INTERNAL SHEAR STRENGTH TESTING OF BENTOMAT®

A COMPARISON OF THE INTERNAL SHEAR STRENGTH OF HYDRATED VS. DRY BENTOMAT

Specimens of Bentomat were tested for internal direct shear in accordance with ASTM D 5321 “Determining the Coefficient of Soil and Geosynthetic and Geosynthetic Friction by the Direct Shear Method”. One series of Bentomat specimens were tested in the as received “dry” condition, and the second series were tested in a hydrated condition after soaking in water for 72 hours. Each series was tested for internal shear at 4 different normal loads to determine the internal friction angles and the “apparent” adhesions. Normal stresses of 50 psf, 150 psf, 300 psf and 500 psf were used to define the total stress envelopes. Test results defined total stress internal friction angles of 59° and 57° for the hydrated and dry specimens of Bentomat respectively.

THE INTERNAL SHEAR STRENGTH OF BENTOMAT UNDER HIGH NORMAL STRESSES

Specimens of hydrated Bentomat were tested for internal shear strength under high normal stresses. Normal stresses of 2,000 psf, 10,000 psf and 20,500 psf were applied. Test results showed an internal friction angle of 24° and a residual friction angle of 7°. “Apparent adhesion” values are also summarized in the test report.

TR-102
Revised 12/00

A wholly owned subsidiary of AMCOL International Corporation. The information and data contained herein are believed to be accurate and reliable, CETCO makes no warranty of any kind and accepts no responsibility for the results obtained through application of this information.

GEOSYNTEC CONSULTANTS

7 December 1993

Mr. Bob Trauger, P.E.
Technical Services Manager
Colloid Environmental Technologies Company
1500 West Shure Drive
Arlington Heights, Illinois 60004-7803

Subject: Final Report
Direct Shear Testing
Internal Strength of Bentomat GCL

Dear Mr. Trauger:

GeoSyntec Consultants (GeoSyntec) is pleased to present the results of the direct shear testing program recently performed for Colloid Environmental Technologies Company (CETCO). The direct shear testing was conducted in GeoSyntec's Geomechanics and Environmental Laboratory located in Atlanta, Georgia. This letter report was prepared by Mr. Robert H. Swan, Jr. and Dr. Zehong Yuan, both of GeoSyntec. The report was reviewed by Dr. Gary R. Schmertmann, also of GeoSyntec, in accordance with the internal peer review policy of the firm.

The testing program was conducted in accordance with the test procedures defined in GeoSyntec's Agreement for Testing Services issued to CETCO on 12 July 1993. GeoSyntec understands that the purpose of the testing program was to evaluate the internal shearing resistance of CETCO's Bentomat geosynthetic clay liner (GCL) under two different moisture conditions: (i) a dry condition (i.e., as-received moisture), and (ii) a hydrated condition, using the direct shear method. The GCL consisted of a woven geotextile on one side of a bentonite component and a nonwoven geotextile on other side of the bentonite component. GeoSyntec also understands that the sample preparation procedures and testing conditions used in the testing program were selected by CETCO to simulate anticipated field conditions.

The remaining sections of this letter report present: (i) a description of the configuration of the test specimens used in the direct shear tests; (ii) the testing procedures used in the direct shear tests; and (iii) the test results.

GL3419/GEL93291

CONFIGURATION OF THE TEST SPECIMENS

Two direct shear test series were conducted to evaluate the internal shear strength of the Bentomat GCL under dry and hydrated moisture conditions. Each test series consisted of four direct shear tests with each test conducted at a different level of normal stress ranging from 50 to 500 psf (2 to 24 kPa) using a freshly prepared test specimen. Table 1 summarizes the general testing conditions that were used for the two direct shear test series. The configuration of each test specimen used in the test series, from top to bottom, was as follows:

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

Bulk samples of the Bentomat GCL were provided to GeoSyntec by CETCO. The rigid substrates with textured steel gripping surfaces were provided by GeoSyntec.

TESTING PROCEDURES

The direct shear tests were performed in general accordance with the American Society for Testing and Materials (ASTM) Standard Test Method D 5321, "*Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method.*" 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 measures 12 in. by 14 in. (300 mm by 350 mm) in plan and 3 in. (75 mm) in depth.

A summary of the test equipment and conditions used to conduct the direct shear tests is presented in Table 2. This table indicates the size of the shear box, the initial moisture content of the GCL specimen, the normal stress used for hydration, the time for hydration, the

RECYCLED AND RECYCLABLE

moisture content of the GCL specimen at the completion of testing, the normal stress applied to the rigid substrate in the upper shear box during testing, and the horizontal displacement rate for each test.

For each series, a fresh GCL specimen was used for each normal stress condition. Each test was conducted specifically to evaluate the internal strength of the GCL specimen. This was achieved by constraining the GCL specimen such that shearing could only occur through the middle of the bentonite component of GCL specimen. Specimen constraint was accomplished by completely bonding the geotextile component on each side of the GCL specimen to the rigid wooden substrate with the use of the 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 1. The entire test specimen was then placed in the direct shear box to provide confinement for the exposed bentonite component. It should be noted that the textured steel gripping surfaces are believed to provide a uniform transfer of load through each geotextile component and to minimize slippage between the geotextile component and the rigid wooden substrate. However, the textured steel gripping surfaces did not appear to damage the geotextile in any way during each test.

For each test in Test Series 1, the GCL specimen was hydrated in tap water for 72 hours under a normal stress of 50 psf (2 kPa) prior to being sheared. The normal stress during hydration was applied to the GCL specimen prior to submerging the test specimen in the tap water. After the 72-hour hydration period, the GCL specimen was then attached to the rigid wooden substrates and secured in the shear box. The normal stress during shearing was applied to the test specimen within approximately five minutes of the removal of the hydration normal stress, and shearing of the test specimen followed immediately. For each test in Test Series 2, the GCL specimen was tested under dry conditions (i.e., as-received moisture conditions).

Other features of the testing procedure included the following:

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

- the direction of shear for each test was in the direction of manufacture (machine direction) of the GCL sample;
- for each test, a constant shear area of 1 ft^2 (0.1 m^2) was assumed in computing normal and shear stresses for each test; and
- all of the tests were sheared until a peak shear load was recorded.

TEST RESULTS

The total-stress internal shearing resistance was evaluated for each applied normal stress. The test data were plotted on a graph of shear force versus horizontal displacement. The resulting plots are presented in Attachment 1 to this report. The peak value of shear force was used to calculate the peak shear strength.

The total-stress peak shear strengths derived from the plotted test results are summarized in Table 3. These strengths were plotted on a graph of shear stress versus normal stress and the results were used to evaluate total-stress peak strength envelopes. A best fit straight line was drawn through the four data points from each test series to obtain total-stress peak 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. The plot of shear stress versus normal stress for each test series is also presented in Attachment 1. The friction angles, adhesions, and R^2 values derived from the plotted test results are summarized in Table 4.

For each test series, it is noted that the reported adhesion is the shear stress axis intercept of the best fit straight line drawn through the test data on a plot of shear stress versus normal stress. This value may not be the "true adhesion" of the GCL specimen and caution should be exercised in using this adhesion value for applications involving normal stresses outside the range of stresses covered by the test series.

RECYCLED AND RECYCLABLE

The reported results apply only to the materials and test conditions used during the laboratory program. The results do not necessarily apply to other materials or test conditions. The test results should not be used in engineering analyses 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 CETCO.

CLOSURE

GeoSyntec appreciates the opportunity to conduct direct shear testing for CETCO. If you have any questions about this report, or if you require additional information, please do not hesitate to contact any of the undersigned.

Sincerely,

Zehong Yuan, Ph.D.
Assistant Division Manager
Soil-Geosynthetic Interaction Testing

Robert H. Swan, Jr.
Division Manager
Soil-Geosynthetic Interaction Testing

Gary R. Schmertmann, Ph.D.
Project Engineer

Attachments

GL3419/GEL93291

TABLE 1

SUMMARY OF GENERAL TESTING CONDITIONS
INTERNAL DIRECT SHEAR TESTING
COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY

Test Series Number	Test Specimen(1)	Hydration Stress (psf)	Hydration Soaking (hours)	Normal Stresses (psf)	Rate of Shear (in./min)
1	Internal Strength of Hydrated Bentomat GCL	50	72	50, 150, 300 and 500	0.04
2	Internal Strength of Dry Bentomat GCL	0	0	50, 150, 300 and 500	0.04

NOTE: (1) For Test Series 1, the GCL specimen was hydrated in tap water for 72 hours under a normal stress of 50 psf prior to shearing. For Test Series 2, the GCL specimen was tested under dry conditions.

GL3419/GEL93291

ATTACHMENT 1

DIRECT SHEAR TEST RESULTS

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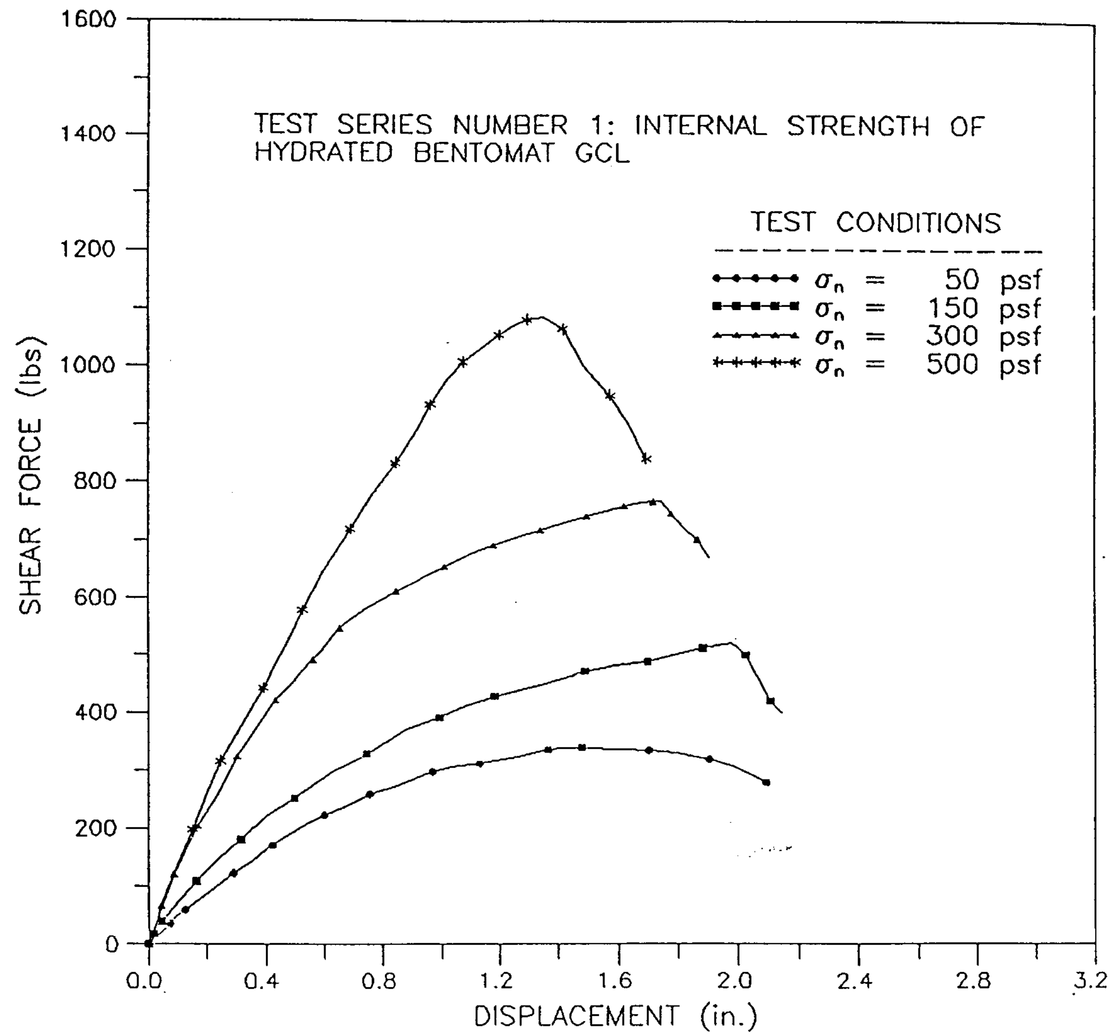
COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
DIRECT SHEAR TESTING



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: 20 AUGUST 1993

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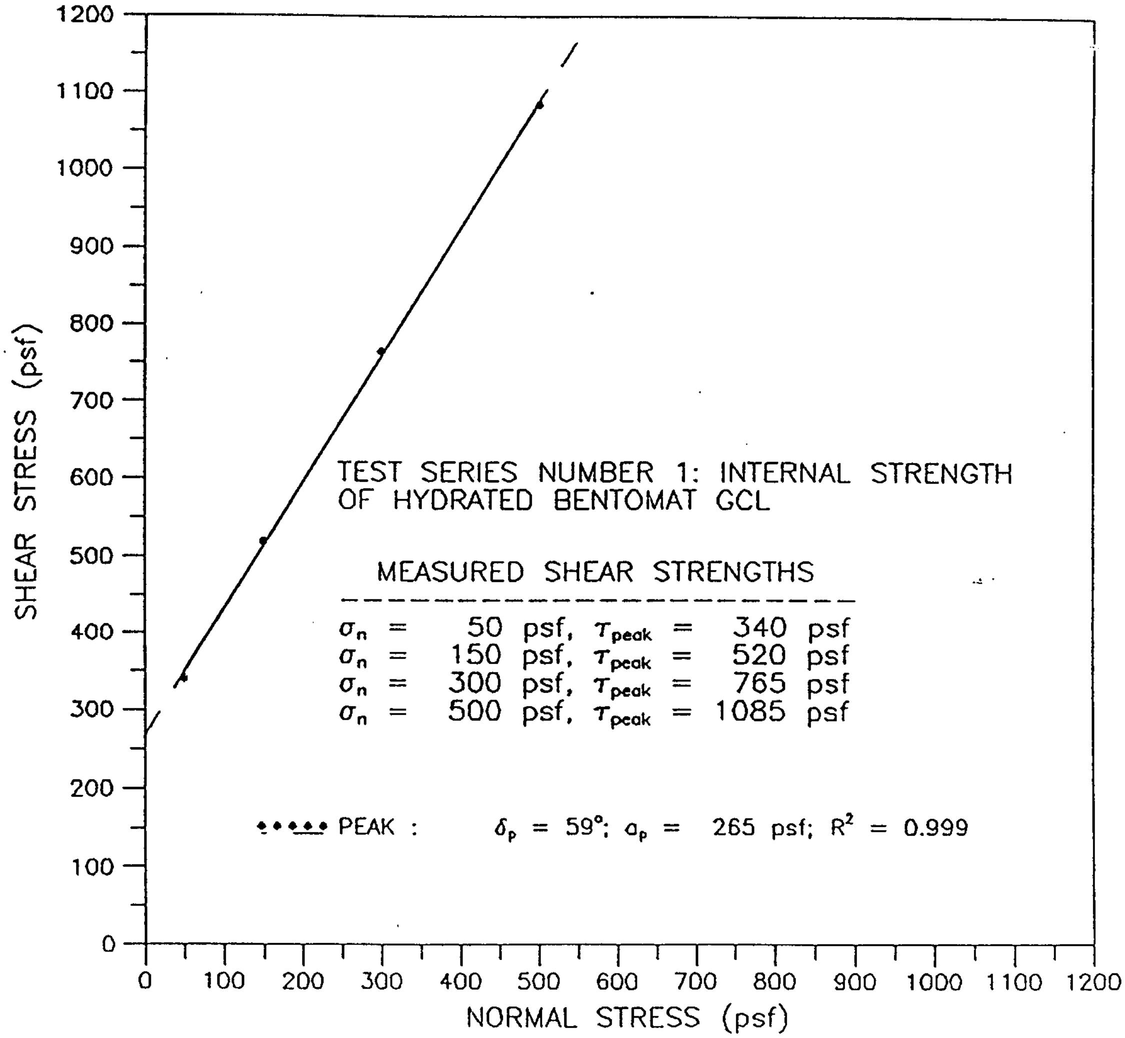
FIGURE NO.	1-1
PROJECT NO.	GL3419
DOCUMENT NO.	GEL93291
PAGE NO.	

308913

COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
DIRECT SHEAR TESTING



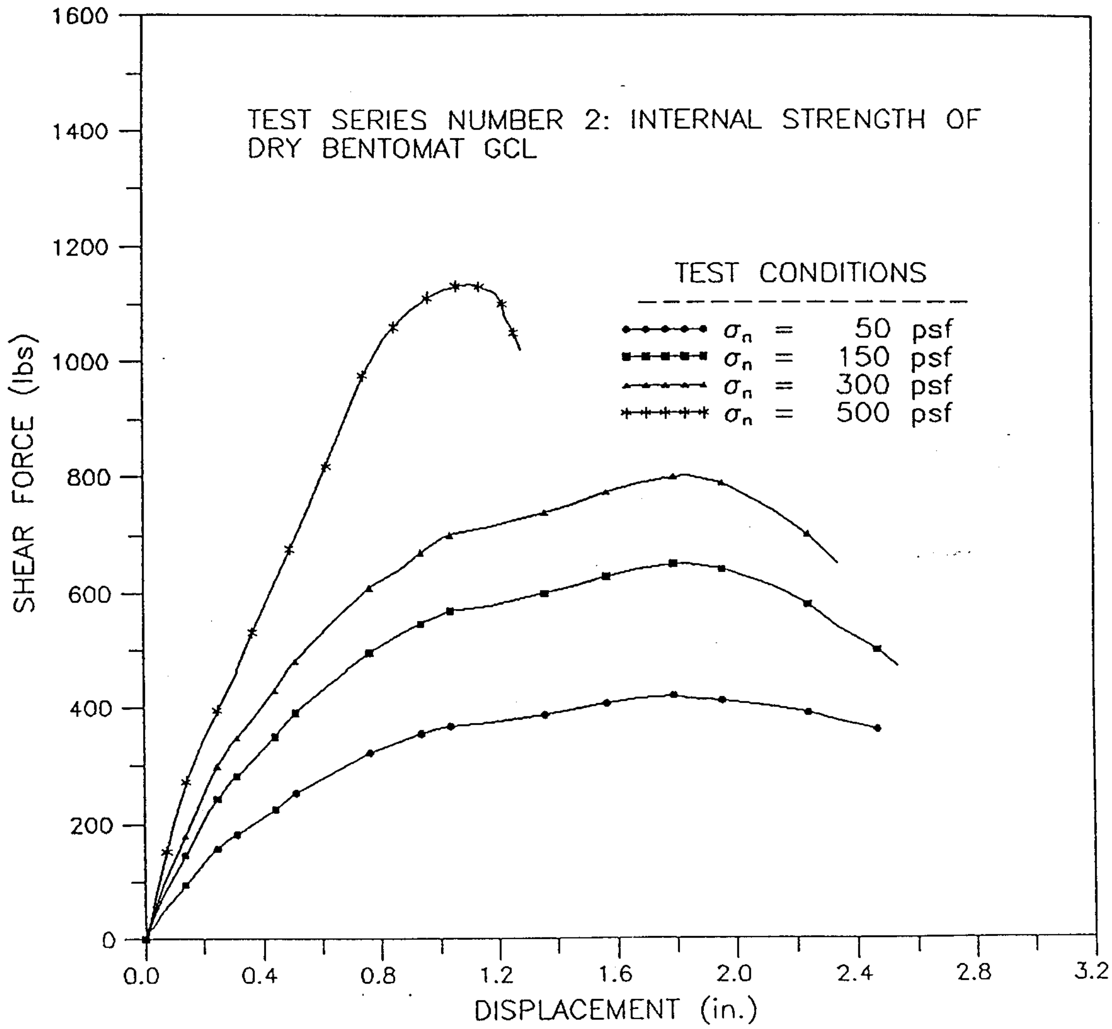
NOTE: The reported value of adhesion may not be the true adhesion of the GCL specimen, and caution should be exercised in using this adhesion value for applications involving normal stresses outside the range of stresses covered by the test.

DATE TESTED: 20 AUGUST 1993

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

FIGURE NO.	1-2
PROJECT NO.	GL3419
DOCUMENT NO.	GEL93291
PAGE NO.	

COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
DIRECT SHEAR TESTING



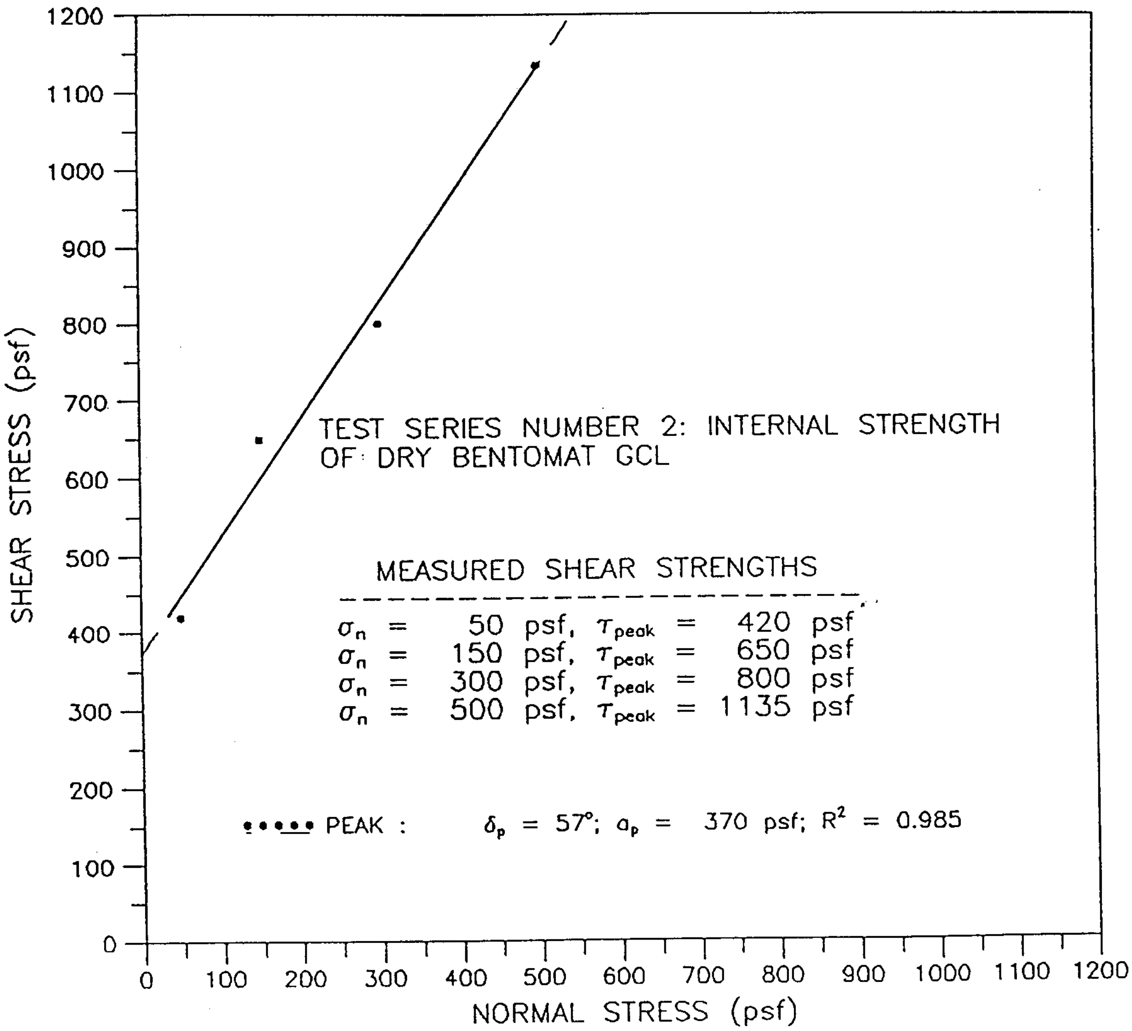
NOTE: The shear box size was 12 in. by 12 in.(300 mm by 300 mm), and the contact area remained constant throughout the entire test.

DATE TESTED: 19 AUGUST 1993

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

FIGURE NO.	1-3
PROJECT NO.	GL3419
DOCUMENT NO.	GEL93291
PAGE NO.	

COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
DIRECT SHEAR TESTING



NOTE: The reported value of adhesion may not be the true adhesion of the GCL specimen, and caution should be exercised in using this adhesion value for applications involving normal stresses outside the range of stresses covered by the test.

DATE TESTED: 19 AUGUST 1993

FIGURE NO.	1–4
PROJECT NO.	GL3419
DOCUMENT NO.	GEL93291
PAGE NO.	

GeoSyntec Consultants
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

TABLE 2

SUMMARY OF ACTUAL INTERNAL DIRECT SHEAR
TEST EQUIPMENT AND CONDITIONS
COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY

Test Series Number	Shear Box Size	TEST CONDITIONS[1]				Normal Stress (psf)	Rate of Shear (in./min)
		ω_{ci} (%)	Hydration Stress (psf)	Time of Hydration (Hours)	ω_{cf} (%)		
1	12" x 12"	17.1	50	72	169.3	50	0.04
		16.6	50	72	160.0	150	0.04
		16.8	50	72	153.2	300	0.04
		17.1	50	72	148.1	500	0.04
2	12" x 12"	16.7	N/A	N/A	16.5	50	0.04
		16.5	N/A	N/A	16.3	150	0.04
		17.1	N/A	N/A	16.8	300	0.04
		16.8	N/A	N/A	16.5	500	0.04

Note: (1) ω_{ci} refers to initial moisture content of GCL specimen.
ω_{cf} refers to final moisture content of GCL specimen.
N/A refers to data which is not applicable to the test.

TABLE 3

INTERNAL DIRECT SHEAR TEST RESULTS
MEASURED PEAK AND RESIDUAL TOTAL SHEAR STRENGTHS
COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY

Test[1] Series Number	Normal[2] Stress (psf)	Measured Peak Shear Strength (psf)	Reference Attachment Figure Number
1	50 150 300 500	340 520 765 1085	1-1 and 1-2
2	50 150 300 500	420 650 800 1135	1-3 and 1-4

Notes: (1) For Test Series 1, the GCL specimen was hydrated in tap water for 72 hours under a normal stress of 50 psf prior to shearing. For Test Series 2, the GCL specimen was tested under dry condition.

(2) Test specimens were sheared immediately after application of normal stress used for shearing.

TABLE 4

INTERNAL DIRECT SHEAR TEST RESULTS
MEASURED TOTAL STRESS SHEAR STRENGTH PARAMETERS
COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY

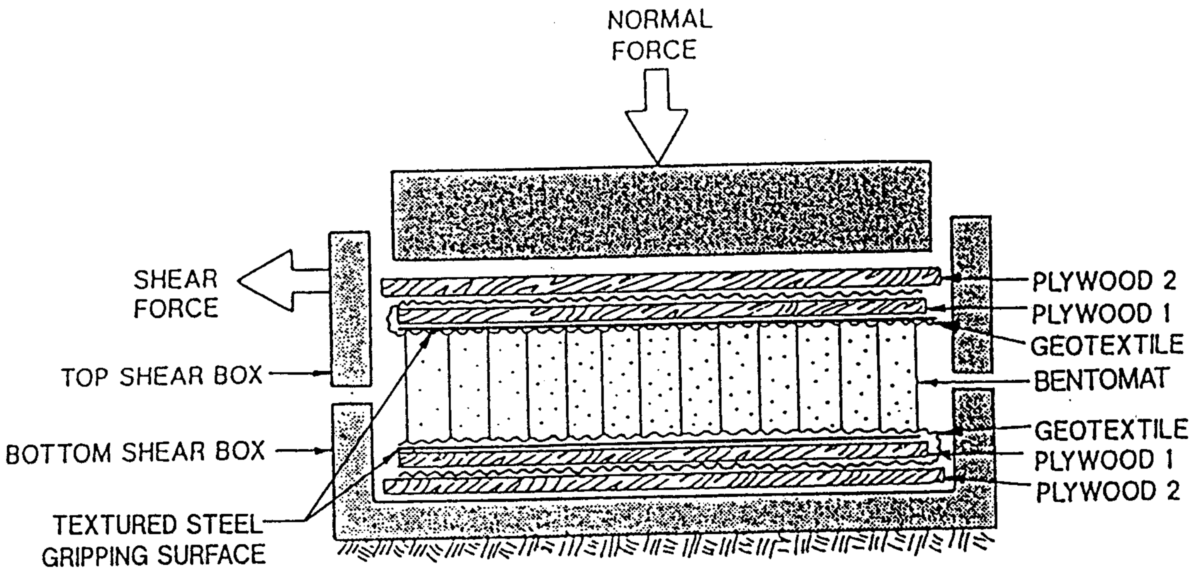
Test Series Number	Test Specimen[1]	Normal Stress (psf)[2]	Peak Strength		
			Friction Angle	Adhesion[3] (psf)	R^2
1	Internal Strength of Hydrated Bentomat GCL	50 to 500	59°	265	0.999
2	Internal Strength of dry Bentomat GCL	50 to 500	57°	370	0.985

Notes:
(1) For Test Series 1, the GCL specimen was hydrated in tap water for 72 hours under a normal stress of 50 psf prior to shearing. For Test Series 2, the GCL specimen was tested under dry conditions.

(2) Test specimens were sheared immediately after application of normal stress used for shearing.

(3) The reported value of adhesion may not be the "true adhesion" of the GCL specimen and caution should be exercised in using this adhesion value for applications involving normal stresses outside the range of stresses covered by the test series.

BENTOMAT TEST SPECIMEN CONFIGURATION



GEOSYNTEC CONSULTANTS GEOMECHANICS AND ENVIRONMENTAL LABORATORY	FIGURE NO. 1
	PROJECT NO. GL3419
	DOCUMENT NO. GEL93291
	PAGE NO.

GEOSYNTEC CONSULTANTS

Geomechanics and Environmental Laboratory
5775 Peachtree Dunwoody Road • Suite 10D
Atlanta, Georgia 30342 • USA
Tel. (404) 705-9500 • Fax (404) 705-9300

2 February 1994

Mr. Bob Trauger, P.E.
Technical Services Manager
Colloid Environmental Technologies Company
1500 West Shure Drive
Arlington Heights, Illinois 60004-7803

Carmo Environmental Systems Inc.
1866 Maurice Avenue
East Meadow, NY 11554
(516) 794-7904

Subject: Final Report
Direct Shear Testing
Internal Strength of Bentomat GCL
Under High Normal Stresses

Dear Mr. Trauger:

GeoSyntec Consultants (GeoSyntec) is pleased to present the results of the direct shear testing program recently performed for Colloid Environmental Technologies Company (CETCO) on their Bentomat geosynthetic clay liner (GCL). The direct shear testing was conducted in GeoSyntec's Geomechanics and Environmental Laboratory located in Atlanta, Georgia. This letter report was prepared by Mr. Robert H. Swan, Jr. and Dr. Zehong Yuan, both of GeoSyntec. The report was reviewed by Dr. Gary R. Schmertmann, P.E. (Georgia), also of GeoSyntec, in accordance with the internal peer review policy of the firm.

The testing program was conducted in accordance with the test procedures defined in the 18 December 1993 facsimile transmittal prepared by Mr. Bob Trauger, P.E. of CETCO and the 22 December 1993 telephone conversation between Mr. Trauger and Mr. Swan. GeoSyntec understands that the purpose of the testing program was to evaluate the internal shearing resistance of CETCO's Bentomat GCL when hydrated under high normal stress conditions, using the direct shear method. The GCL consisted of a woven geotextile on one side of a bentonite component and a nonwoven geotextile on other side of the bentonite component. GeoSyntec also understands that the sample preparation procedures and testing conditions used in the testing program were selected by CETCO to simulate anticipated field conditions.

The remaining sections of this letter report present: (i) a description of the configuration of the test specimens used in the direct shear tests; (ii) the testing procedures used in the direct shear tests; and (iii) the test results.

GL3529/GEL94024

CONFIGURATION OF THE TEST SPECIMENS

A direct shear test series was conducted to evaluate the internal shear strength of the Bentomat GCL when hydrated under high normal stress conditions. The test series consisted of three direct shear tests with each test conducted at a different level of normal stress ranging from 2,000 to 20,500 psf (97 to 997 kPa) using a freshly prepared test specimen. Table 1 summarizes the general testing conditions that were used for the direct shear test series. The configuration of each test specimen used in the test series, from top to bottom, was as follows:

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

Bulk samples of the Bentomat GCL were provided to GeoSyntec by CETCO. The rigid substrates with textured steel gripping surfaces were provided by GeoSyntec.

TESTING PROCEDURES

The direct shear tests were performed in general accordance with the American Society for Testing and Materials (ASTM) Standard Test Method D 5321, "*Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method*." 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 measures 12 in. by 14 in. (300 mm by 350 mm) in plan and 3 in. (75 mm) in depth.

A summary of the test equipment and conditions used to conduct the direct shear tests is presented in Table 2. This table indicates the size of the shear box, the initial moisture content of the GCL specimen, the normal stress used for hydration, the time for hydration, the moisture content of the GCL specimen at the completion of testing, the normal stress applied to the rigid substrate in the upper shear box during testing, and the horizontal displacement rate for each test.

For the test series, a fresh GCL specimen was trimmed from the bulk sample of GCL provided by CETCO for each normal stress condition. Each test was conducted specifically to evaluate the internal strength of the GCL specimen. This was achieved by constraining the GCL specimen such that shearing could only occur through the bentonite component of GCL specimen. Specimen constraint was accomplished by completely bonding the geotextile component on each side of the GCL specimen to the rigid wooden substrate with the use of the 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 1. The entire test specimen was then placed in the direct shear box to provide confinement for the exposed bentonite component.

It is believed that the textured steel gripping surfaces provide a more uniform application of shear load to the entire GCL specimen than other known specimen gripping methods. Other methods may allow significant slippage to occur between the geotextile components and the substrates in local areas. Inspection of the GCL specimens after testing indicates that the textured steel gripping surfaces do not damage or distort the structure of the geotextile components. The inspection also indicates that the textured steel gripping surfaces do not appear to interfere significantly with the interaction of the geotextile components and the geotextile fibers which are needle-punched from the nonwoven geotextile component to the woven geotextile component.

For each test in the test series, the entire GCL specimen (including the rigid substrates) was hydrated in tap water for 48 hours under each applied normal stress prior to being sheared. The normal stress during hydration was applied to the GCL specimen prior to submerging the test specimen in the tap water. Immediately following the 48-hour hydration period, each test specimen was sheared.

Other features of the testing procedure included the following:

- each specimen was sheared at a constant displacement rate immediately after application of the normal stress used for shearing;
- the direction of shear for each test was in the direction of manufacture (machine direction) of the GCL sample;
- a constant shear area of 1 ft^2 (0.1 m^2) was assumed in computing normal and shear stresses for each test; and
- all of the tests were sheared until a constant, residual shear load was recorded.

TEST RESULTS

The total-stress internal shearing resistance was evaluated for each applied normal stress. The test data were plotted on a graph of shear force versus horizontal displacement. The resulting plots are presented in Attachment 1 to this report. The peak value of shear force was used to calculate the peak shear strength. For this report, the residual shear strength was assumed to be equal to the stabilized, post-peak shear force measured at the end of each test.

The total-stress peak and residual shear strengths derived from the plotted test results are summarized in Table 3. These strengths were plotted on a graph of shear stress versus normal stress and the results were used to evaluate total-stress peak and residual strength envelopes. A best-fit straight line was drawn through the three data points from the test series to obtain total-stress peak and residual 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. The plot of shear stress versus normal stress for the test series is also presented in Attachment 1. The friction angles, adhesions, and R^2 values derived from the plotted test results are summarized in Table 4.

For the test series, it is noted that the reported adhesion is the shear stress axis intercept of the best fit straight line drawn through the test data on a plot of shear stress versus normal stress. This value may not be the "true adhesion" of the GCL specimen and caution should be exercised in using this adhesion value for applications involving normal stresses outside the range of stresses covered by the test series.

The reported results apply only to the materials and test conditions used during the laboratory program. The results do not necessarily apply to other materials or test conditions. The test results should not be used in engineering analyses 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 CETCO.

CLOSURE

GeoSyntec appreciates the opportunity to conduct direct shear testing for CETCO. If you have any questions about this report, or if you require additional information, please do not hesitate to contact any of the undersigned.

Sincerely,

Zehong Yuan, Ph.D.
Assistant Division Manager
Soil-Geosynthetic Interaction Testing

Robert H. Swan, Jr.
Division Manager
Soil-Geosynthetic Interaction Testing

Gary R. Schmertmann, Ph.D., P.E. (Georgia)
Project Engineer

Attachments

GL3529/GEL94024

ATTACHMENT 1

DIRECT SHEAR TEST RESULTS

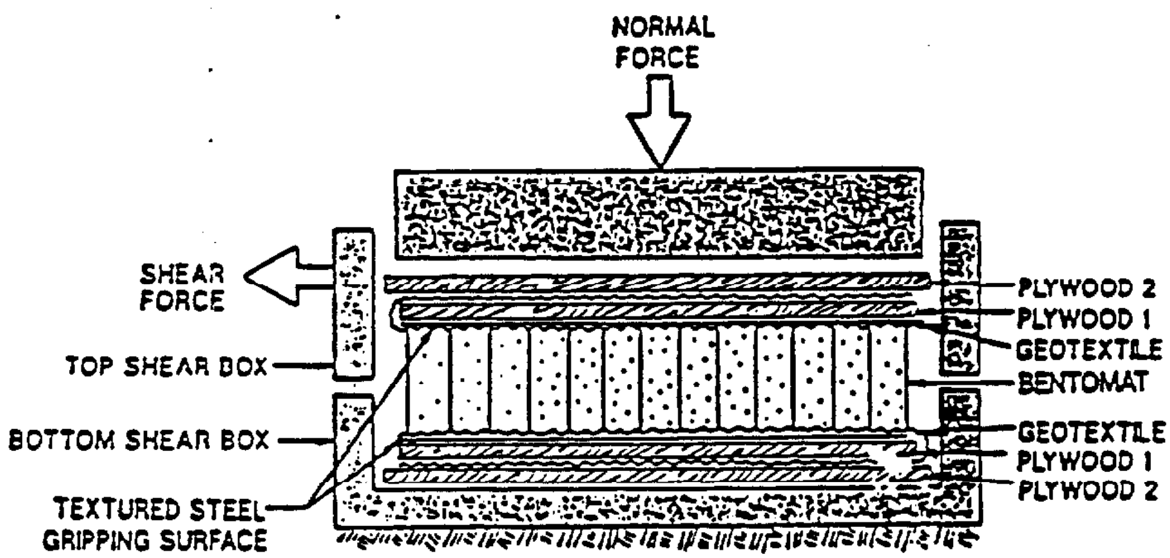
TABLE 1

SUMMARY OF GENERAL TESTING CONDITIONS
DIRECT SHEAR TESTING
COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY

Test Series Number	Test Specimen[1]	Hydration Stress (psf)	Hydration Soaking (hours)	Normal Stresses (psf)	Rate of Shear (in./min)
1	Internal Strength of Hydrated Bentomat GCL	2,000, 10,000 and 20,500	48	2,000, 10,000 and 20,500	0.04

NOTE: (1) For the test series, the GCL specimen was hydrated in tap water for 48 hours under each applied normal stress prior to shearing.

BENTOMAT TEST SPECIMEN CONFIGURATION



GeoSyntec Consultants
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

FIGURE NO.	1
PROJECT NO.	GL3529
DOCUMENT NO.	GEL94024

TABLE 2

SUMMARY OF DIRECT SHEAR
TEST EQUIPMENT AND CONDITIONS
COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY

Test Series Number	Shear Box Size	TEST CONDITIONS[1]				Normal Stress (psf)	Rate of Shear (in./min)
		ω_{i} (%)	Hydration Stress (psf)	Time of Hydration (Hours)	ω_{f} (%)		
1	12" x 12"	48.2	2,000	48	124.8	2,000	0.04
		48.2	10,000	48	111.3	10,000	0.04
		48.2	20,500	48	103.5	20,500	0.04

Note: (1) ω_{i} refers to initial moisture content of GCL specimen.
ω_{f} refers to final moisture content of GCL specimen.

GL3529/GEL94024

TABLE 3

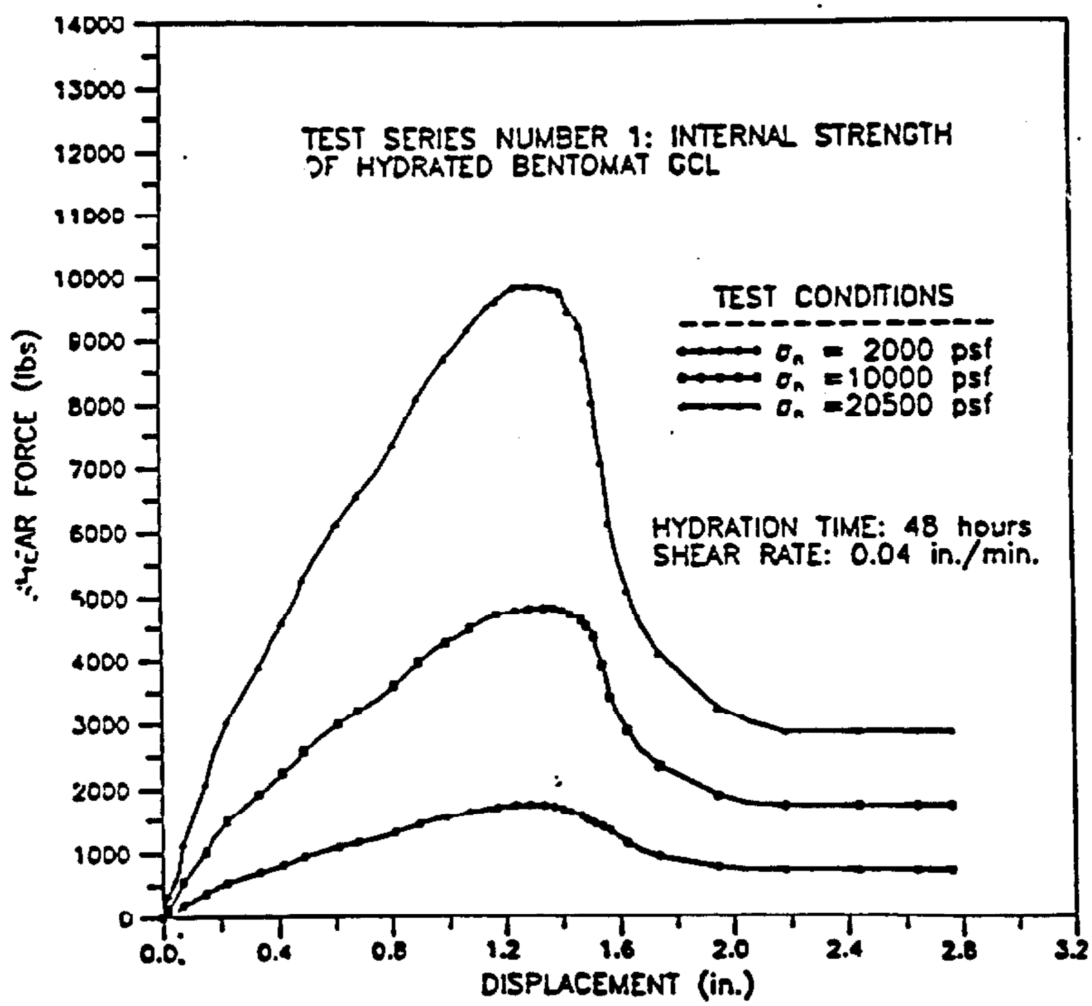
DIRECT SHEAR TEST RESULTS
MEASURED PEAK AND RESIDUAL TOTAL SHEAR STRENGTHS
COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY

Test(1) Series Number	Normal(2) Stress (psf)	Measured Peak Shear Strength (psf)	Measured Residual Shear Strength (psf)	Reference Attachment Figure Number
1	2,000 10,000 20,500	1,740 4,820 9,845	705 1,720 2,840	1-1 and 1-2

Notes: (1) For the test series, the GCL specimen was hydrated in tap water for 48 hours under an each applied normal stress prior to shearing.

(2) Test specimens were sheared immediately after application of normal stress used for shearing.

COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
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: 10 TO 17 JANUARY 1994

GeoSyntec Consultants
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

FIGURE NO.	1-1
PROJECT NO.	GL3529
DOCUMENT NO.	GEL94024
PAGE NO.	

TABLE 4

DIRECT SHEAR TEST RESULTS
MEASURED TOTAL STRESS SHEAR STRENGTH PARAMETERS
COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY

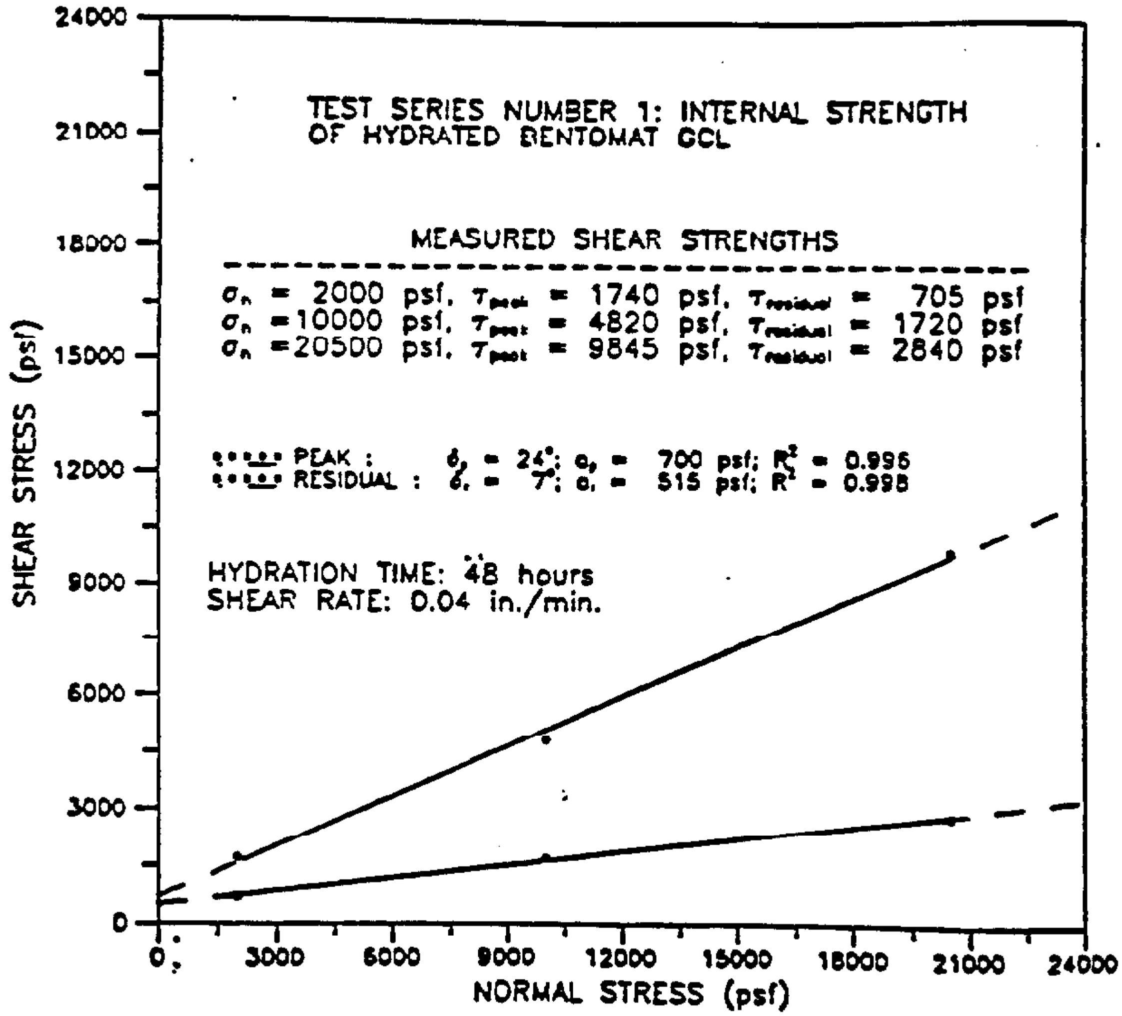
Test Series Number	Test Specimen[1]	Normal[2] Stress (psf)	Peak Strength[3]			Residual Strength[3]		
			Friction Angle	Adhesion (psf)	R^2	Friction Angle	Adhesion (psf)	R^2
1	Internal Strength of Hydrated Bentomat GCL	2,000 to 20,500	24°	700	0.998	7°	515	0.998

Notes: (1) For the test series, the GCL specimen was hydrated in tap water for 48 hours under each applied normal stress prior to shearing.

(2) Test specimens were sheared immediately after application of normal stress used for shearing.

(3) The reported value of adhesion may not be the "true adhesion" of the GCL specimen and caution should be exercised in using this adhesion value 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.

COLLOID ENVIRONMENTAL TECHNOLOGIES COMPANY
DIRECT SHEAR TESTING



NOTE: The reported value of adhesion may not be the true adhesion of the GCL specimen, and caution should be exercised in using this adhesion value for applications involving normal stresses outside the range of stresses covered by the test series.

DATE TESTED: 10 TO 17 JANUARY 1994

GEOSYNTEC CONSULTANTS
GEOMECHANICS AND ENVIRONMENTAL LABORATORY

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