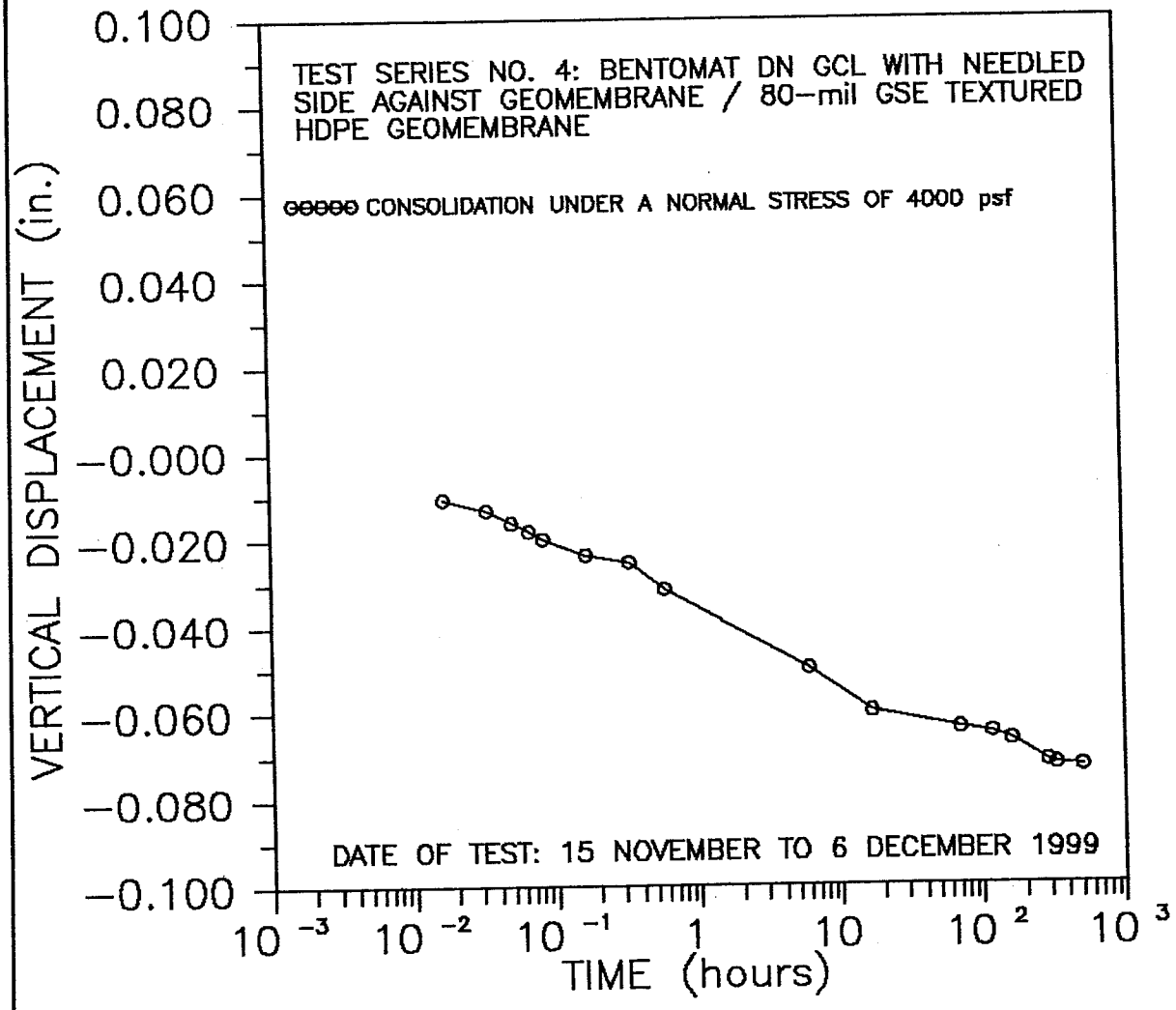
FILE NO.	

COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
CREEP SHEAR TESTING
CONSOLIDATION PHASE 2



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SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

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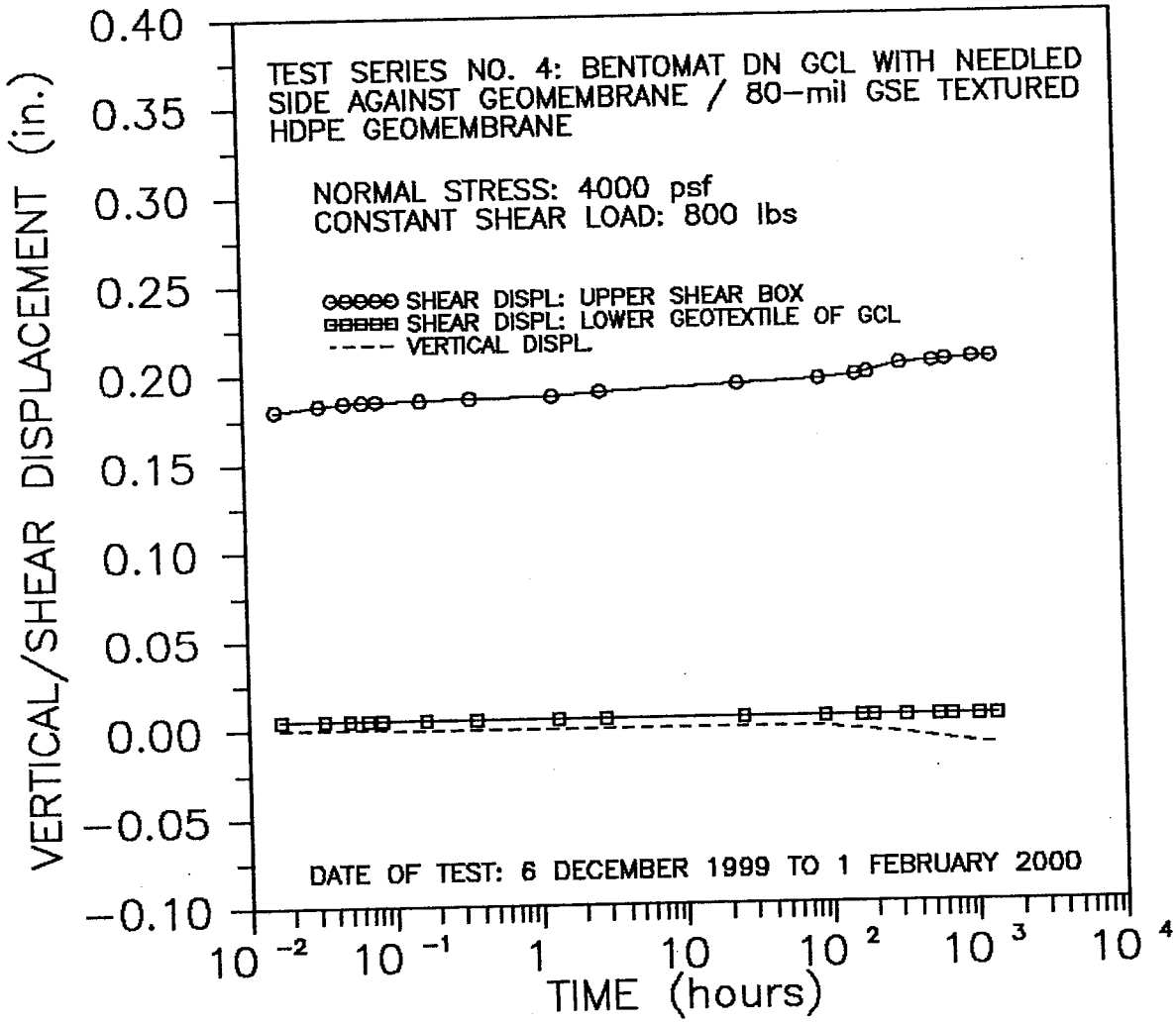
DOCUMENT NO.	
FILE NO.	

COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
CREEP SHEAR TESTING
SHEARING PHASE 2



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SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

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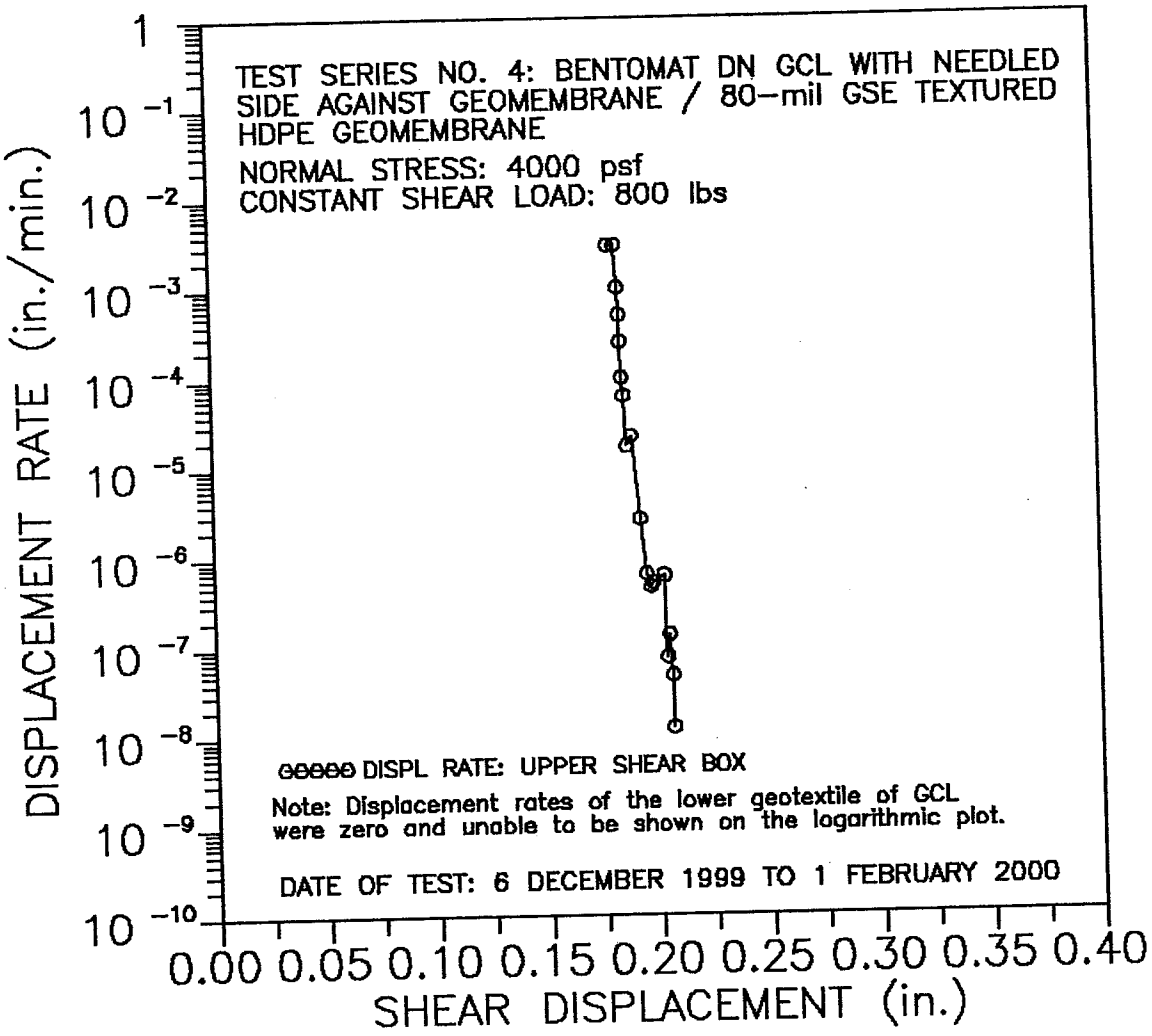
COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
CREEP SHEAR TESTING
SHEARING PHASE 2



TESTING ATMOSPHERE: AIR MAINTAINED AND REGULARLY MONITORED AT A RELATIVE HUMIDITY OF 50 TO 72 PERCENT AND A TEMPERATURE OF 70 +/- 2 degF(21 +/- 1 degC).

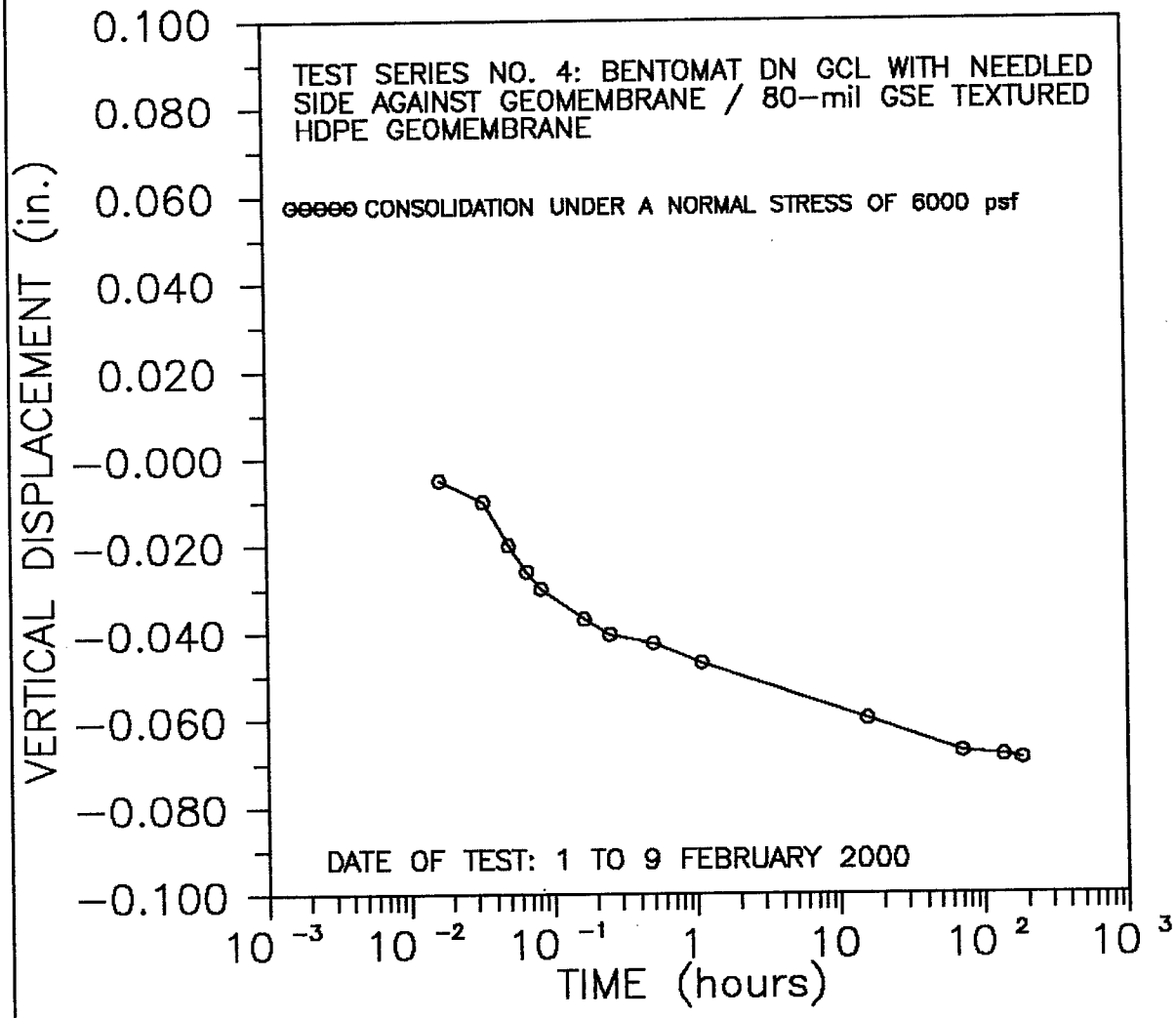
DATE REPORTED: 16 FEBRUARY 2000

GeoSyntec Consultants

SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	
PROJECT NO.	GLI3545-02
DOCUMENT NO.	
FILE NO.	

COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
CREEP SHEAR TESTING
CONSOLIDATION PHASE 3



TESTING ATMOSPHERE: AIR MAINTAINED AND REGULARLY MONITORED AT A RELATIVE HUMIDITY OF 50 TO 72 PERCENT AND A TEMPERATURE OF 70 +/− 2 degF(21 +/− 1 degC).

DATE REPORTED: 31 JANUARY 2001

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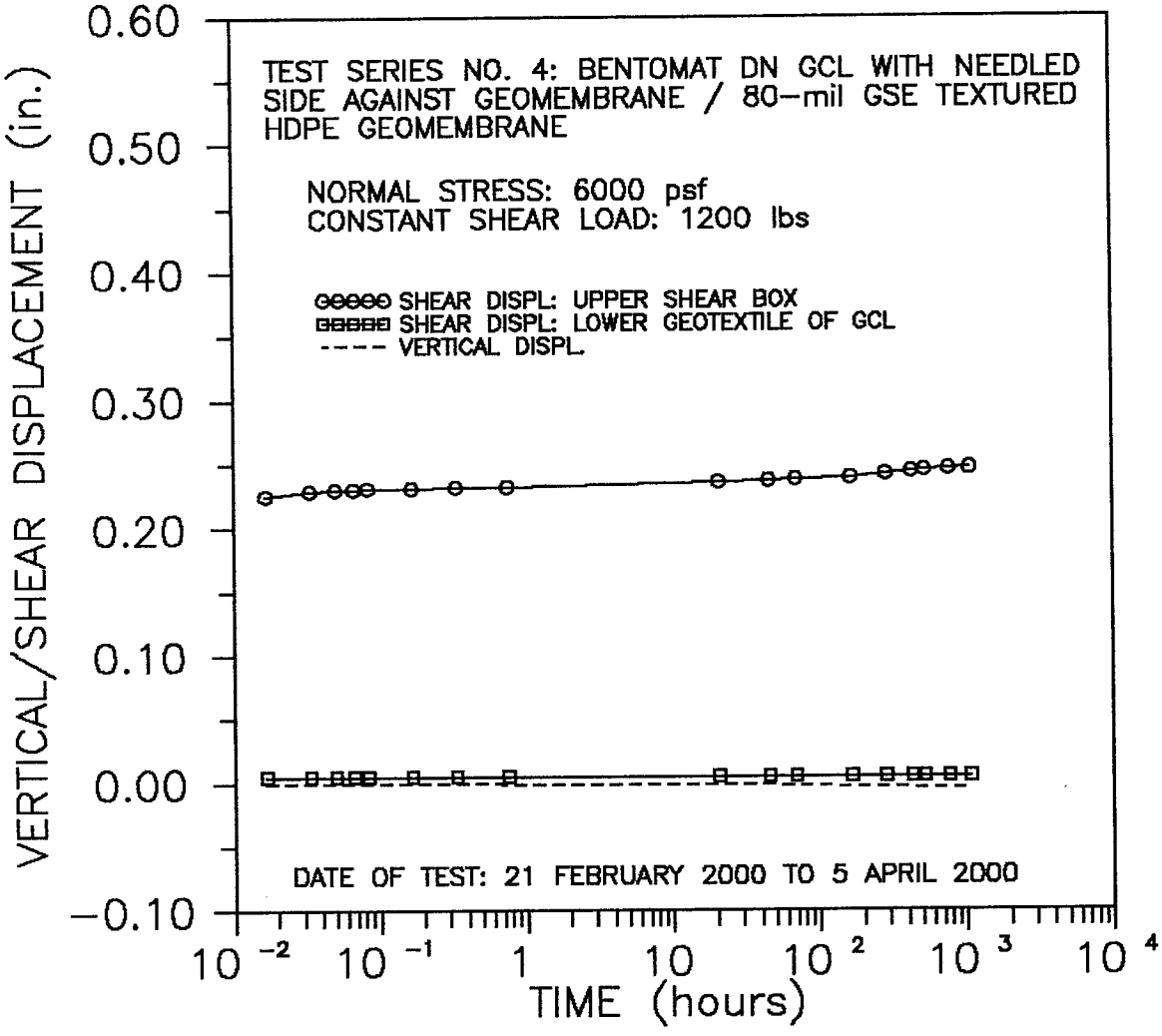
SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	
PROJECT NO.	GLI3545−02
DOCUMENT NO.	
FILE NO.	

COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
CREEP SHEAR TESTING
SHEARING PHASE 3



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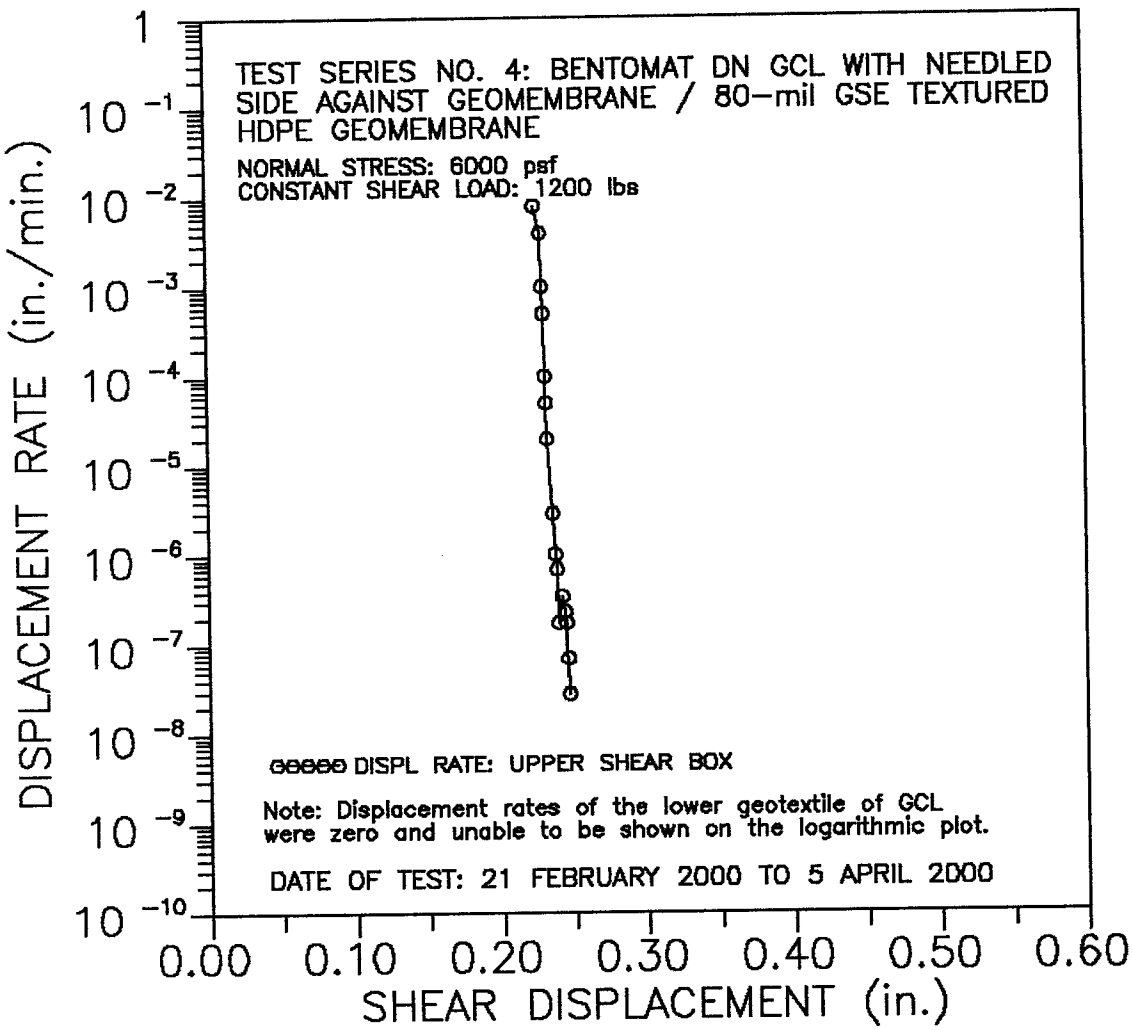
COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
CREEP SHEAR TESTING
SHEARING PHASE 3



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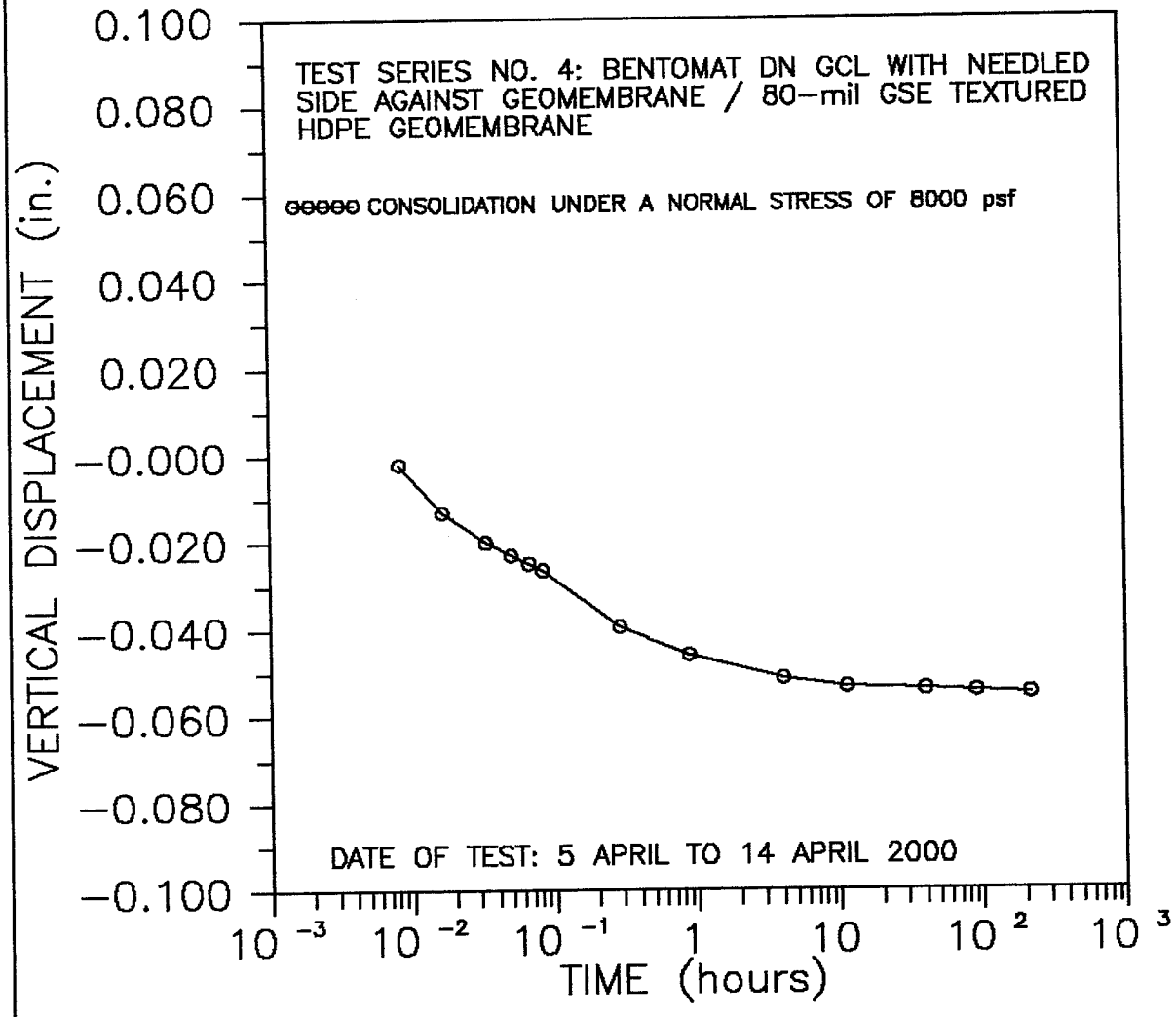
SOIL-GEOSYNTHETIC INTERACTION TESTING LABORATORY

FIGURE NO.	
PROJECT NO.	GLI3545-02
DOCUMENT NO.	
FILE NO.	

COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
CREEP SHEAR TESTING
CONSOLIDATION PHASE 4



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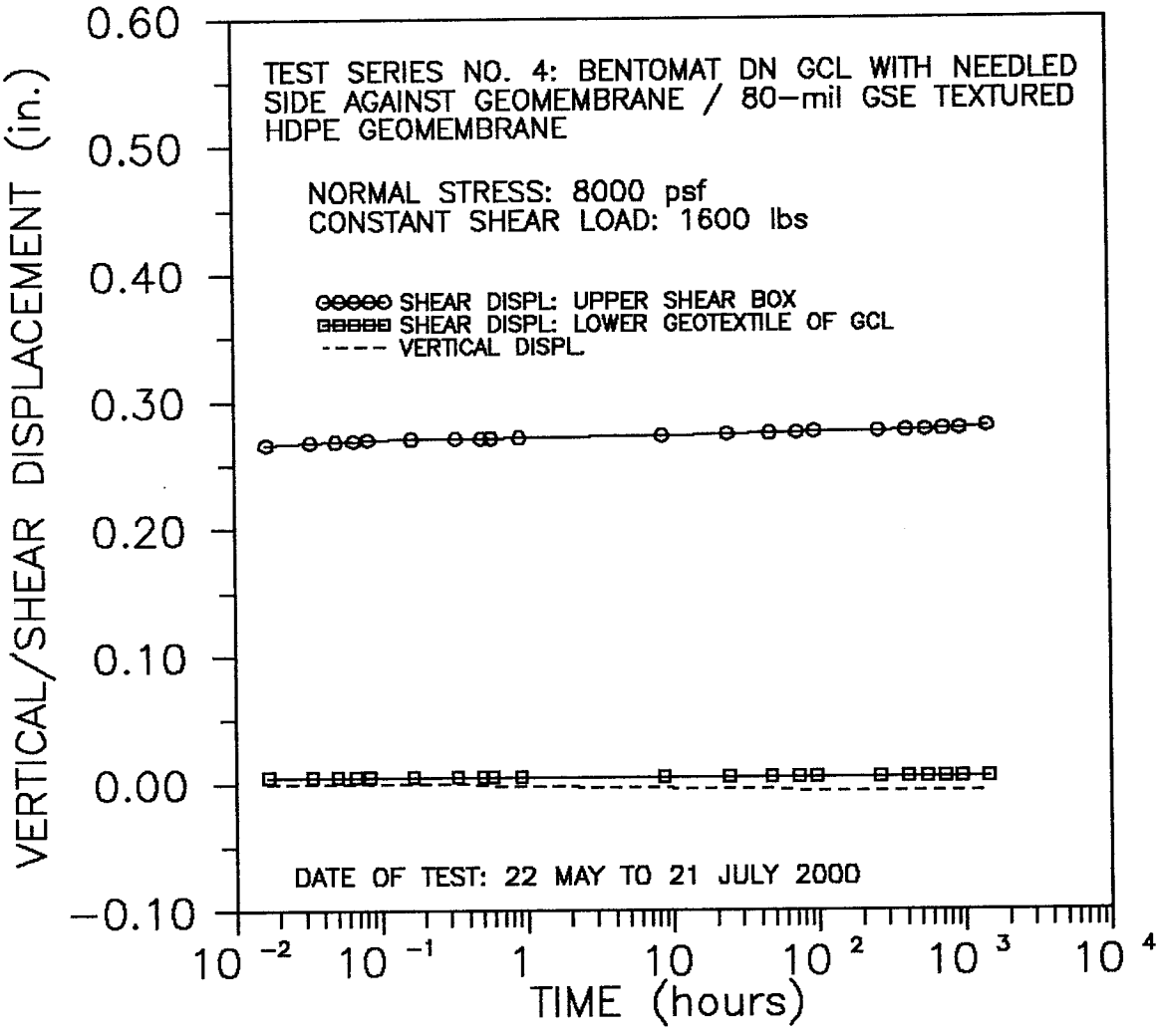
FILE NO.	

COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
CREEP SHEAR TESTING
SHEARING PHASE 4



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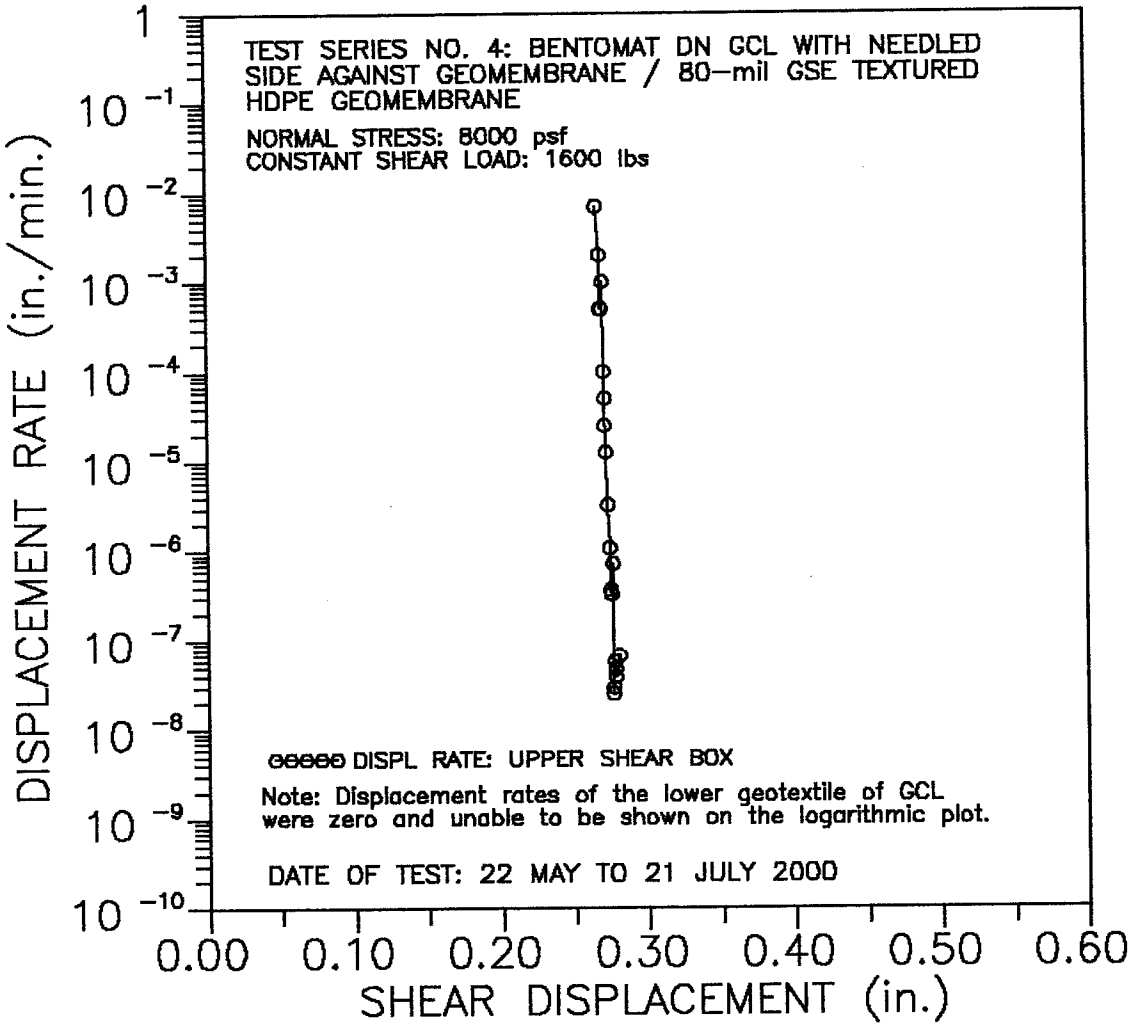
COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
CREEP SHEAR TESTING
SHEARING PHASE 4



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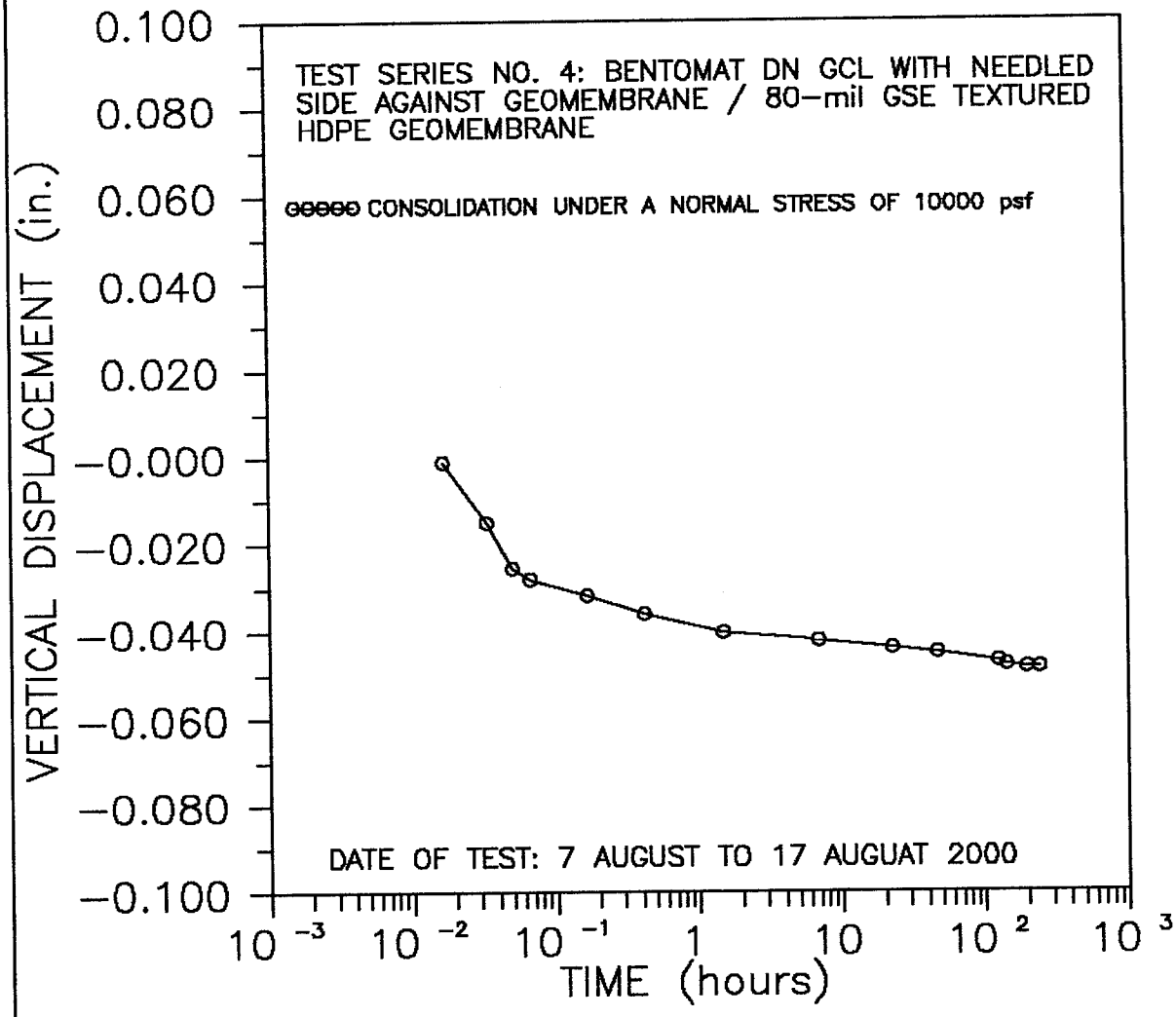
COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
CREEP SHEAR TESTING
CONSOLIDATION PHASE 5



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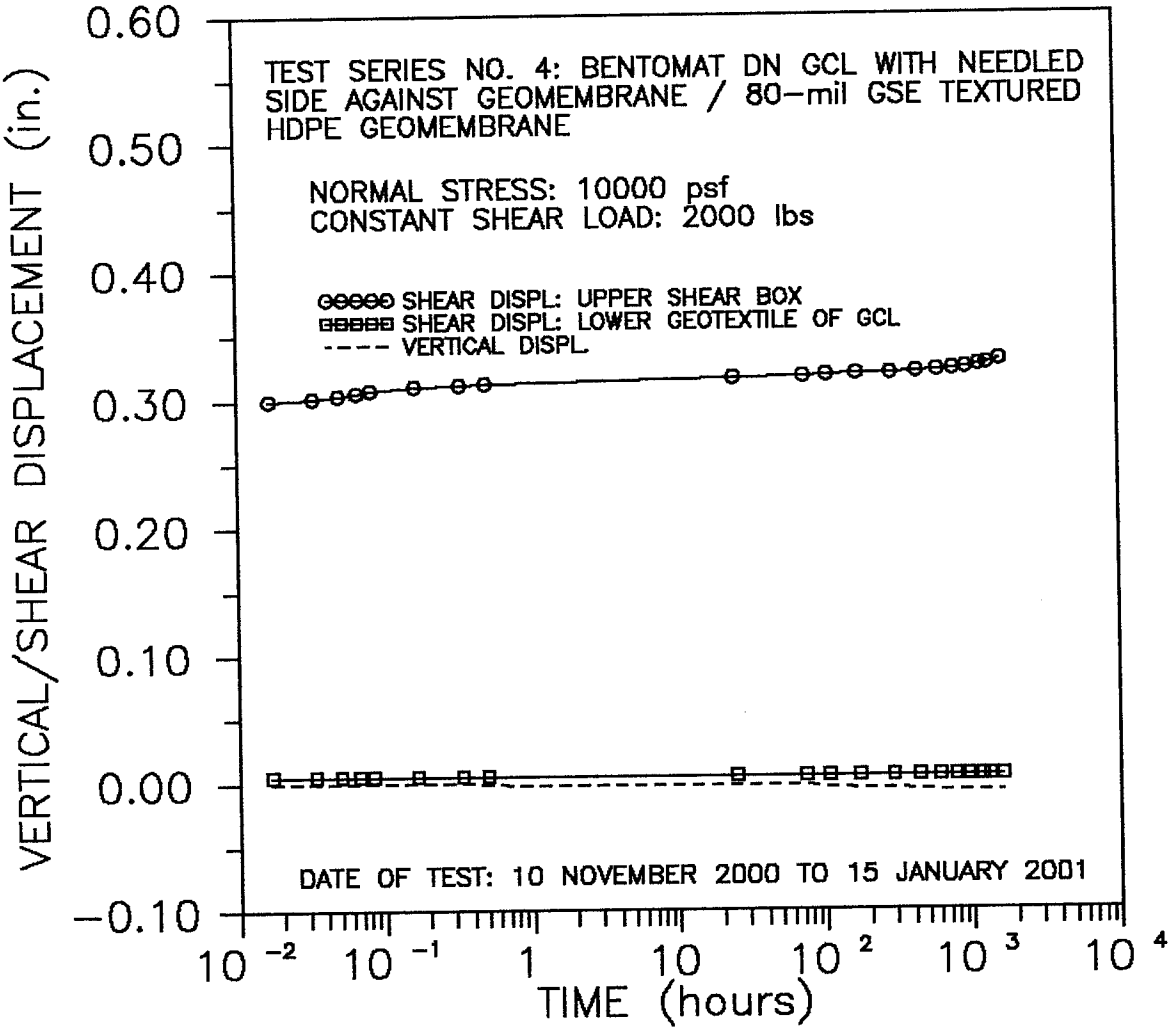
PROJECT NO.	GLI3545-02
DOCUMENT NO.	
FILE NO.	

COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
CREEP SHEAR TESTING
SHEARING PHASE 5



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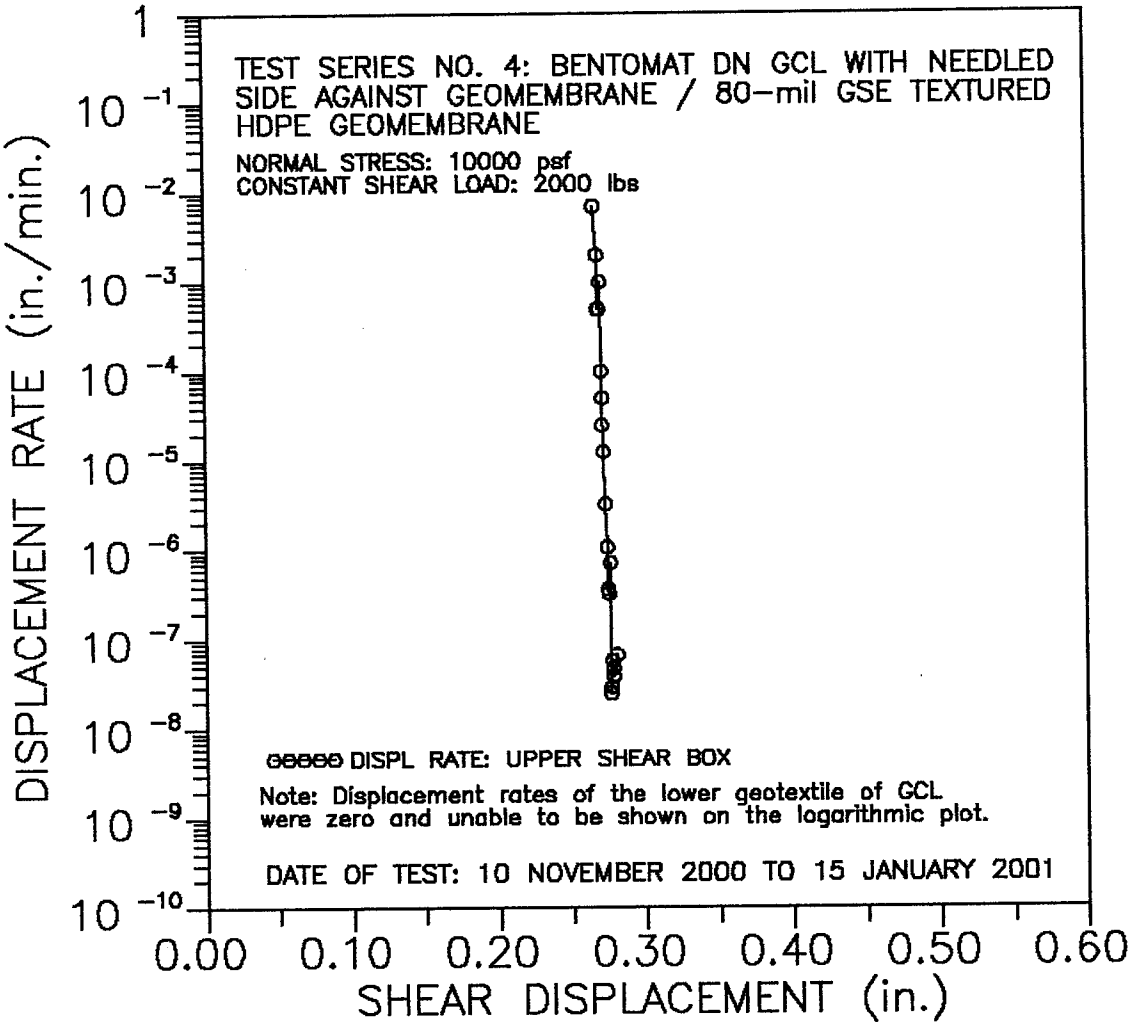
FILE NO.	

COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
CREEP SHEAR TESTING
SHEARING PHASE 5



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