BENTOMAT SDN 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 SDN, a GCL consisting of bentonite reinforced with needlepunched fibers between two nonwoven geotextiles with MARV mass per unit area of 6 ounce/sq.yd. and 2.7 ounce/sq.yd. 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 of up to 10,000 psf and constant shear stress of up to 3500 psf 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 high normal load shear testing reached the 10,000-hour mark before the test was stopped. For the Bentomat SDN high normal load study, the total displacement at 10,000 hours was 0.398 in. (10.1 mm) and the displacement rate decreased over time to approximately 6.40×10^{-9} in/min. (1.63×10^{-7} mm/min).
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 0.127 in. (3.23 mm) and the displacement rate decreased over time to approximately 1.41×10^{-8} in/min. (3.58×10^{-7} mm/min). The displacement at peak internal shear strength for Bentomat SDN at this low normal load is typically between 0.75 to 1 inch. Thus, Bentomat SDN appears to be quite stable with respect to constant-load creep shear.

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.

SGI Testing Services, Norcross, GA, "Final Report – 10,000 hour Constant-Load (Creep) Shear Testing: Bentomat SDN GCL Landfill Cover System Evaluation", Project No. SGI2038, December 17, 2005.

SGI Testing Services, Norcross, GA, "Interim Report – Multi-Step Constant-Load (Creep) Shear Testing: Bentomat SDN GCL/Polyflex Textured Geomembrane Landfill Lining System Evaluation", Project No. SGI2038, December 17, 2005.

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 SDN GCL LANDFILL COVER SYSTEM EVALUATION

Prepared by:

SGI TESTING SERVICES, LLC

4405 International Blvd., Suite B-117
Norcross, GA 30093
Project Number SGI2038

17 December 2005

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 SGI Testing Services, LLC (SGI_{SM}), 4405 International Blvd., Suite B-117, Norcross, Georgia 30093, are as follows:

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

Client: CETCO Lining Technologies

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

Materials Tested: Bentomat SDN GCL consisting of a nonwoven geotextile on each side of the bentonite component, 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 SGI_{SM} is informed otherwise.

* * * * *

REPORT REVIEW

REPORT PREPARATION BY:

TECHNICAL REVIEW BY:

Zehong Yuan, Ph.D., P.E.
Chief Technical Officer

Robert H. Swan, Jr.
President & CEO

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 the following major components:

- 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 loads to the test specimen.

The schematic diagram of the creep shear test device is shown in Figure A-1.

Sample Description and Test Configuration

The creep shear test was conducted on the Bentomat SDN 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 SDN GCL; and
- rigid substrate with textured steel gripping surface.

The bulk sample of the GCL material was provided to SGI_{SM} by CETCO.

Test Procedures

For the creep shear test, the entire test specimen was constructed and tested under the 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 textured steel gripping surfaces as shown in Figure A-2. The textured steel gripping surface was fixed onto a rigid wooden substrate to minimize slippage between the geotextile component of the GCL and the rigid wood substrate, therefore providing a relatively uniform transfer of shear load onto the GCL specimen.

- Soaking Conditions: the GCL 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. 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 a dial gage attached to a "tell-tail" wire connected to the upper shear. Both the vertical and horizontal displacements were monitored on a regular basis.

Test Data Presentation

A creep shear test was conducted to evaluate the behavior of the Bentomat SDN GCL 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. Measured vertical and shear displacements during the shearing 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 displacements and plotted on 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. Table 1 presents the total shear displacement and incremental shear displacement rate at 1, 10, 100, 500, 1,000, 5,000, and 10,000 hours of elapsed time for the creep test. It is noted that the values of the total shear displacement and incremental shear rate at a selected time presented in Table 1 were calculated by linear interpolation between two nearest measured data points and the selected time was within the time domain defined by these two nearest measured data points.

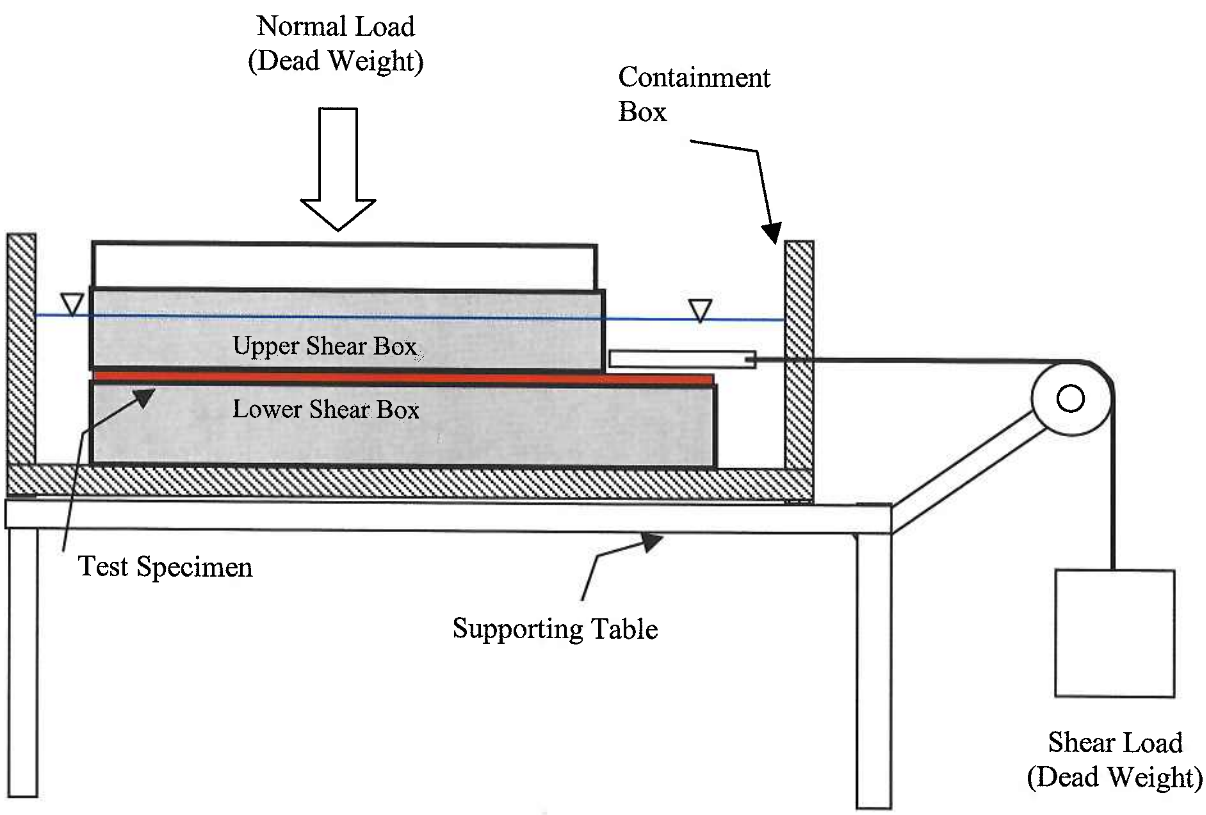


Figure 1. Schematic Diagram of Creep Shear Test Device (Not to Scale)

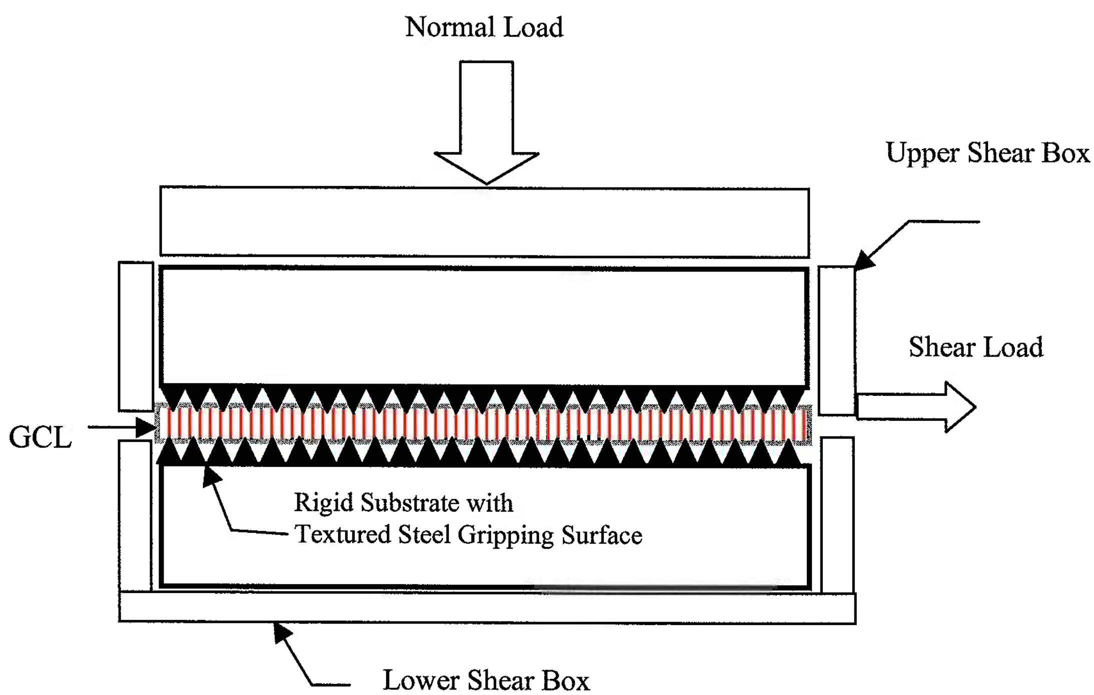


Figure 2. Schematic Diagram of Test Specimen Cross-Section (Not to Scale)

APPENDIX B

SUMMARY OF TEST RESULTS

APPENDIX B

SUMMARY OF TEST RESULTS

TABLE 1
SUMMARY OF CREEP SHEAR TEST RESULTS
CETCO LINING TECHNOLOGIES
BENTOMAT SDN GCL (LOT NO. 200230FA/ROLL NO. 289)
LANDFILL COVER SYSTEM EVALUATION

Test Phase	Soaking Phase	Shear Phase	
Loading Conditions		Normal Stress = 500 psf Shear Stress = 250 psf	
Selected Time (hours)		Total Shear Displacement (in.)	Incremental Shear Displacement Rate (in./min)
1	Soaked in Tap Water at a Normal Stress of 500 psf for 120 hours Prior to Shearing	0.044	1.33E-04
10		0.060	3.36E-05
100		0.081	1.60E-06
500		0.100	7.95E-07
1000		0.106	2.08E-07
5000		0.120	3.67E-08
10000		0.127	1.41E-08

NOTES:

(1) Shear displacement and incremental shear displacement rate at a selected time were calculated by linear interpolation between two nearest measured data points.

(2) The select time is within the time domain defined by the two nearest measured data points.

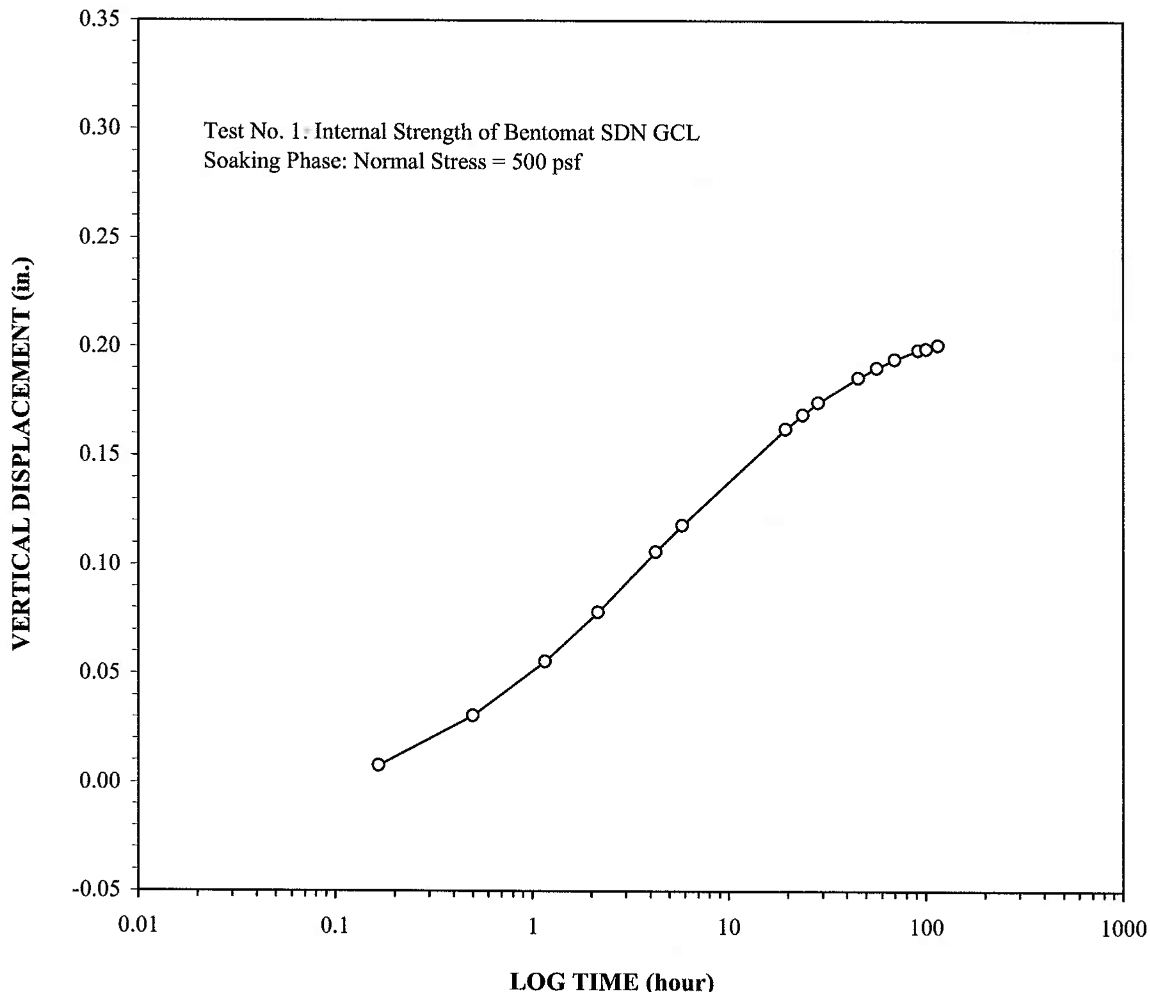
SGI TESTING SERVICES, LLC

DATE OF REPORT:	17 December 2005
FIGURE NO.	B-1
PROJECT NO.	SGI2038
DOCUMENT NO.	SGI03074
FILE NO.	

APPENDIX C

CREEP SHEAR TEST DATA

CETCO LINING TECHNOLOGIES
CREEP SHEAR TESTING - ASTM 6243
SOAKING PHASE



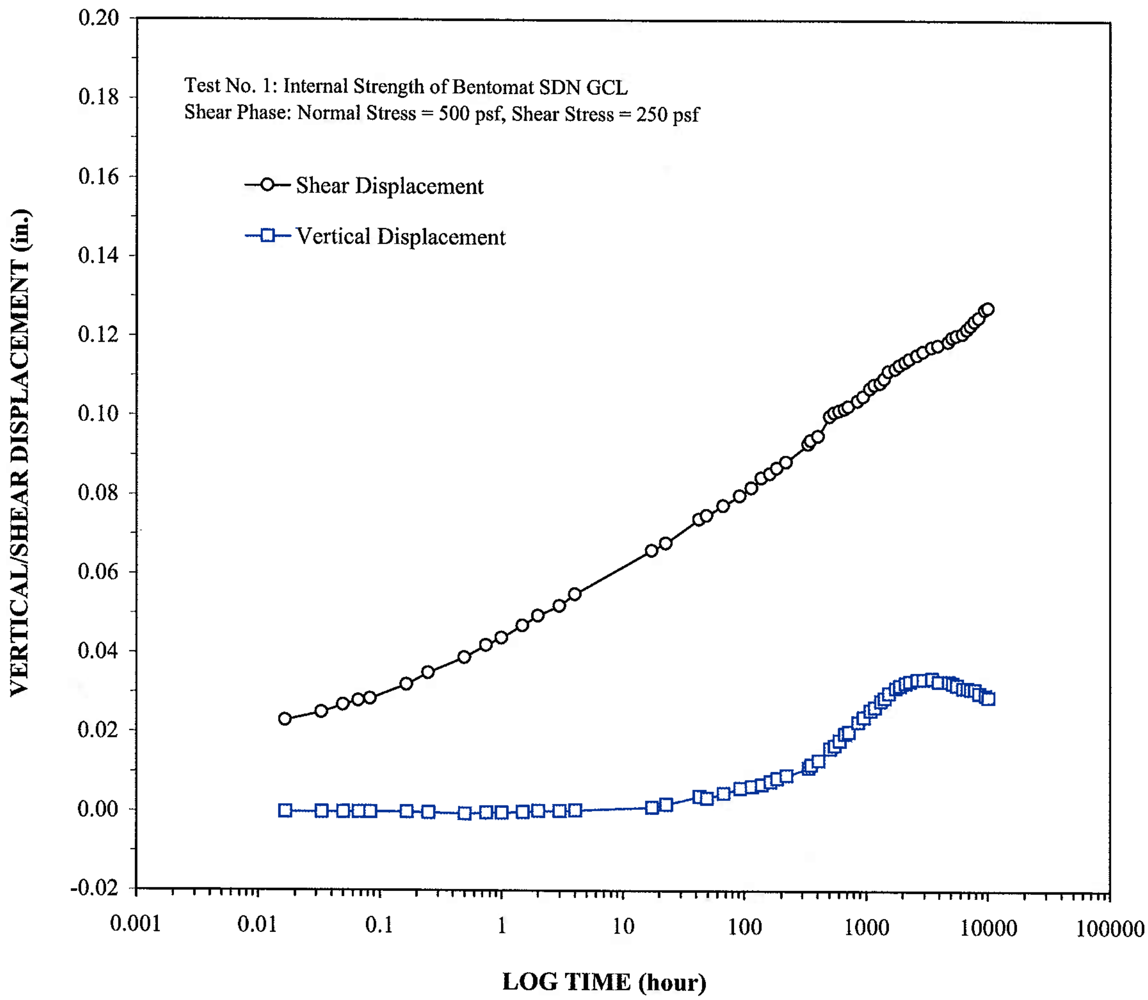
NOTES:

Test Configuration: textured steel grip / Bentomat SDN GCL (Lot No. 200230FA/Roll No. 289) / textured steel grip
Test Shear Plane: internal within the GCL specimen

SGI TESTING SERVICES, LLC

DATE TESTED:	4/10/2003 to 4/15/2003
FIGURE NO.	C-1
PROJECT NO.	SGI2038
DOCUMENT NO.	SGI03074
FILE NO.	

CETCO LINING TECHNOLOGIES
CREEP SHEAR TESTING (ASTM 6243)
SHEAR PHASE



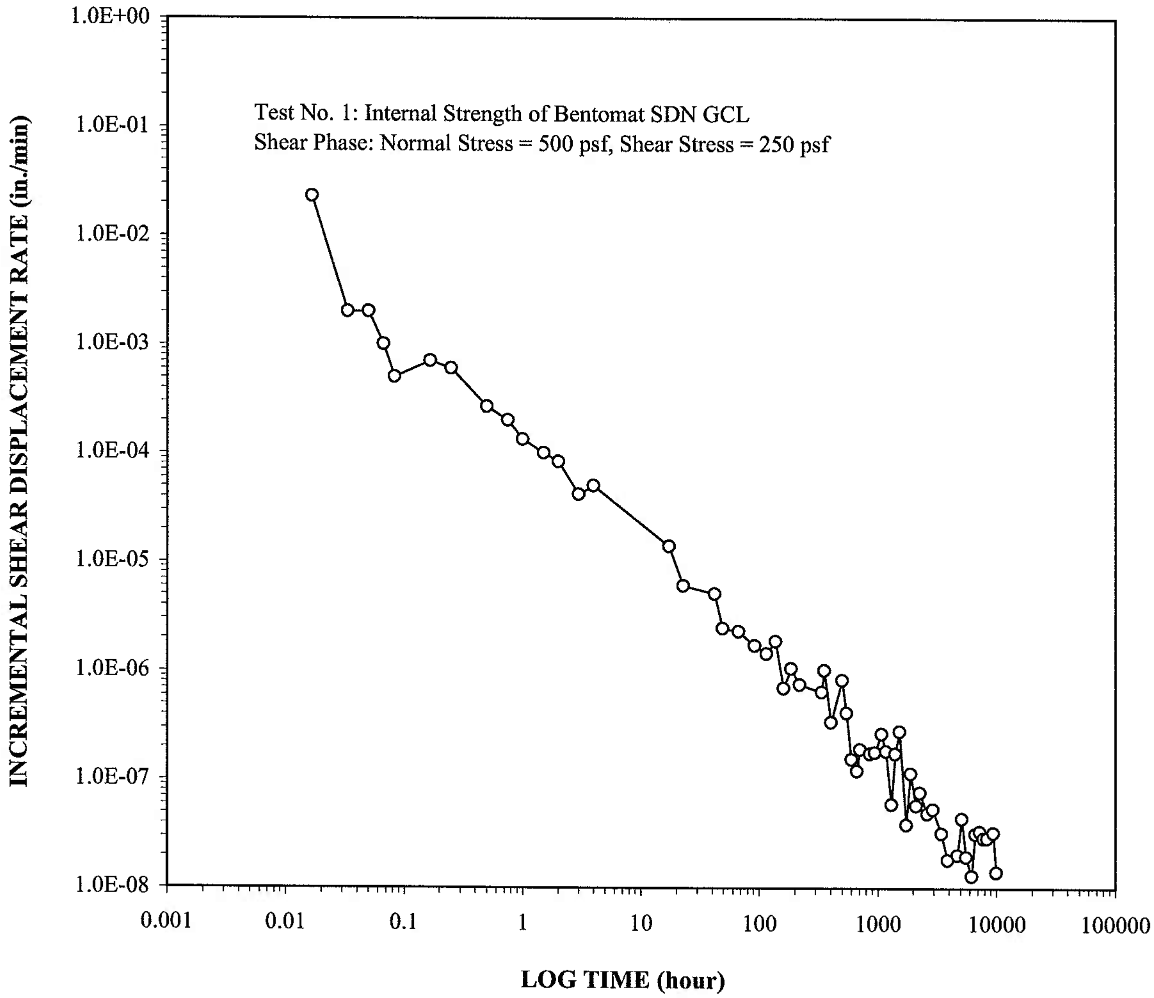
NOTES:

Test Configuration: textured steel grip / Bentomat SDN GCL (Lot No. 200230FA/Roll No. 289) / textured steel grip
Test Shear Plane: internal within the GCL specimen

DATE TESTED:	4/15/2003 to 6/5/2004
FIGURE NO.	C-2
PROJECT NO.	SGI2038
DOCUMENT NO.	SGI03074
FILE NO.	

SGI TESTING SERVICES, LLC

CETCO LINING TECHNOLOGIES
CREEP SHEAR TESTING (ASTM 6243)
SHEAR PHASE



NOTES:

Incremental Displacement Rate is defined as: $R = (U_i - U_{i-1})/(t_i - t_{i-1})$

where:

U_i = upper shear box displacement at time = t_i

U_{i-1} = upper shear box displacement at time = t_{i-1}

Test Configuration: textured steel grip / Bentomat SDN GCL (Lot No. 200230FA/Roll No. 289) / textured steel grip

Test Shear Plane: internal within the GCL specimen

SGI TESTING SERVICES, LLC

DATE TESTED:	4/15/2003 to 6/5/2004
FIGURE NO.	C-3
PROJECT NO.	SGI2038
DOCUMENT NO.	SGI03074
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 SDN GCL / POLYFLEX TEXTURED HDPE GEOMEMBRANE LANDFILL LINING SYSTEM EVALUATION

Prepared by:

SGI TESTING SERVICES, LLC

4405 International Blvd., Suite B-117
Norcross, GA 30093
Project Number SGI2038

17 December 2005

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 SGI Testing Services, LLC (SGI_{SM}), 4405 International Blvd., Suite B-117, Norcross, Georgia 30093, are as follows:

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

Client: CETCO Lining Technologies

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

Materials Tested: Bentomat SDN GCL consisting of a nonwoven geotextile on each side of the bentonite component, needlepunched together to form the finished product and 60-mil Polyflex 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 SGI_{SM} is informed otherwise.

* * * * *

REPORT REVIEW

REPORT PREPARATION BY:

Zehong Yuan, Ph.D., P.E.
Chief Technical Officer

TECHNICAL REVIEW BY:

Robert H. Swan, Jr.
President & CEO

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 creep shear device consisting of the following major components:

- 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.

The schematic diagram of the creep shear test device is shown in Figure A-1.

Sample Description and Test Configuration

The creep shear test was conducted on the Bentomat SDN GCL/60-mil Polyflex 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 SDN GCL (black nonwoven geotextile against geomembrane);
- 60-mil Polyflex textured HDPE geomembrane; and
- dense concrete sand.

The bulk samples of the GCL and geomembrane materials were provided to SGI_{SM} by CETCO. The test specimens were setup in such a way that sliding (shear failure) could occur within the Bentomat SDN GCL or at the interface between the Bentomat SDN GCL and the Polyflex textured geomembrane.

Test Procedures

For the creep shear test, the entire test specimen was constructed and tested under the 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 black nonwoven geotextile in contact with the geomembrane. A rigid wooden substrate with textured steel gripping surface was placed on top of the GCL specimen as shown in Figure A-2. 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 consolidated for 120 hours under a normal stress of 2,000 psf and then subjected to a constant shear stress of 700 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 consolidated for 120 hours under a normal stress of 4,000 psf and then subjected to a constant shear stress of 1,400 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 3: the entire test specimen was consolidated for 120 hours under a normal stress of 6,000 psf and then subjected to a constant shear stress of 2,100 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 consolidated for 120 hours under a normal stress of 8,000 psf and then subjected to a constant shear stress of 2,800 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 5: the entire test specimen was consolidated for 120 hours under a normal stress of 10,000 psf and then subjected to a constant shear stress of 3,500 psf for approximately 10,000 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 (black) 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 SDN GCL against a textured HDPE geomembrane under constant-load conditions. For the test, measured vertical displacements during the initial soaking phase and each of the five consolidation phases were plotted on a graph of vertical displacement versus logarithm of time. For each of the five shearing phases, measured vertical and shear displacements were plotted on a graph of vertical and shear displacement versus logarithm of time. Incremental shear displacement rates were calculated using the measured shear displacements at the upper shear box and plotted on a graph of logarithm of displacement rate versus logarithm of time. The results of the initial soaking, five consolidation, and five shear phases are presented graphically in Appendix C.

A summary of the creep shear test results for each shear phase is presented in Table 1 of Appendix B. Table 1 presents the total shear displacement and incremental shear displacement rate at 1, 10, 100, 500, and 1,000 hours of elapsed time for shear phases 1 through 4, and 1, 10, 100, 500, 1,000, 5,000, and 10,000 hours of elapsed time for shear phase 5 of the creep shear test. It is noted that the values of the total shear displacement and incremental shear rate at a selected time presented in Table 1 were calculated by linear interpolation between two nearest measured data points and the selected time was within the time domain defined by these two nearest measured data points.

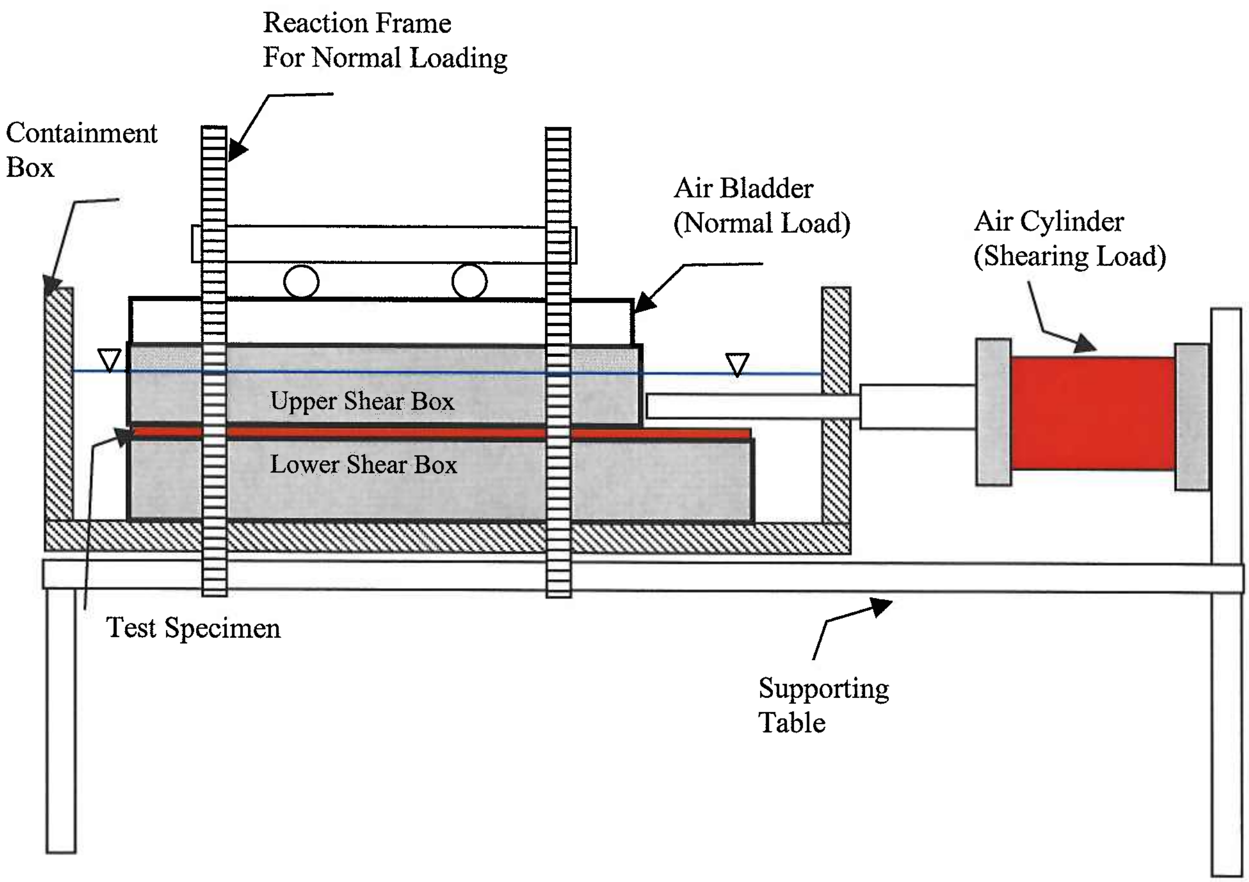


Figure 1. Schematic Diagram of Creep Shear Test Device (Not to Scale)

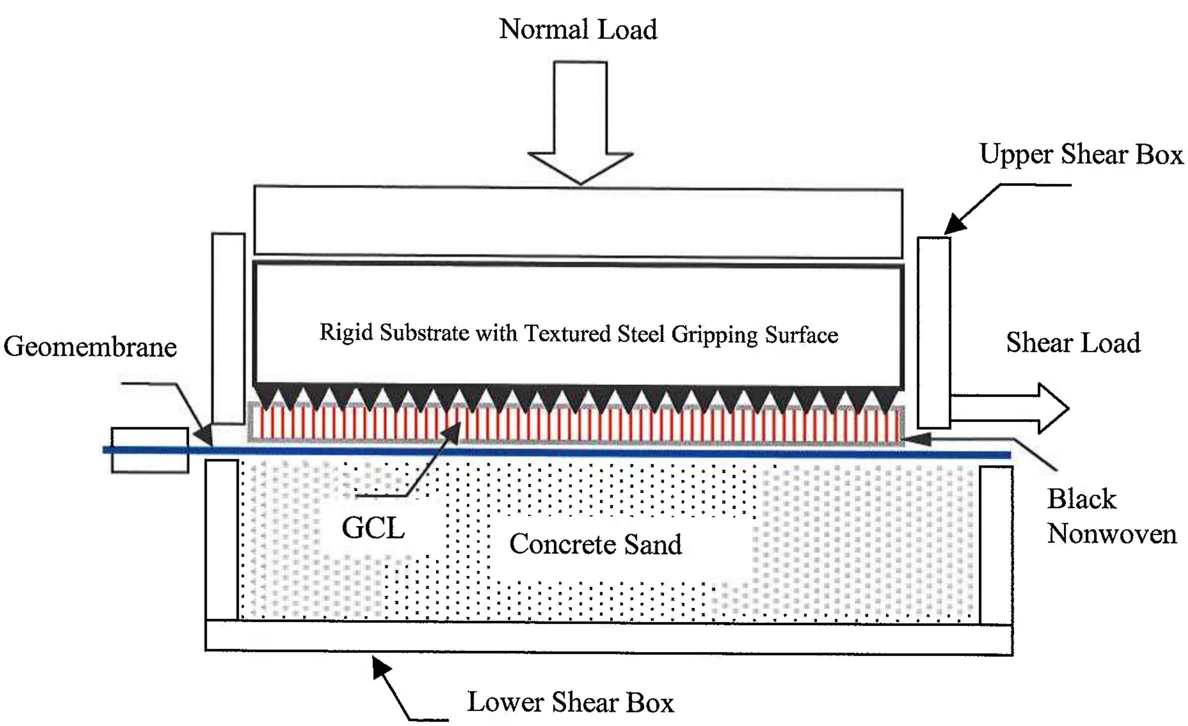


Figure 2. Schematic Diagram of Test Specimen Cross-Section (Not to Scale)

APPENDIX B

SUMMARY OF TEST RESULTS

TABLE 1
SUMMARY OF CREEP SHEAR TEST RESULTS
CETCO LINING TECHNOLOGIES
BLACK NONWOVEN GEOTEXTILE OF BENTOMAT SDN GCL (LOT NO. 200230FA/ROLL NO. 289) AGAINST 60-MIL POLYFLEX TEXTURED HDPE GEOMEMBRANE
LANDFILL LINING SYSTEM EVALUATION

Shear Phase No.	1		2		3		4		5	
Soaking	at 400 psf for 120 hours		None		None		None		None	
Consolidation	at 2000 psf for 120 hours		at 4000 psf for 120 hours		at 6000 psf for 120 hours		at 8000 psf for 120 hours		at 10000 psf for 120 hours	
Loading Conditions	Normal Stress = 2000 psf Shear Stress = 700 psf		Normal Stress = 4000 psf Shear Stress = 1400 psf		Normal Stress = 6000 psf Shear Stress = 2100 psf		Normal Stress = 8000 psf Shear Stress = 2800 psf		Normal Stress = 10000 psf Shear Stress = 3500 psf	
Selected Time (hours)	Total Shear Displacement (in.)	Incremental Shear Displacement Rate (in./min)	Total Shear Displacement (in.)	Incremental Shear Displacement Rate (in./min)	Total Shear Displacement (in.)	Incremental Shear Displacement Rate (in./min)	Total Shear Displacement (in.)	Incremental Shear Displacement Rate (in./min)	Total Shear Displacement (in.)	Incremental Shear Displacement Rate (in./min)
1	0.159	1.86E-04	0.223	1.38E-04	0.274	1.61E-04	0.324	1.16E-04	0.383	1.06E-04
10	0.166	1.08E-05	0.228	5.77E-06	0.281	1.07E-05	0.328	2.92E-06	0.389	8.21E-06
100	0.171	2.38E-07	0.233	3.93E-07	0.287	6.78E-07	0.334	9.58E-07	0.392	4.86E-07
500	0.174	1.25E-07	0.237	1.14E-07	0.292	1.41E-07	0.338	6.14E-08	0.394	7.38E-08
1000	0.176	4.95E-08	0.239	3.33E-08	0.293	2.43E-08	0.338	2.24E-08	0.395	1.65E-08
5000									0.396	7.48E-09
10000									0.398	6.40E-09

NOTES:
(1) Shear displacement and incremental shear displacement rate at a selected time were calculated by linear interpolation between two nearest measured data points.
(2) The select time is within the time domain defined by the two nearest measured data points.
(3) Total shear displacement = shear displacement measured at the upper shear box.

SGI TESTING SERVICES, LLC

DATE OF REPORT:	17 December 2005
FIGURE NO.	B-1
PROJECT NO.	SGI2038
DOCUMENT NO.	SGI05040
FILE NO.	

APPENDIX C

CREEP SHEAR TEST DATA

TABLE 1
SUMMARY OF CREEP SHEAR TEST RESULTS
CETCO LINING TECHNOLOGIES
BLACK NONWOVEN GEOTEXTILE OF BENTOMAT SDN GCL (LOT NO. 200230FA/ROLL NO. 289) AGAINST 60-MIL POLYFLEX TEXTURED HDPE GEOMEMBRANE
LANDFILL LINING SYSTEM EVALUATION

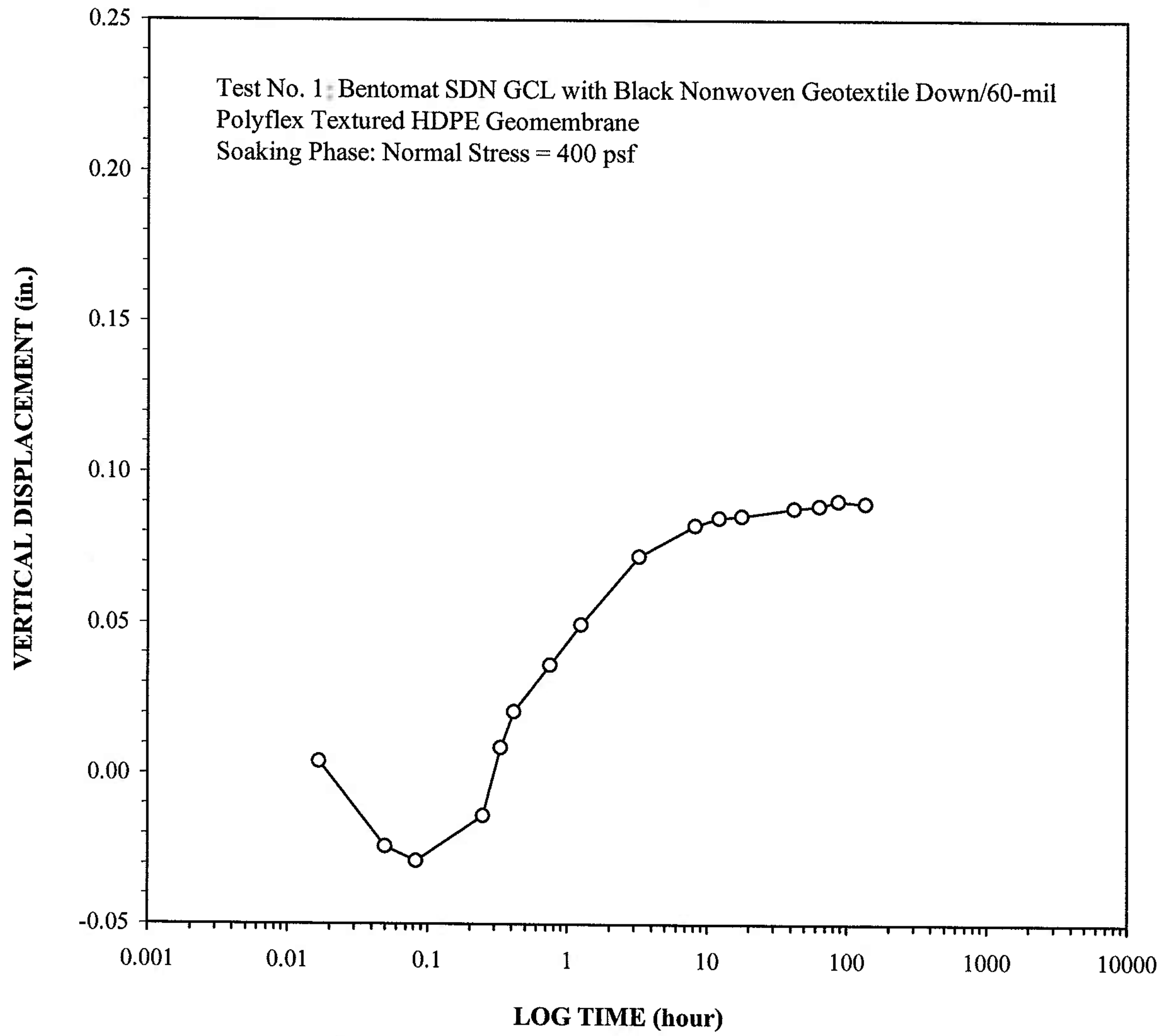
Shear Phase No.	1		2		3		4		5	
Soaking	at 400 psf for 120 hours		None		None		None		None	
Consolidation	at 2000 psf for 120 hours		at 4000 psf for 120 hours		at 6000 psf for 120 hours		at 8000 psf for 120 hours		at 10000 psf for 120 hours	
Loading Conditions	Normal Stress = 2000 psf Shear Stress = 700 psf		Normal Stress = 4000 psf Shear Stress = 1400 psf		Normal Stress = 6000 psf Shear Stress = 2100 psf		Normal Stress = 8000 psf Shear Stress = 2800 psf		Normal Stress = 10000 psf Shear Stress = 3500 psf	
Selected Time (hours)	Total Shear Displacement (in.)	Incremental Shear Displacement Rate (in./min)	Total Shear Displacement (in.)	Incremental Shear Displacement Rate (in./min)	Total Shear Displacement (in.)	Incremental Shear Displacement Rate (in./min)	Total Shear Displacement (in.)	Incremental Shear Displacement Rate (in./min)	Total Shear Displacement (in.)	Incremental Shear Displacement Rate (in./min)
1	0.159	1.86E-04	0.223	1.38E-04	0.274	1.61E-04	0.324	1.16E-04	0.383	1.06E-04
10	0.166	1.08E-05	0.228	5.77E-06	0.281	1.07E-05	0.328	2.92E-06	0.389	8.21E-06
100	0.171	2.38E-07	0.233	3.93E-07	0.287	6.78E-07	0.334	9.58E-07	0.392	4.86E-07
500	0.174	1.25E-07	0.237	1.14E-07	0.292	1.41E-07	0.338	6.14E-08	0.394	7.38E-08
1000	0.176	4.95E-08	0.239	3.33E-08	0.293	2.43E-08	0.338	2.24E-08	0.395	1.65E-08
5000									0.396	7.48E-09
10000									0.398	6.40E-09

NOTES:
(1) Shear displacement and incremental shear displacement rate at a selected time were calculated by linear interpolation between two nearest measured data points.
(2) The select time is within the time domain defined by the two nearest measured data points.
(3) Total shear displacement = shear displacement measured at the upper shear box.

SGI TESTING SERVICES, LLC

DATE OF REPORT:	17 December 2005
FIGURE NO.	B-1
PROJECT NO.	SGI2038
DOCUMENT NO.	SGI05040
FILE NO.	

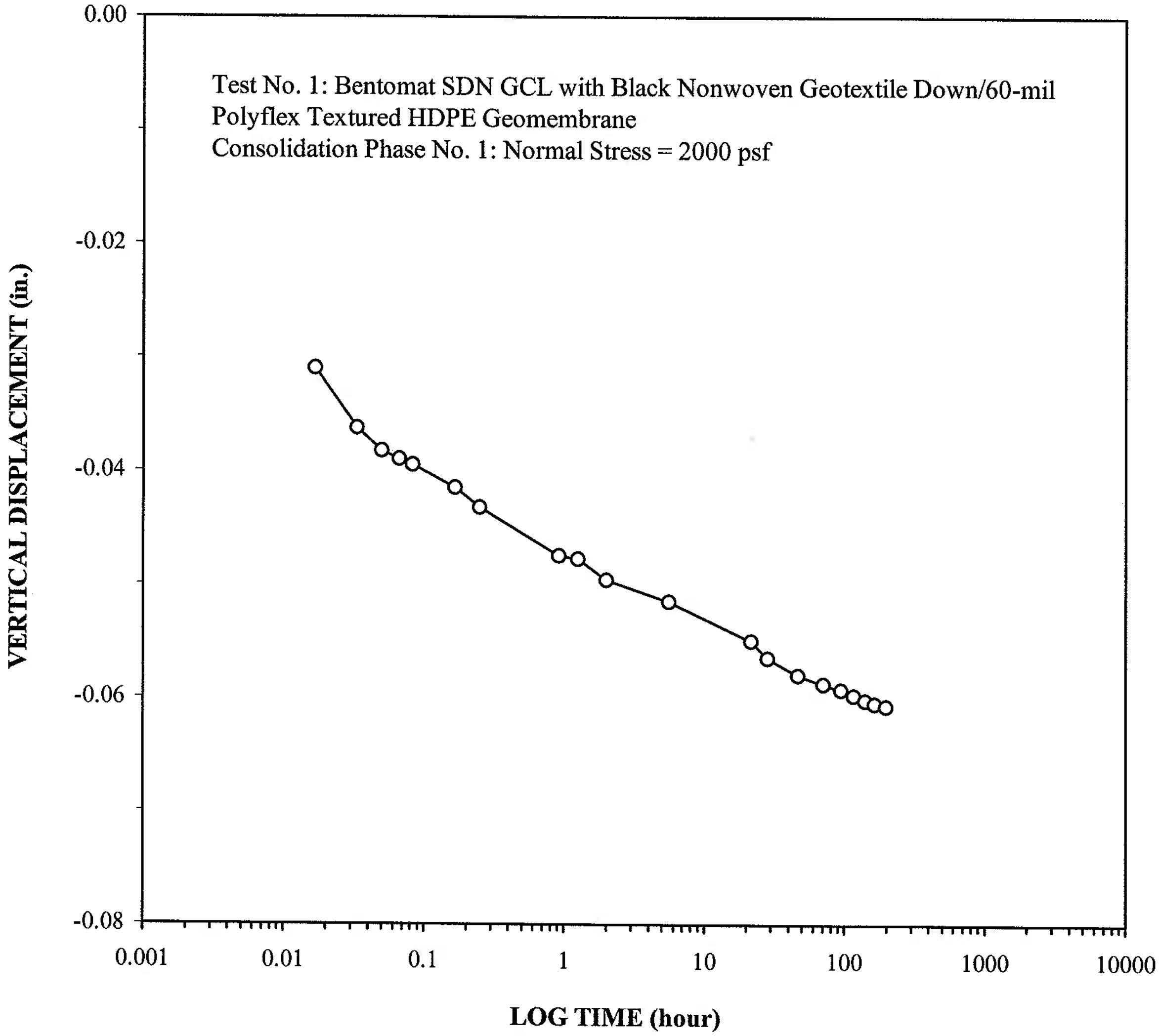
CETCO LINING TECHNOLOGIES
CREEP SHEAR TESTING - ASTM 6243
SOAKING PHASE NO. 1



NOTES:
1. Positive values of vertical displacements means increase of specimen thickness (swelling)
2. Negative values of vertical displacements means decrease of specimen thickness (compression)

SGI TESTING SERVICES, LLC	DATE TESTED:	5/19 to 5/27/2003
	FIGURE NO.	C-1
	PROJECT NO.	SGI2038
	DOCUMENT NO.	SGI05040
	FILE NO.	

CETCO LINING TECHNOLOGIES
CREEP SHEAR TESTING - ASTM 6243
CONSOLIDATION PHASE NO. 1



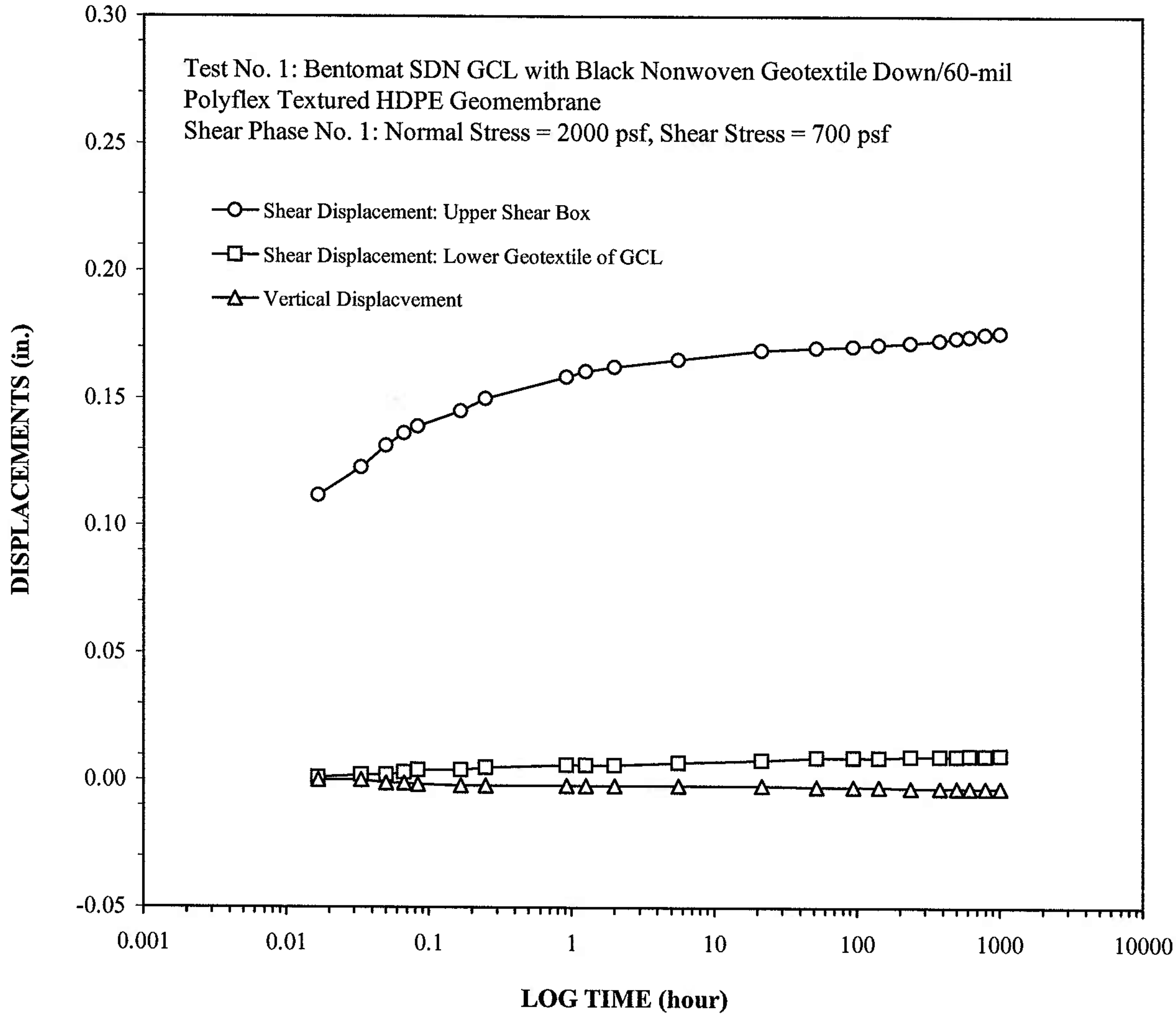
NOTES:

1. Positive values of vertical displacements means increase of specimen thickness (swelling)
2. Negative values of vertical displacements means decrease of specimen thickness (compression)

DATE TESTED:	5/27 to 6/12/2003
FIGURE NO.	C-2
PROJECT NO.	SGI2038
DOCUMENT NO.	SGI05040
FILE NO.	

SGI TESTING SERVICES, LLC

CETCO LINING TECHNOLOGIES
CREEP SHEAR TESTING - ASTM 6243
SHEAR PHASE NO. 1



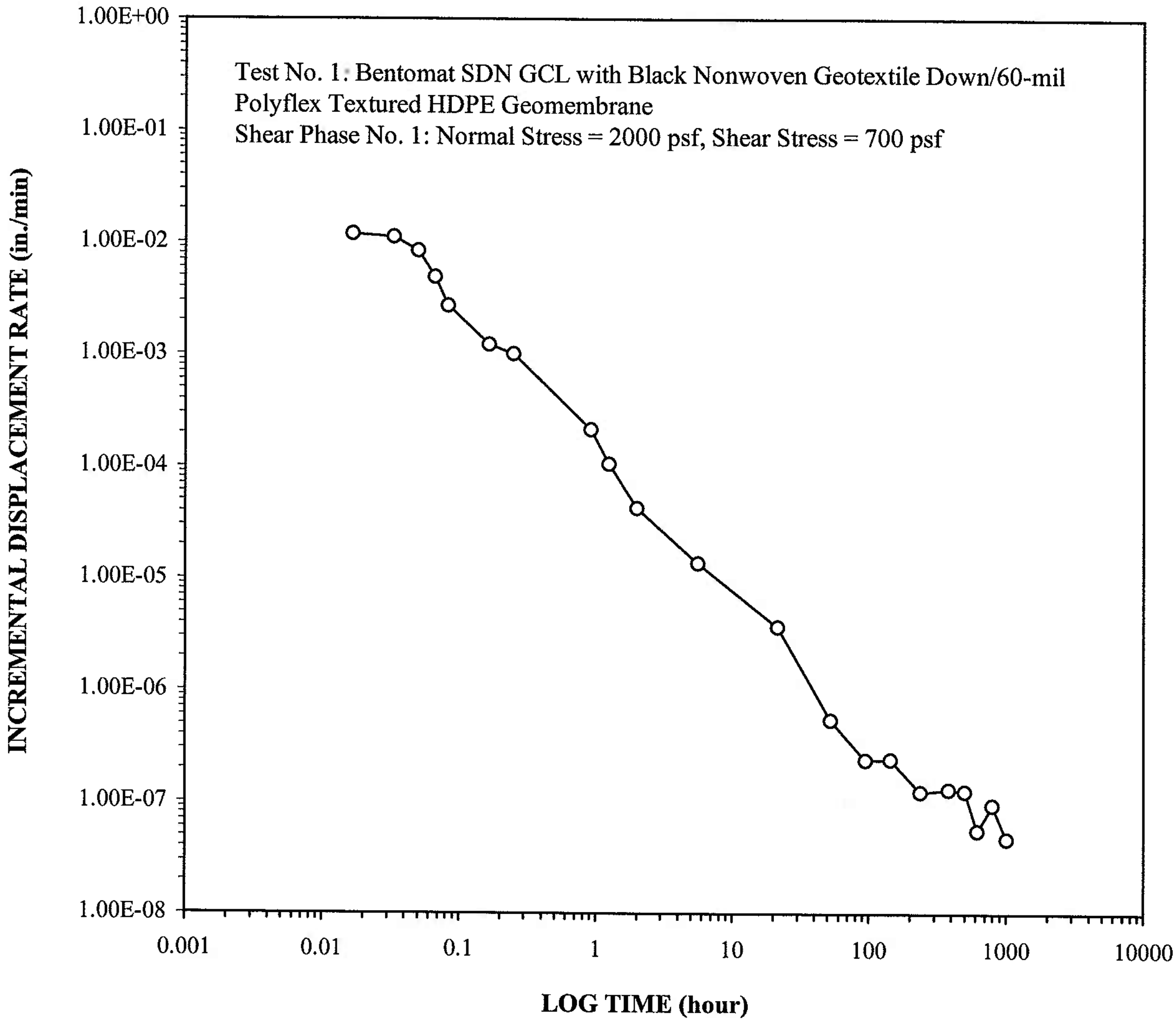
NOTES:

1. Positive values of vertical displacements means increase of specimen thickness (swelling)
2. Negative values of vertical displacements means decrease of specimen thickness (compression)

DATE TESTED:	6/12 to 7/24/2003
FIGURE NO.	C-3
PROJECT NO.	SGI2038
DOCUMENT NO.	SGI05040
FILE NO.	

SGI TESTING SERVICES, LLC

CETCO LINING TECHNOLOGIES
CREEP SHEAR TESTING - ASTM 6243
SHEAR PHASE NO. 1



NOTE:

Incremental Displacement Rate is defined as: $R = (U_i - U_{i-1})/(t_i - t_{i-1})$

where:

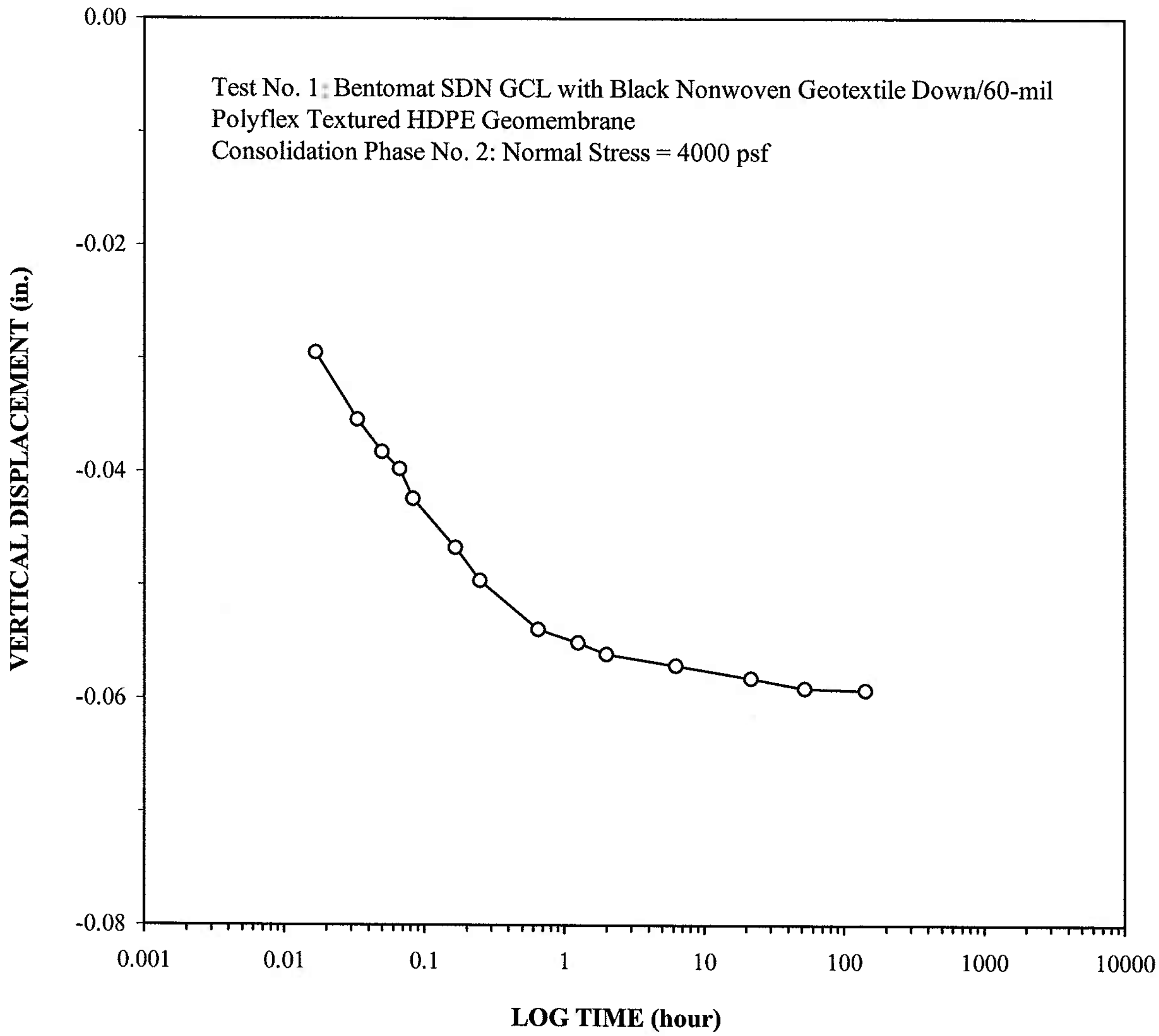
U_i = upper shear box displacement at time = t_i

U_{i-1} = upper shear box displacement at time = t_{i-1}

SGI TESTING SERVICES, LLC

DATE TESTED:	6/12 to 7/24/2003
FIGURE NO.	C-4
PROJECT NO.	SGI2038
DOCUMENT NO.	SGI05040
FILE NO.	

CETCO LINING TECHNOLOGIES
CREEP SHEAR TESTING - ASTM 6243
CONSOLIDATION PHASE NO. 2



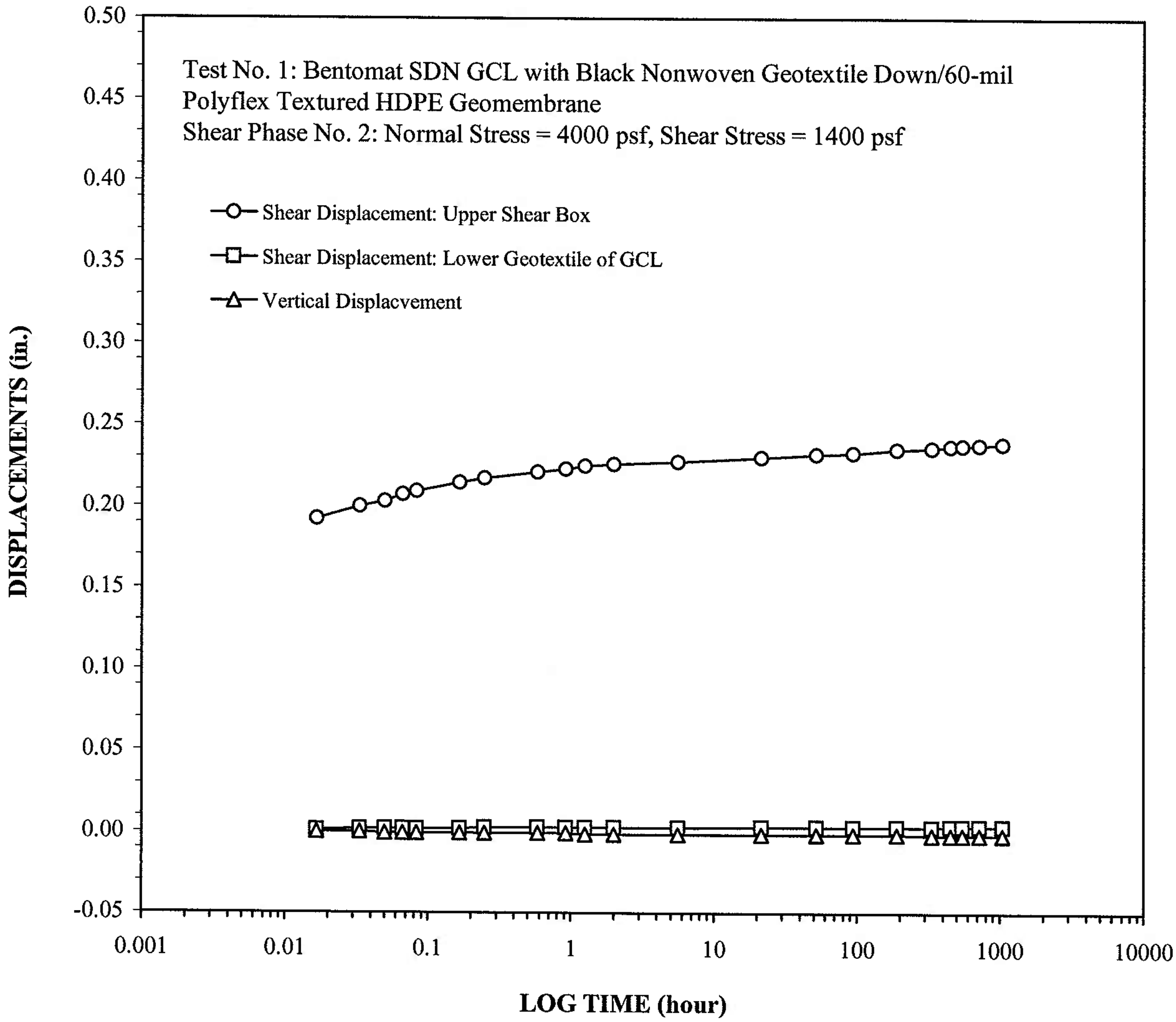
NOTES:

1. Positive values of vertical displacements means increase of specimen thickness (swelling)
2. Negative values of vertical displacements means decrease of specimen thickness (compression)

SGI TESTING SERVICES, LLC

DATE TESTED:	7/27 to 7/31/2003
FIGURE NO.	C-5
PROJECT NO.	SGI2038
DOCUMENT NO.	SGI05040
FILE NO.	

CETCO LINING TECHNOLOGIES
CREEP SHEAR TESTING - ASTM 6243
SHEAR PHASE NO. 2



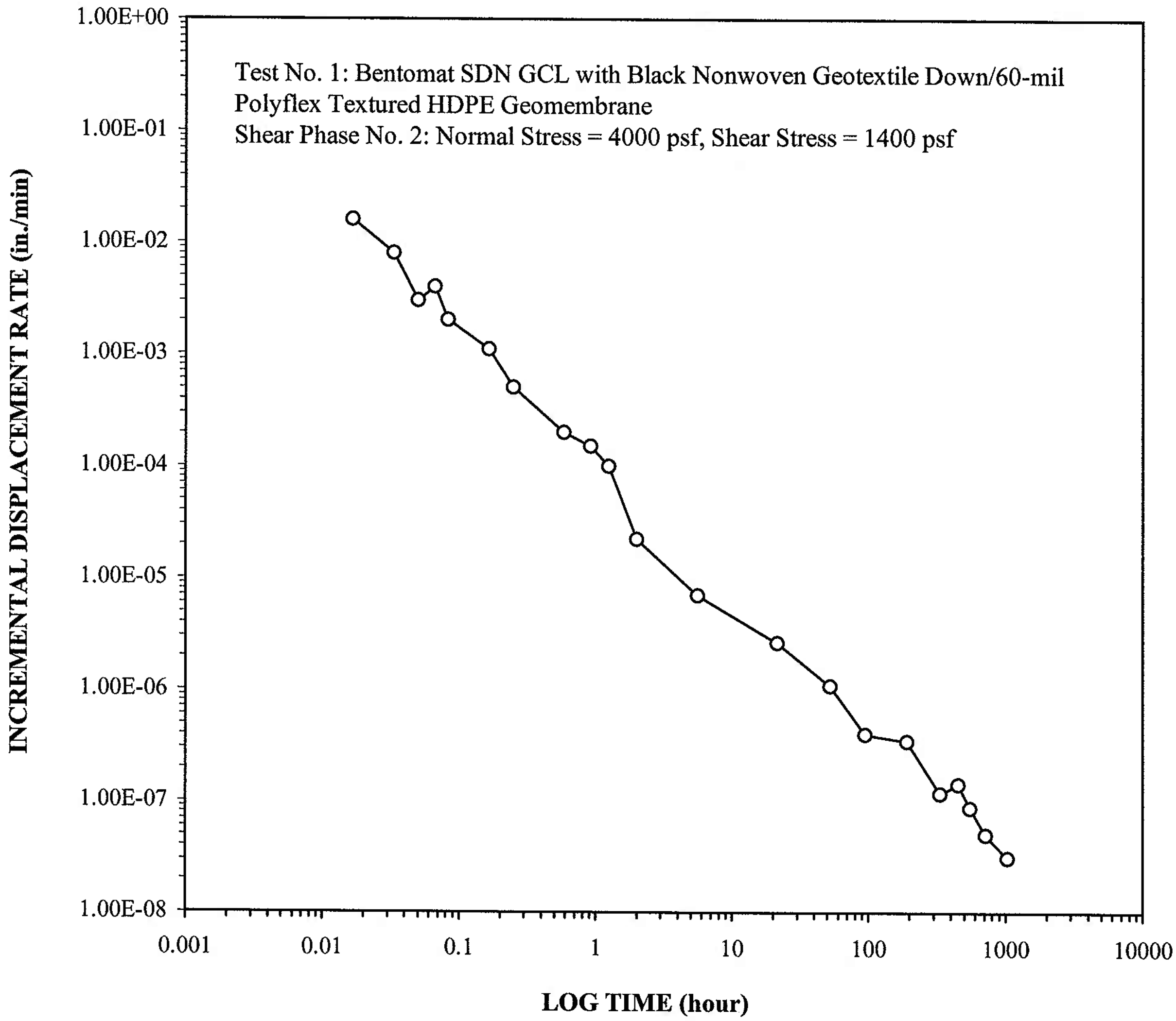
NOTES:

1. Positive values of vertical displacements means increase of specimen thickness (swelling)
2. Negative values of vertical displacements means decrease of specimen thickness (compression)

DATE TESTED:	8/1 to 9/13/2003
FIGURE NO.	C-6
PROJECT NO.	SGI2038
DOCUMENT NO.	SGI05040
FILE NO.	

SGI TESTING SERVICES, LLC

CETCO LINING TECHNOLOGIES
CREEP SHEAR TESTING - ASTM 6243
SHEAR PHASE NO. 2



NOTE:

Incremental Displacement Rate is defined as: $R = (U_i - U_{i-1})/(t_i - t_{i-1})$

where:

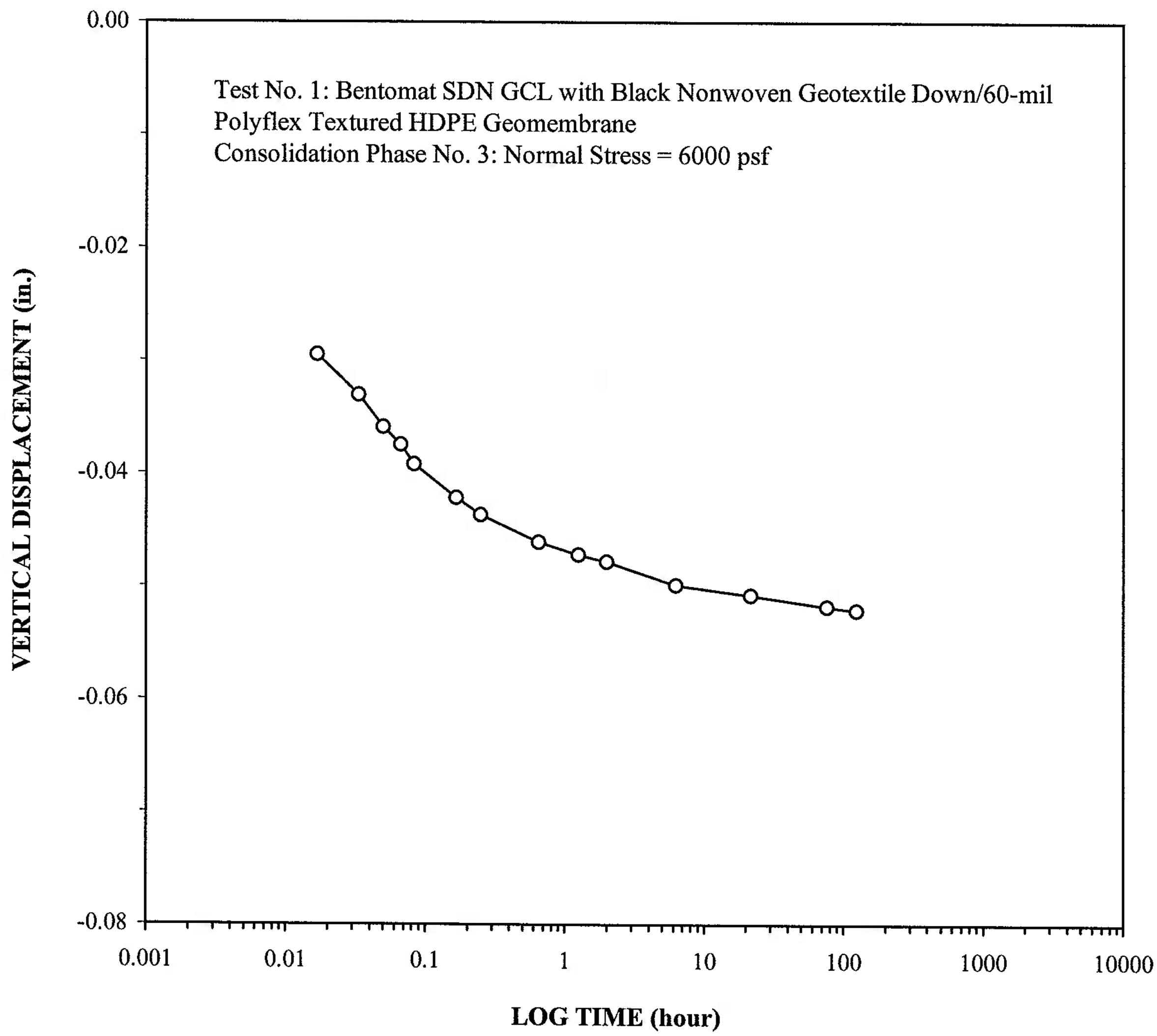
U_i = upper shear box displacement at time = t_i

U_{i-1} = upper shear box displacement at time = t_{i-1}

SGI TESTING SERVICES, LLC

DATE TESTED:	8/1 to 9/13/2003
FIGURE NO.	C-7
PROJECT NO.	SGI2038
DOCUMENT NO.	SGI05040
FILE NO.	

CETCO LINING TECHNOLOGIES
CREEP SHEAR TESTING - ASTM 6243
CONSOLIDATION PHASE NO. 3

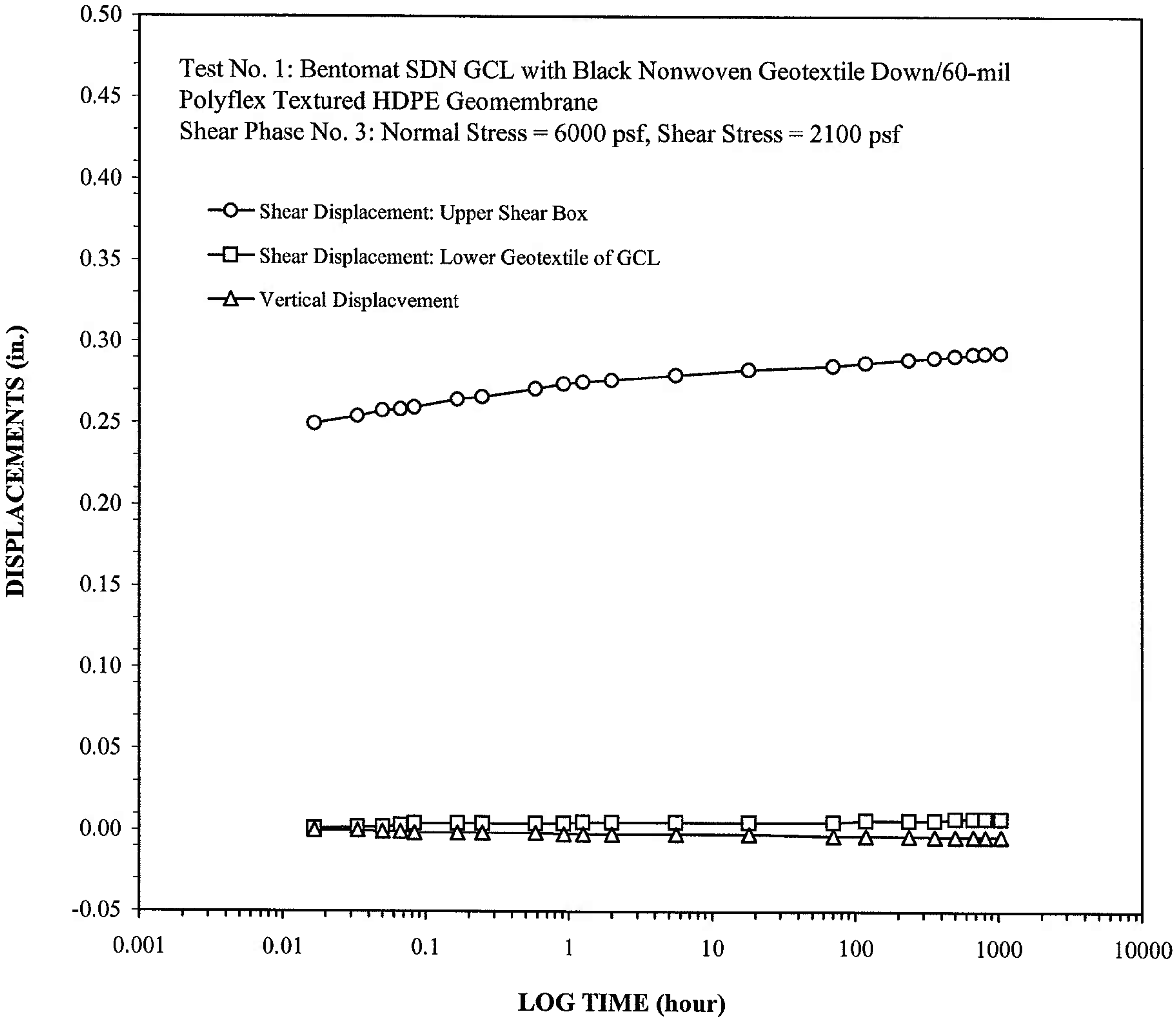


NOTES:

1. Positive values of vertical displacements means increase of specimen thickness (swelling)
2. Negative values of vertical displacements means decrease of specimen thickness (compression)

	DATE TESTED:	9/14 to 9/19/2003
SGI TESTING SERVICES, LLC	FIGURE NO.	C-8
	PROJECT NO.	SGI2038
	DOCUMENT NO.	SGI05040
	FILE NO.	

CETCO LINING TECHNOLOGIES
CREEP SHEAR TESTING - ASTM 6243
SHEAR PHASE NO. 3



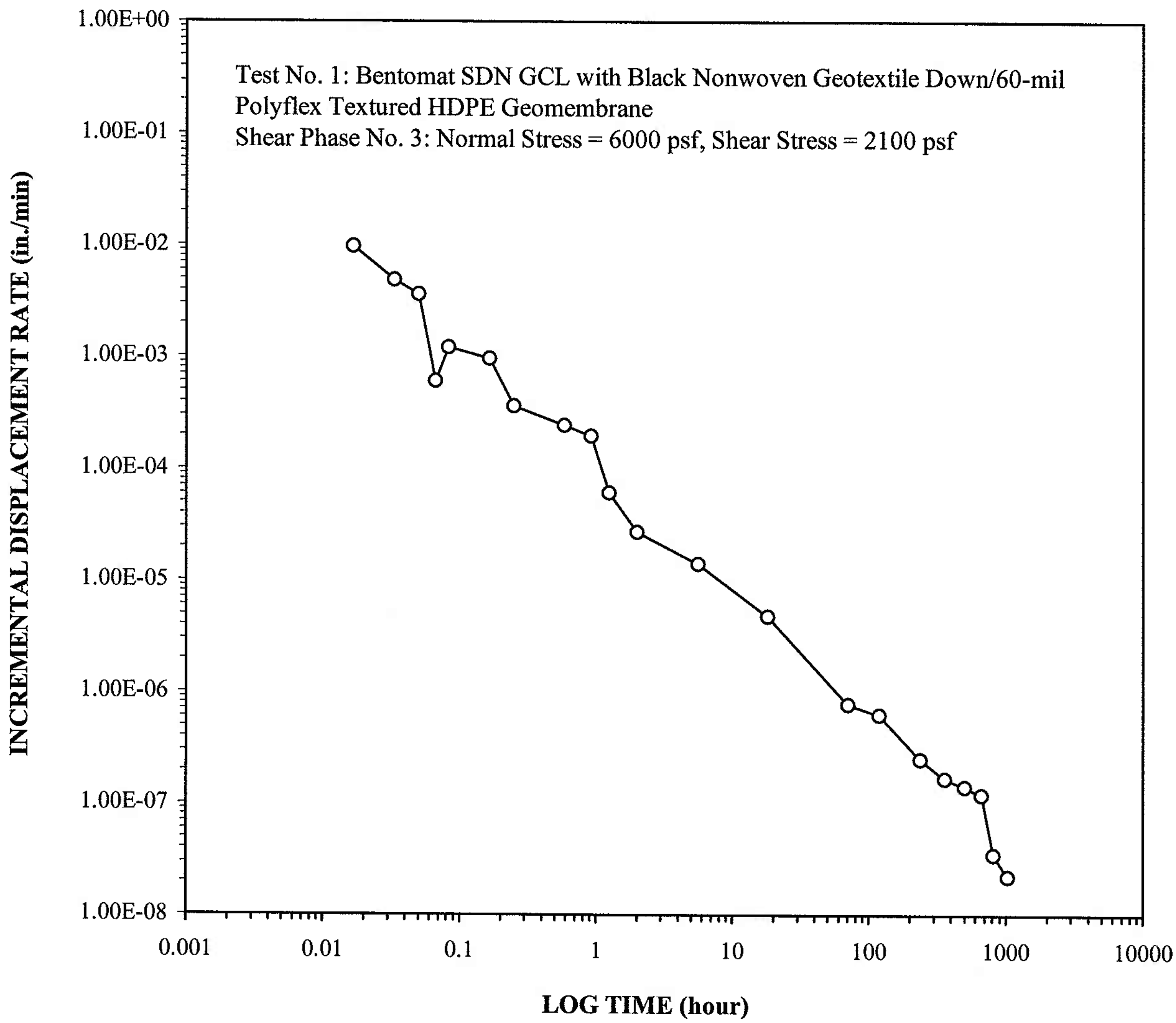
NOTES:

1. Positive values of vertical displacements means increase of specimen thickness (swelling)
2. Negative values of vertical displacements means decrease of specimen thickness (compression)

DATE TESTED:	9/19 to 11/1/2003
FIGURE NO.	C-9
PROJECT NO.	SGI2038
DOCUMENT NO.	SGI05040
FILE NO.	

SGI TESTING SERVICES, LLC

CETCO LINING TECHNOLOGIES
CREEP SHEAR TESTING - ASTM 6243
SHEAR PHASE NO. 3

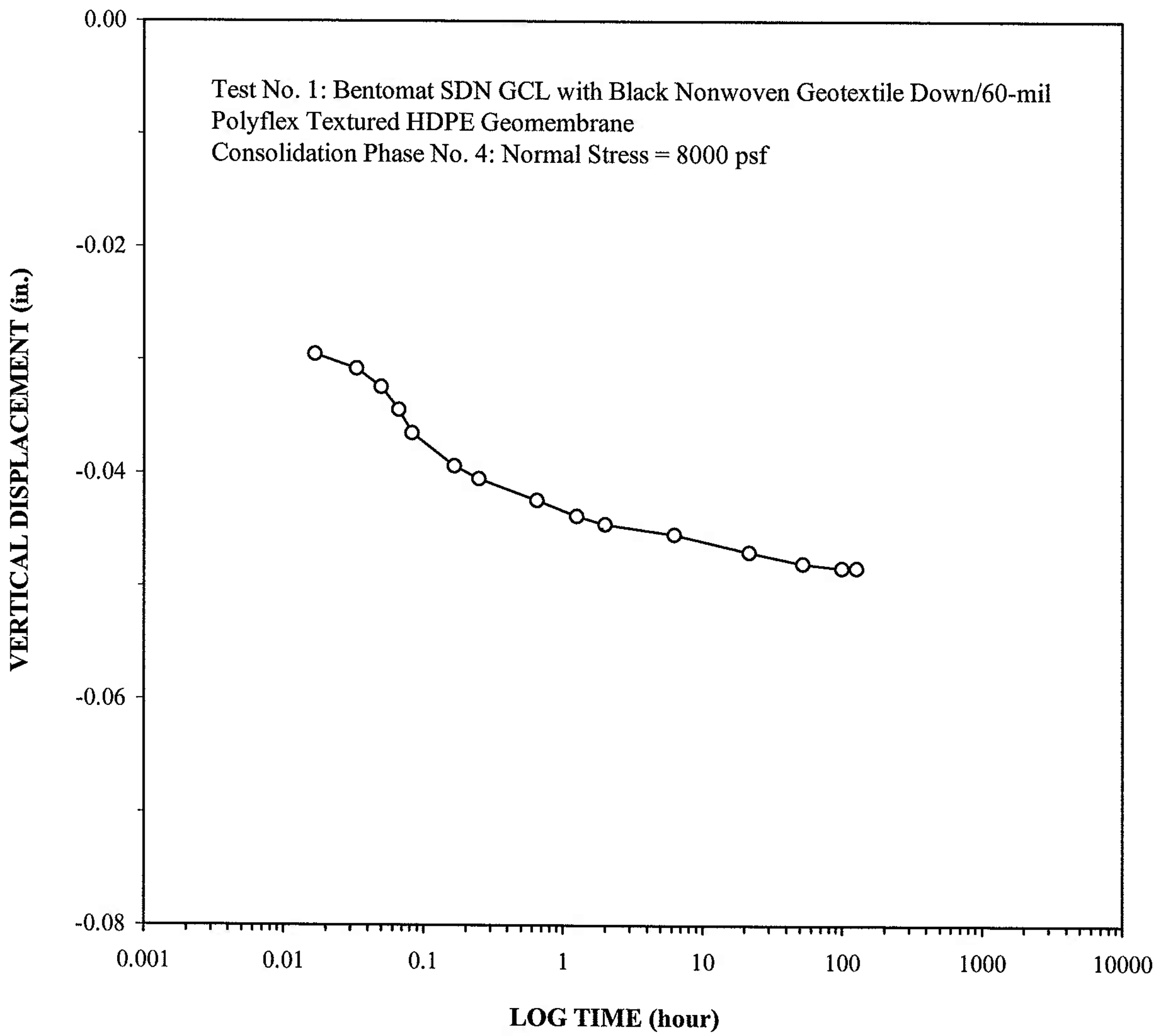


NOTE:
Incremental Displacement Rate is defined as: $R = (U_i - U_{i-1})/(t_i - t_{i-1})$
where:
U_i = upper shear box displacement at time = t_i
U_{i-1} = upper shear box displacement at time = t_{i-1}

DATE TESTED:	9/19 to 11/1/2003
FIGURE NO.	C-10
PROJECT NO.	SGI2038
DOCUMENT NO.	SGI05040
FILE NO.	

SGI TESTING SERVICES, LLC

CETCO LINING TECHNOLOGIES
CREEP SHEAR TESTING - ASTM 6243
CONSOLIDATION PHASE NO. 4

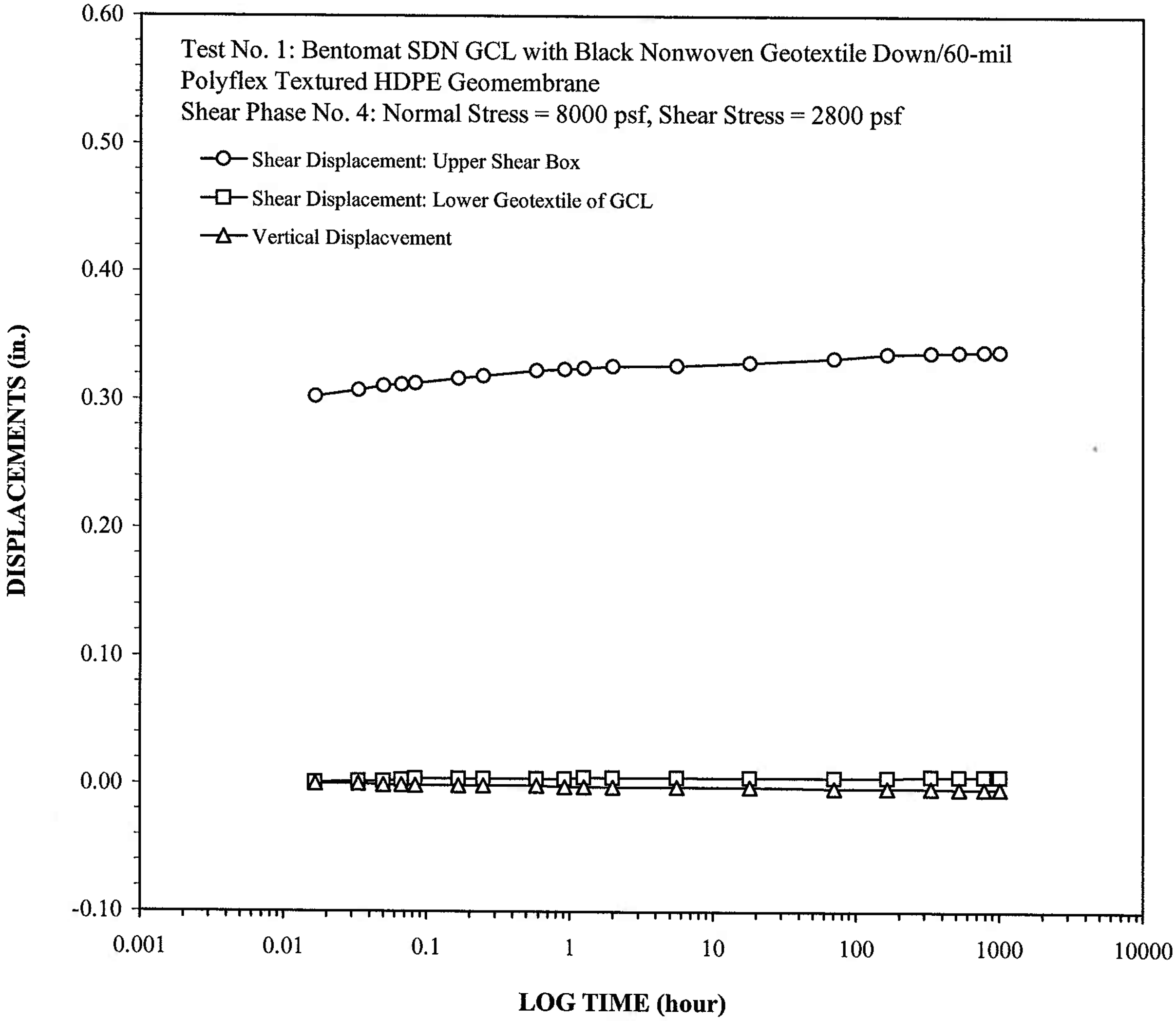


NOTES:

1. Positive values of vertical displacements means increase of specimen thickness (swelling)
2. Negative values of vertical displacements means decrease of specimen thickness (compression)

SGI TESTING SERVICES, LLC	DATE TESTED:	11/2 to 11/7/2003
	FIGURE NO.	C-11
	PROJECT NO.	SGI2038
	DOCUMENT NO.	SGI05040
	FILE NO.	

CETCO LINING TECHNOLOGIES
CREEP SHEAR TESTING - ASTM 6243
SHEAR PHASE NO. 4



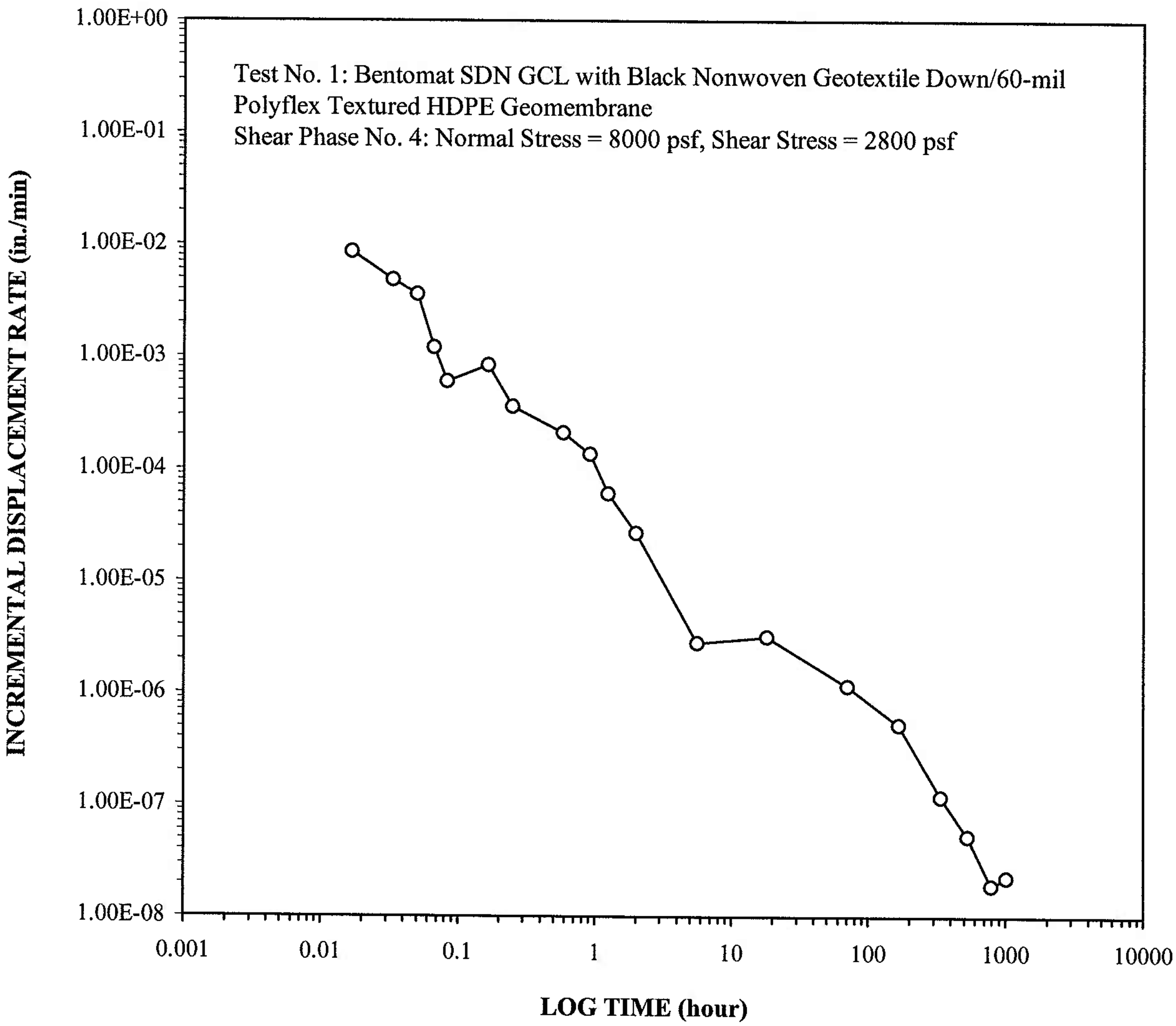
NOTES:

1. Positive values of vertical displacements means increase of specimen thickness (swelling)
2. Negative values of vertical displacements means decrease of specimen thickness (compression)

SGI TESTING SERVICES, LLC

DATE TESTED:	12/8/2003 to 1/19/2004
FIGURE NO.	C-12
PROJECT NO.	SGI2038
DOCUMENT NO.	SGI05040
FILE NO.	

CETCO LINING TECHNOLOGIES
CREEP SHEAR TESTING - ASTM 6243
SHEAR PHASE NO. 4



NOTE:

Incremental Displacement Rate is defined as: $R = (U_i - U_{i-1})/(t_i - t_{i-1})$

where:

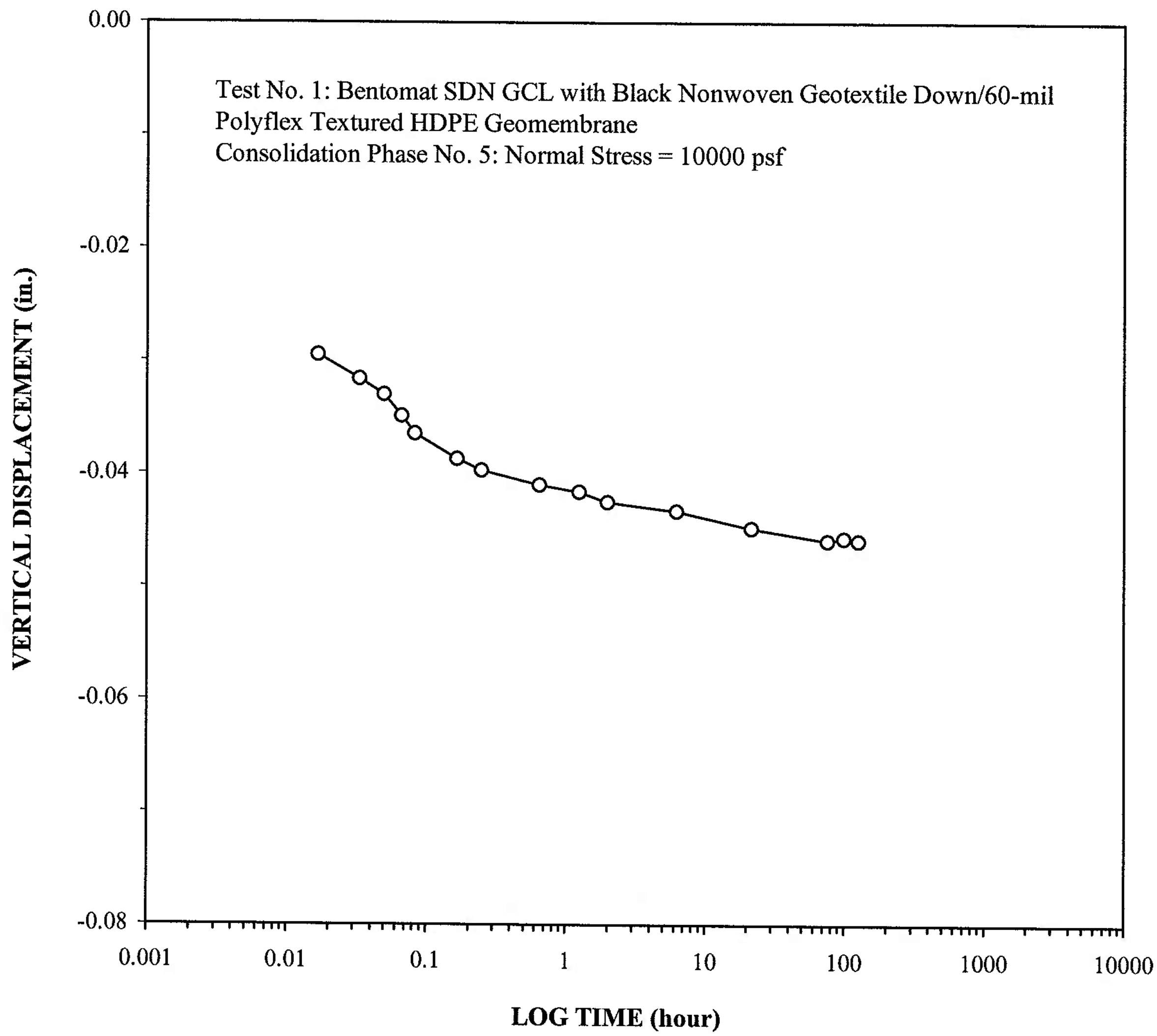
U_i = upper shear box displacement at time = t_i

U_{i-1} = upper shear box displacement at time = t_{i-1}

SGI TESTING SERVICES, LLC

DATE TESTED:	12/8/2003 to 1/19/2004
FIGURE NO.	C-13
PROJECT NO.	SGI2038
DOCUMENT NO.	SGI05040
FILE NO.	

CETCO LINING TECHNOLOGIES
CREEP SHEAR TESTING - ASTM 6243
CONSOLIDATION PHASE NO. 5

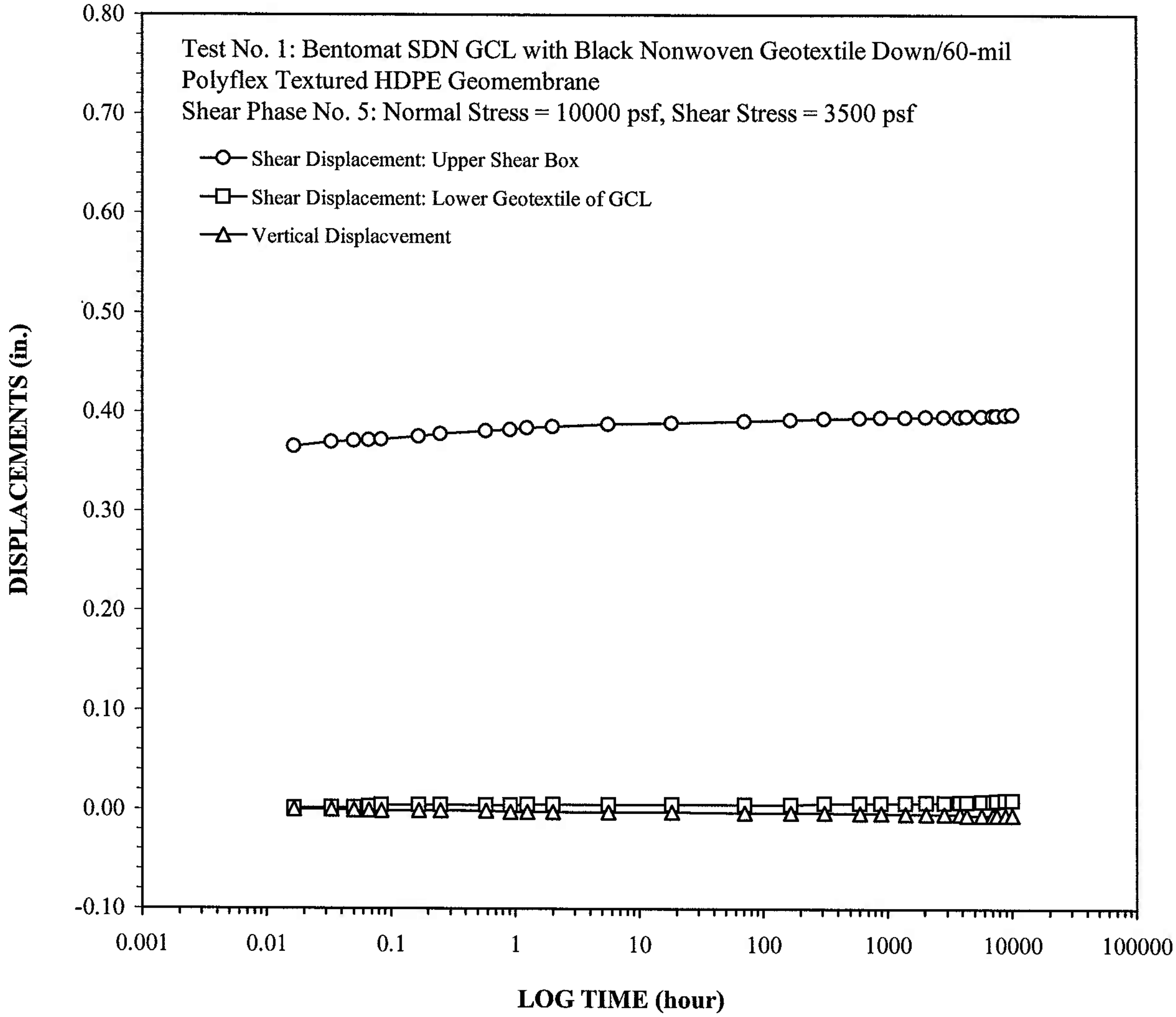


NOTES:
1. Positive values of vertical displacements means increase of specimen thickness (swelling)
2. Negative values of vertical displacements means decrease of specimen thickness (compression)

SGI TESTING SERVICES, LLC

DATE TESTED:	1/19 to 1/24/2004
FIGURE NO.	C-14
PROJECT NO.	SGI2038
DOCUMENT NO.	SGI05040
FILE NO.	

CETCO LINING TECHNOLOGIES
CREEP SHEAR TESTING - ASTM 6243
SHEAR PHASE NO. 5



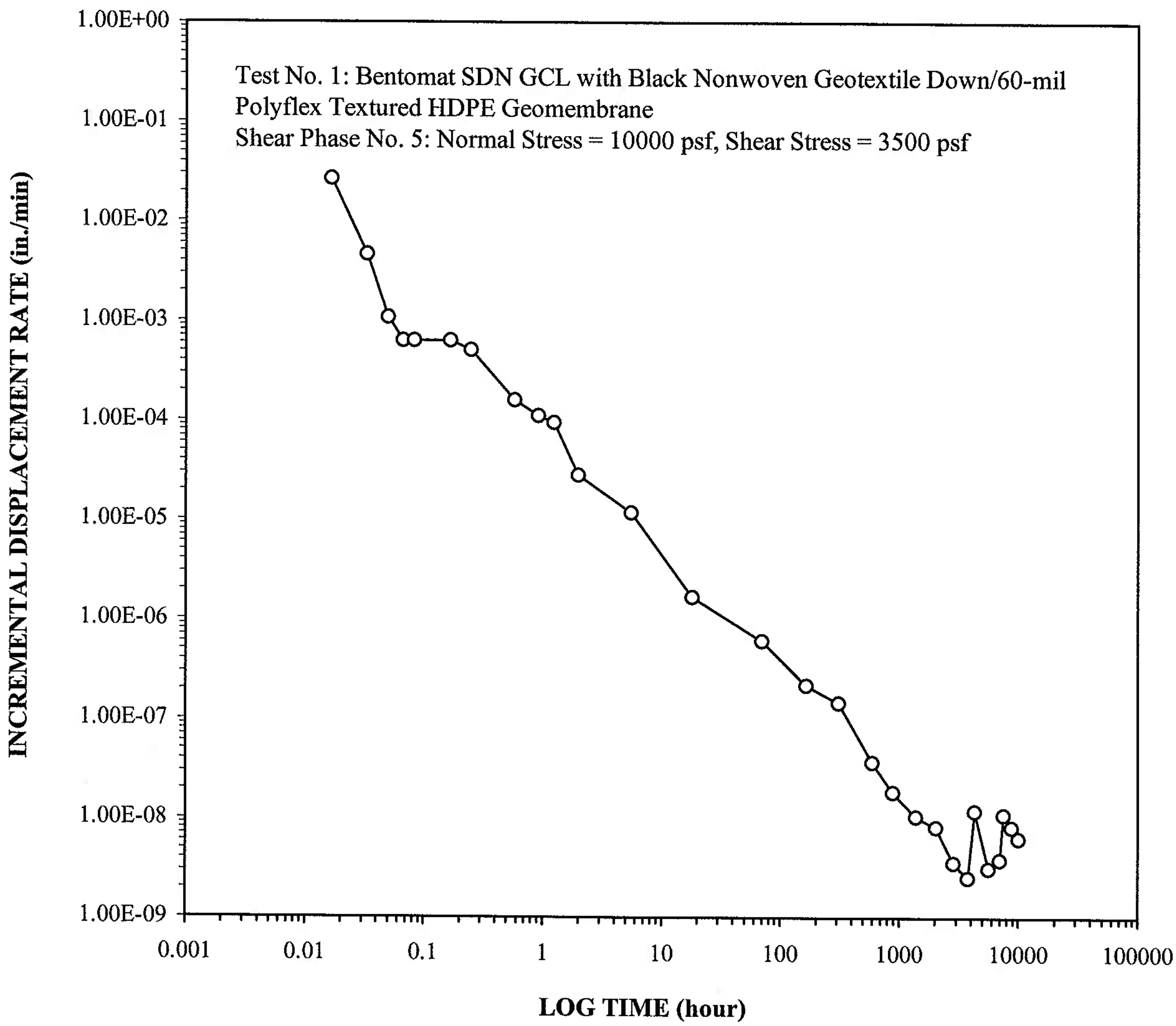
NOTES:

1. Positive values of vertical displacements means increase of specimen thickness (swelling)
2. Negative values of vertical displacements means decrease of specimen thickness (compression)

DATE TESTED:	1/24/2004 to 3/19/2005
FIGURE NO.	C-15
PROJECT NO.	SGI2038
DOCUMENT NO.	SGI05040
FILE NO.	

SGI TESTING SERVICES, LLC

CETCO LINING TECHNOLOGIES
CREEP SHEAR TESTING - ASTM 6243
SHEAR PHASE NO. 5



NOTE:

Incremental Displacement Rate is defined as: $R = (U_i - U_{i-1})/(t_i - t_{i-1})$

where:

U_i = upper shear box displacement at time = t_i

U_{i-1} = upper shear box displacement at time = t_{i-1}

SGI TESTING SERVICES, LLC

DATE TESTED:	1/24/2004 to 3/19/2005
FIGURE NO.	C-16
PROJECT NO.	SGI2038
DOCUMENT NO.	SGI05040
FILE NO.	