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**Department of Energy**

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

OCT 20 1997

DOE-0056-98

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

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

Dear Mr. Saric and Mr. Schneider:

REQUEST FOR CLARIFICATION/INFORMATION - ON-SITE DISPOSAL FACILITY GEOCOMPOSITE LINER MATERIALS

Enclosed for your information is the GeoSyntec Request for Clarification/Information (RCI) pertaining to the geocomposite liner (GCL) of Cell 1 of the On-Site Disposal Facility. Also enclosed is the result of the independent review performed by Mr. Dave Daniels of the University of Illinois.

The Department of Energy, Fernald Environmental Management Project (DOE-FEMP) and Fluor Daniel Fernald, as well as the independent expert, believe the GeoSyntec RCI presents a technically sound and defensible approach to assessing the suitability of GCL materials. On October 10, 1997, DOE-FEMP concurred with initiating liner installation consistent with the terms of the RCI.

If you have any questions, please contact Jay Jalovec at (513) 648-3122.

Sincerely,

Johnny Reising

FEMP:Jalovec

Johnny W. Reising
Fernald Remedial Action
Project Manager

Enclosures: As Stated

cc w/enc:

N. Hallein, EM-42/CLOV
J. Reising, DOE-FEMP
R. Warner, DOE-FEMP
G. Jablonowski, USEPA-V, 5HRE-8J
T. Schneider, OEPA-Dayton (3 copies total of enc.)
R. Beaumier, Manager TPSS/DERR, OEPA-Columbus
M. Rochotte, OEPA-Columbus
F. Bell, ATSDR
R. Geiger, PRC
F. Barker, Tetra Tech
R. Vandegrift, ODH
D. Ward, HSI GeoTrans
D. Carr, FDF/52-2
T. Hagen, FDF/65-2
M. Hickey, FDF/64
U. Kumthekar, FDF/64
T. Walsh, FDF/65-2
AR Coordinator/78

GEOSYNTEC CONSULTANTS

1100 Lake Hearn Drive • Suite 200
Atlanta, Georgia 30342-1523 • USA
Tel. (404) 705-9500 • Fax (404) 705-9400

7 October 1997

Mr. Mike Hickey
Project Coach
Fluor Daniel Fernald
P.O. Box 538704
Cincinnati, OH 45253-8704

Subject: Discussion of GCL Shear Strength Issue
and Transmittal of Proposed GCL RCI
OSDF Phase 1 Construction

Dear Mr. Hickey:

**PURPOSE**

The purpose of this letter is to discuss an issue that has arisen related to the quality assurance (QA) and quality control (QC) shear strength testing of the geosynthetic clay liner (GCL) specified for use in OSDF Phase I construction. The letter also transmits a proposed Request for Clarification of Information (RCI) regarding the shear strength requirements given in technical specification Section 02772, of the OSDF Phase I contract documents. GeoSyntec understands that Fluor Daniel Fernald (FDF) intends to discuss the GCL issue with the U.S. Department of Energy (DOE) and to accept the proposed RCI, as appropriate.

GeoSyntec requests that FDF's and DOE's review of this submittal be conducted as quickly as possible. This request is based on the current status of construction. Placement of geosynthetic materials in the liner system, starting with the secondary GCL, is expected to begin shortly. Currently, GCL material has been delivered to the site by Petro and QC and QA shear testing of the material is being performed by Petro and GeoSyntec, respectively. There is an immediate need to clarify the outstanding issue so that GeoSyntec can examine the shear testing results and evaluate whether the GCL material complies with the shear strength specification.

**ORGANIZATION OF LETTER**

This letter provides background information on the GCL shear strength requirements and

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OSDF design process relevant to understanding the GCL shear strength issue. The letter also presents relevant test data and evaluation results. The remainder of this letter is organized into the sections listed below.

- project participants;
- OSDF design and approval process;
- direct shear testing of GCLs;
- GCL material specification;
- purpose of proposed RCI;
- GCL supplied for construction; and
- references.

The proposed RCI is presented in Attachment A to this letter.

## PROJECT PARTICIPANTS

Several project participants will be referred to throughout this letter. The following table is provided to identify the project participants and their roles:

TABLE 1

| ORGANIZATION | ACRONYM | PROJECT ROLE |
|---|---|---|
| U.S. Department of Energy | DOE | Owner |
| U.S. Environmental Protection Agency | USEPA | Federal Review Agency |
| Ohio Environmental Protection Agency | OEPA | State Review Agency |
| Fluor Daniel Fernald | FDF | Prime Contractor |
| Petro Environmental Technologies | Petro | Prime Construction Subcontractor |
| GeoSyntec Consultants | GeoSyntec | Design Engineer-of-Record, CQ Consultant |

## OSDF DESIGN AND APPROVAL PROCESS

This section of the letter provides background information relevant to the design of the OSDF.

*Overview*

GCL shear strength is an important design input because it affects the stability of OSDF slopes. The following paragraphs provide information on how GCL shear strength was considered during the process of design and design review for the facility. The concept of a slope stability factor of safety is introduced because it is an essential part of the design requirements.

*Slope Stability*

An important part of the engineering design of the OSDF was verification that liner system, impacted material, and final cover system slopes in the OSDF are stable and safe. In the design process, the degree of stability and safety of a slope is evaluated by calculating the slope stability factor of safety (FS). If the slope stability FS is larger than 1.0, the slope is predicted to be stable. If the slope stability FS is less than 1.0, the slope is predicted to be unstable. Technically, the slope stability FS is defined as the ratio of the shear strength of the slope material to the shear stresses acting in the slope. In other words, if the shear strength of the material comprising the slope is higher than the shear stresses caused by gravity and other forces acting on the slope, the slope stability FS is larger than 1.0 and the slope is stable.

During OSDF design, slope stability FS values were computed for the critical interim and final impacted material slope. The critical slope configurations take account of both the slope face and the foundation beneath the slope. As the liner system forms part of that foundation, the strength of the materials, and the interfaces between materials within the liner system, were needed for the slope stability analyses. With respect to slope stability, it is the strength of the weakest material that governs. It was determined that the weakest materials in the slope foundation were the GCL and the interfaces between the GCL and adjacent materials (termed 'GCL interfaces').

As a result of the geometry of both interim and final impacted material slopes, the GCL material in the liner system will be underneath a thickness of impacted material and cover soil that varies from a few feet to more than 50 feet. This geometry is illustrated in Figure 1. This range of thickness causes the pressures (normal stresses) acting on the GCL to also vary, as the normal stress is equal to the thickness of overlying material multiplied by the material unit weight. The slope stability analyses performed for the OSDF took into account the fact that the GCL material shear strength varies depending on the normal stress applied to the liner system.

*Design Review and Approval*

The approach to slope stability described above was incorporated into the design and design approval process for the OSDF. This process consisted of the following basic steps: (i) establish design criteria; (ii) review and approval of design calculations; and (iii) review and approval of technical specifications. These steps are described further below.

- Design Criteria. The *Design Criteria Package* (DCP) was developed to provide design requirements for the OSDF. The DCP provides minimum required slope stability factors of safety (FS) based on several reference documents including the UMTRA Technical Approach Document (DOE, 1989). FS requirements for end-of-construction impacted material stability and long-term impacted material stability are given in the DCP. These FS requirements are based on the use of peak GCL shear strength values in the slope stability analyses. The DCP also indicated that the long-term stability of the impacted material should be checked using large-displacement GCL shear strength values. A required minimum FS value for this latter case was established in the design calculations based on a technical paper by Bonaparte et al. (1996). It is noted that the peak shear strength evaluation is applicable to the overall stability (both interim and final) of the OSDF. In contrast, the large-displacement check evaluation is intended primarily to preclude the development of localized overstressing of any part of the facility. The resulting FS requirements, as given in the DCP and design calculations, are:
    - end-of-construction stability (peak GCL strength) FS= 1.3

- long-term stability (peak GCL strength) FS= 1.5
- long-term stability (large-displacement GCL strength) FS= 1.25

The entire DCP was reviewed and either accepted or approved by DOE, USEPA, OEPA and FDF.

- Design Calculations. Design calculations, including slope stability analyses, were prepared by GeoSyntec. The slope stability analyses for the impacted material slopes included GCL shear strengths (Section 3.3 of the design calculations). In these analyses, the weight of impacted material and cover soils overlying the GCL was modeled as a range of normal stresses on the GCL. The design calculation package, including GCL shear strengths, was reviewed and either accepted or approved by DOE, USEPA, OEPA and FDF.

- Technical Specifications. Technical specifications for the OSDF, including the technical specification for the shear strength of the GCL material, were prepared by GeoSyntec. The GCL shear strength specification is discussed in detail in a subsequent section of this letter. The technical specifications were reviewed and either accepted or approved by DOE, USEPA, OEPA and FDF.

## DIRECT SHEAR TESTING OF GCLs

The shear strengths of GCLs and GCL interfaces are measured in the laboratory using a test method referred to as 'direct shear.' The direct shear test method has been in use for decades for the testing of soils. Its more recent use for the testing geosynthetic materials and interfaces has been standardized within the past several years by the American Society for Testing and Materials (ASTM) as test standard D 5321. This ASTM standard does not, however, specify many of the test parameters (e.g., hydration time, normal stress) needed to perform GCL direct shear tests for a particular project. Values of these test parameters must be selected by the design engineer based on site-specific considerations.

The direct shear test is appropriate for evaluating the shear strength of GCLs and GCL interfaces for landfill design because shearing force can be applied directly through the middle of the GCL or directly at the interface. In addition, the test can simulate different thicknesses of overlying impacted material and cover soils because the test device can apply a range of normal stresses to the GCL.

As part of the OSDF design process, a preconstruction direct shear testing program was conducted. The purpose of the preconstruction testing program was to evaluate the internal and interface shear strength of the potentially weakest components of the liner and final cover systems for the OSDF. Although information on the shear strength of liner system components and interfaces is available in published technical papers and articles, the preconstruction testing program was tailored specifically to conditions at the OSDF. In addition, geosynthetic manufacturers occasionally change or modify their products, so it was important to test products of the type currently in production. The preconstruction direct shear testing program was specifically developed to provide the GCL shear strength information needed to prepare the OSDF design and the GCL technical specifications produced as part of that design.

The geosynthetic materials used for the preconstruction testing program were selected to be representative of the commercial products that would be available for OSDF construction. The testing included four GCL products, namely Bentomat, Bentofix, Claymax Shear Pro, and Gundseal. These GCL products represent the commercial products from each of the four GCL suppliers in the United States at the time of the testing program. The testing program also included two textured geomembrane products representing the two major manufacturing techniques for creating a textured geomembrane surface. The specific normal shear levels used in the testing program were 5, 20, and 45 psi; this is the same range of normal stresses acting on the critical potential slip surfaces as determined from the design slope stability analyses. The testing procedures included soaking the samples for seven days under a light pressure (3 psi) prior to consolidation and shearing. This soaking procedure allowed the samples to absorb water and resulted in the samples being at the wettest, i.e. weakest, state that was reasonably conceivable for the liner system.

Each direct shear test resulted in a measurement of both a peak and a large-displacement shear strength. The peak strength is the maximum value measured during the test. The large-displacement strength is the value measured near the end of the test after about two inches of displacement has occurred. As previously noted, peak shear strengths are primarily applicable to the evaluation of overall OSDF stability, while large-displacement shear strength are used primarily to check that localized overstressing of the liner system will not occur. The most recent design guidance on GCLs (e.g., USEPA 600/R-96/149

"Report of 1995 Workshop on Geosynthetic Clay Liners") highlights the importance of considering both peak and large-displacement GCL shear strengths in design. This approach was used for the OSDF design.

The results of the preconstruction testing program are summarized in Figures 2 and 3. Peak strengths are presented in Figure 2 and large-displacement strengths are presented in Figure 3. These figures were generated by plotting measured shear strength on the vertical axis against test pressure (normal stress) on the horizontal axis. These figures include results for all GCL internal and interface shear tests from the preconstruction testing program and there figures also present show the shear strength envelopes that were developed for the GCL material specifications using the results of the testing program.

## GCL QC MATERIAL SPECIFICATION

The GCL material specification provides shear strength requirements and corresponding direct shear QC testing conditions (Section 02772, paragraph 2.01.E). The specification states that both the internal shear strength of the GCL material and the interface shear strength between GCL and geomembrane must meet the same minimum requirements. Separate strength requirements are given for peak and large-displacement conditions. The shear strength requirements are presented in the form of minimum secant friction angles at three normal stress levels, as given below (Table 2). Defining a minimum secant friction angle is mathematically equivalent to defining a minimum shear strength at a given normal stress.

TABLE 2

| Normal Stress (psi) | Peak secant friction angle (deg) | Large-displacement secant friction angle (deg) |
|---|---|---|
| 5 | 17 | 12 |
| 20 | 17 | 7 |
| 45 | 17 | 6.5 |

The GCL shear strength values given above define peak and large-displacement shear strengths for three distinct normal stresses that cover the range of normal stresses that will act on the GCL in the OSDF liner system. Such relationships between shear strength and normal stress, termed shear strength envelopes, are commonly used in evaluating GCL strengths behavior because it is the shearing resistance of the GCL over the entire potential slip surface that most affects OSDF slope stability.

The selection of the direct shear test conditions and shear strength envelopes for the material specification utilized the results of the preconstruction direct shear testing program. The specified test conditions are, in fact, the same as those used in the preconstruction testing program. The specified shear strength envelopes in the specification were selected to be achievable by most of the tested GCL products, as demonstrated in Figures 2 and 3. A review of these figures indicates that the measured GCL shear strengths fell above the shear strength envelopes for the large majority of preconstruction test results. In six of the seven cases shown in Figures 2 and 3 where the measured value fell below the shear strength envelopes, the tests involved the GCL Claymax Shear Pro. The seventh case involved the GCL Bentomat. Based on the results of the preconstruction testing program and other information in the technical literature, it was concluded that all of the tested GCL products, except perhaps the Claymax Shear Pro product, could meet the shear strength envelope requirements in the specification.

When the specified shear strength envelopes are incorporated in slope stability analyses they produce factors of safety that significantly exceed the minimum design FS values given in the DCP. Specifically, slope stability analyses performed using the shear strength envelopes defined by the specification yield the slope stability FS values given in Table 3 below.

TABLE 3

| Design Case | Relevant OSDF Geometry | Relevant GCL Shear Strength | FS Obtained with Strength Envelope in GCL Specification | Minimum Required Value of FS |
|---|---|---|---|---|
| End-of-construction | Interim | Peak | 1.9 | 1.3 |
| Long-term | Final | Peak | 3.0 | 1.5 |
| Long-term with large-displacement in GCL | Final | Large-displacement | 1.6 | 1.25 |

A review of the above table indicates that the shear strength envelopes from the specification provide substantially higher slope stability FS values than the FS values required by the DCP. Given the degree to which the calculated FS values exceed the DCP values, GeoSyntec recognized that the specified GCL shear strength envelopes derived from the preconstruction laboratory testing program could generally be relaxed without violating the DCP or compromising OSDF slope stability. However, because the results of the preconstruction testing program (and available technical literature) indicated that the specified shear strengths could be achieved by most of the tested GCL products, the specified values were not changed. This approach was intended to provide added value to the DOE in that greater than required stability would be achieved with standard GCL products, at no additional cost to the government. This approach also assured that any new or modified GCL product that became available in the future would perform in substantially the same way as currently available GCL products.

## PURPOSE OF PROPOSED RCI

Clarification has been requested as to the intent of the specification in presenting the required shear strengths as secant friction angles at three pressure (normal stress) levels. Specifically, the question has been raised as to whether GCL QC and QA test results should be evaluated on a test-by-test basis or shear strength envelope basis. At issue is whether a GCL that has a satisfactory overall shear strength envelope, but an individual QA or QC test result falling below the envelope, satisfies the material specification.

Consistent with the slope stability analyses for design, and the results of the preconstruction interface direct shear testing program, the intent is to define an acceptable shear strength envelope for a range of normal stresses, not to define a test-by-test pass fail criterion. This approach implies that if a GCL material has an individual test result below the shear strength envelope, it may still comply with the material specification if the individual test results at the other normal stresses are sufficiently above the envelope to achieve the relevant slope stability FS requirements. This interpretation is consistent with the findings of the preconstruction laboratory testing program where the GCLs were seen to exhibit some natural variability and at least a few of the test results fell below the GCL shear strength envelopes provided in the specification. The important point in considering if a given set of QC or QA test results satisfies or meets the shear strength envelopes is whether the results provide slope stability FS values equal to or greater than those associated with the specified shear strength envelopes.

The purpose of the proposed RCI is to clarify the shear strength requirements in the GCL specification (i.e., that the pass/fail evaluation is based on shear strength envelopes). The proposed RCI also provides a step-by-step procedure to evaluate whether the shear strengths measured for a GCL sample comply with the shear strength requirements defined in the specification. The step-by-step procedure involves using the measured strengths to establish a strength envelope and then repeating the critical slope stability analyses performed for the design to check the slope stability FS provided by the measured envelope. If the computed FS is equal to or greater then the values obtained using the strength envelope defined in the specification, then the GCL sample complies with the specification requirements. Full details of the step-by-step procedure are given in the RCI.

## GCL SUPPLIED FOR CONSTRUCTION

Petro has delivered Bentofix NS GCL to the site for construction. The supplier of the Bentofix product is National Seal Corporation (NSC). Bentofix NS was one of the GCL products included in the preconstruction interface direct shear testing program. As discussed above, and indicated in Figures 2 and 3, the results of the preconstruction testing program indicate that the Bentofix product can generally meet the shear strength requirements given in the specification. Also, as previously discussed available information published by the GCL manufacturer/supplier indicates that the specified shear strengths are generally achievable.

As CQC Engineer, GeoSyntec is conducting direct shear testing on conformance samples of the Bentofix GCL product that has been delivered to the site. The conformance shear testing has been conducted to measure both the internal GCL shear strength and the shear strength of the interface between the GCL and the textured geomembrane that has been delivered to the site. As of the date of this memorandum, eight GCL samples have been tested for conformance. Testing to date includes eight sets of internal shear tests and five sets of interface shear tests (total of 13 sets of tests). Each set of tests includes three individual direct shear test at the three specified normal stresses. The QA test results are summarized in Figures 4 and 5. Peak strengths are presented in Figure 4 and large-displacement strengths are presented in Figure 5. These figures were generated by plotting measured shear strength on the vertical axis against test pressure (normal stress) on the horizontal axis. The figures also include the strength envelopes from the GCL material specifications, as well as available results from four QC tests conducted to date by Petro.

With respect to the QA conformance tests conducted by GeoSyntec, the results shown on Figures 4 and 5 are summarized as follows:

- for the tests at normal stresses of 5 psi and 20 psi, virtually all the tests resulted in strengths above the envelope from the GCL specification; and
- for the tests at a normal stress of 45 psi, 6 of the 13 tests resulted in peak strengths at or above the envelope from the GCL specification, and 10 of the 13 tests resulted in large-displacement strengths above the envelope from the GCL specification.

With respect to the QC tests conducted by Petro, the results shown on Figures 4 and 5 are summarized as follows:

- for the test at a normal stress of 5 psi, the peak and large-displacement strengths are above the envelope from the GCL specification; and
- for the tests at a normal stress of 45 psi, all three tests resulted in peak strengths above the envelope from the GCL specification, and none of the three tests resulted in large-displacement strengths above the envelope from the GCL specification.

GeoSyntec has applied the step-by-step procedure in the proposed RCI to the QA conformance shear test results (to date) presented in Figures 4 and 5. The procedure has not yet been applied to the QC test results obtained by Petro because the results available to date are still incomplete. The results of the evaluation for QA conformance samples indicate that of the eight GCL material samples tested, six comply with the shear strength envelopes in the specification. This evaluation is preliminary in that the interface testing of three of the QA samples has not been completed and that Petro may request retests of any failing samples in accordance with the specification.

GeoSyntec proposes to continue to evaluate the GCL QA and QC shear strength test results in accordance with the proposed RCI. Your prompt review of this submittal is appreciated. Please contact either of the undersigned if you have any questions or if you require additional information.

Sincerely,

RBonaparte for

Gary R. Schmertmann, Ph.D., P.E.
Senior Project Engineer

Rudy Bonaparte

Rudolph Bonaparte, Ph.D., P.E.
Principal

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**REFERENCES**

Bonaparte, R., Othman, M.A., Rad, N.R., Swan, R.H., and Vander Linde, D.L., "Evaluation of Various Aspects of GCL Performance," *Report of 1995 Workshop on Geosynthetic Clay Liners*, EPA/600/R-96/149, U.S. Environmental Protection Agency, Office of Research and Development, Washington D.C., June 1996.

U.S. Department of Energy (DOE), "*Uranium Mill Tailings Remedial Action Project, Technical Approach Document, Revision II*", UMTRA-DOE/AL 050425.0002, DOE UMTRA Project Office, Albuquerque, New Mexico, December 1989.

**FIGURE 1**
**Cross-Section Illustrating Geometry of Impacted Material Slope**
**(Not to Scale)**

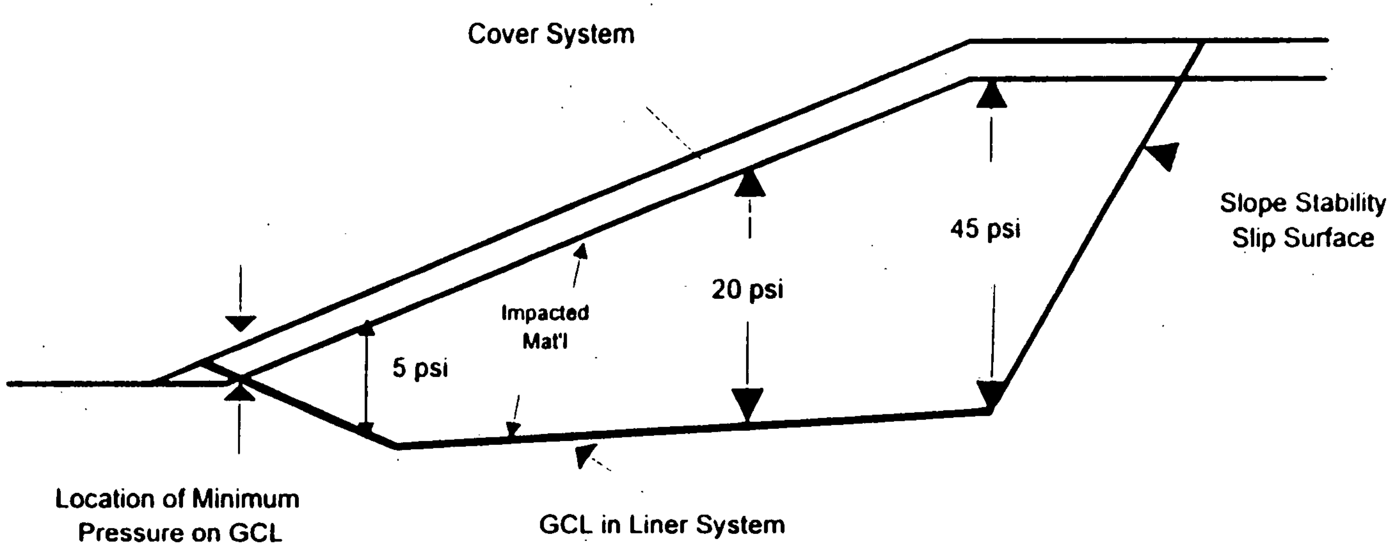


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**FIGURE 2**
**Results from Preconstruction Testing Program**
**GCL and GCL Interfaces**
**Peak Strengths**

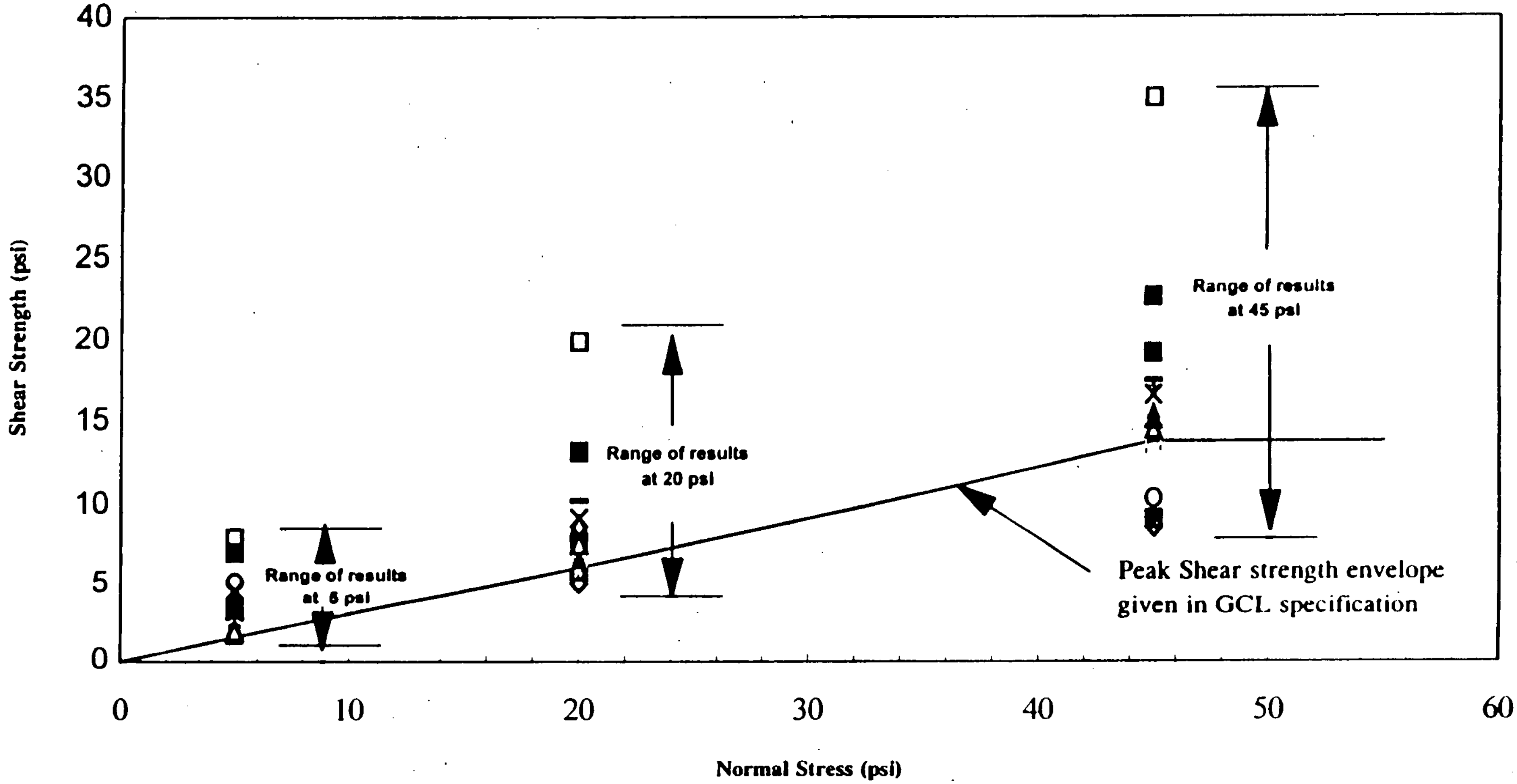


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**Figure 3**
**Results from Preconstruction Testing Program**
**GCL and GCL Interfaces**
**Large-Displacement Strengths**

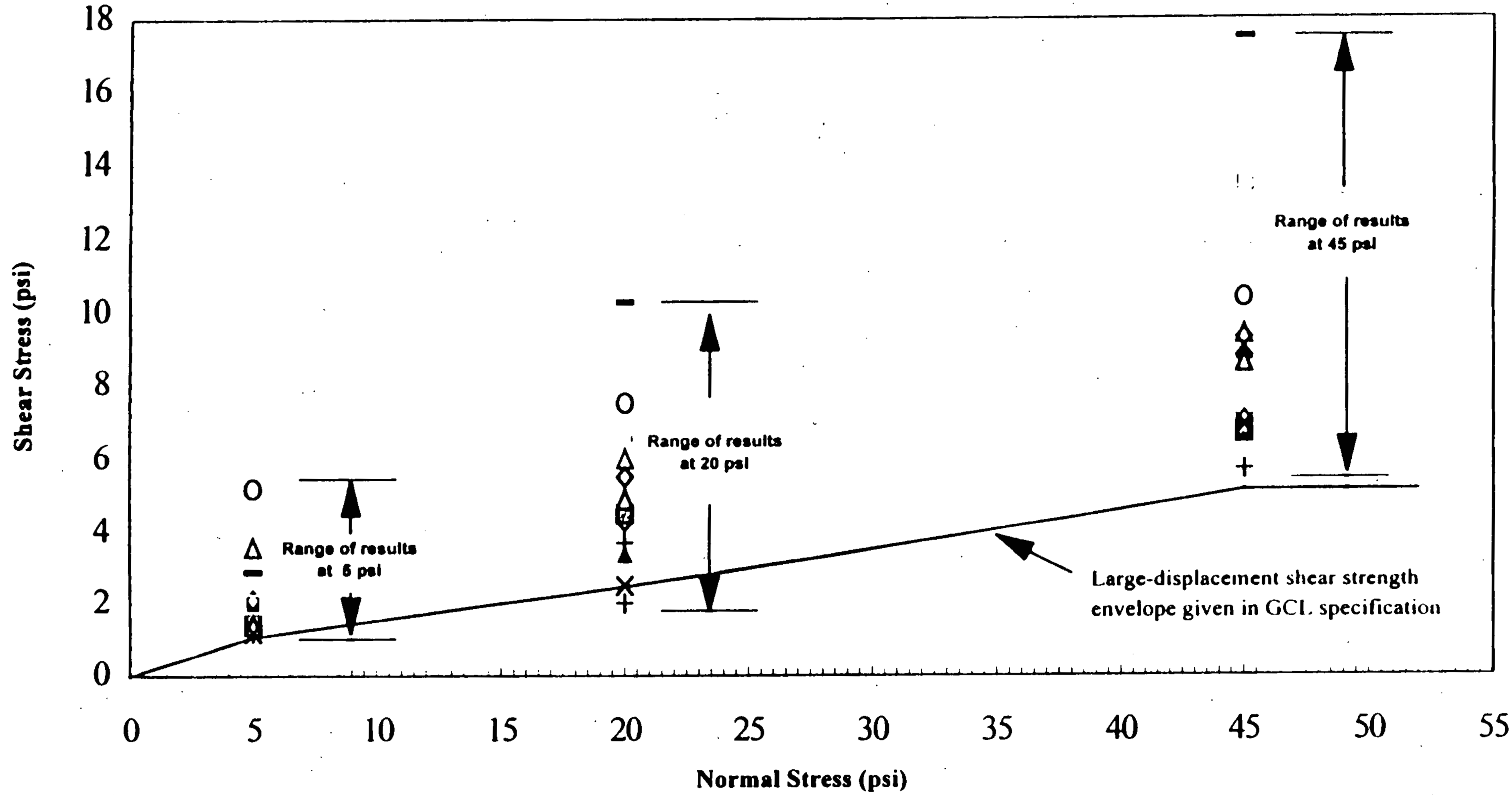


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**FIGURE 4**
**Results from Conformance Testing Program**
**GCL and GCL Interfaces**
**Peak Strengths**

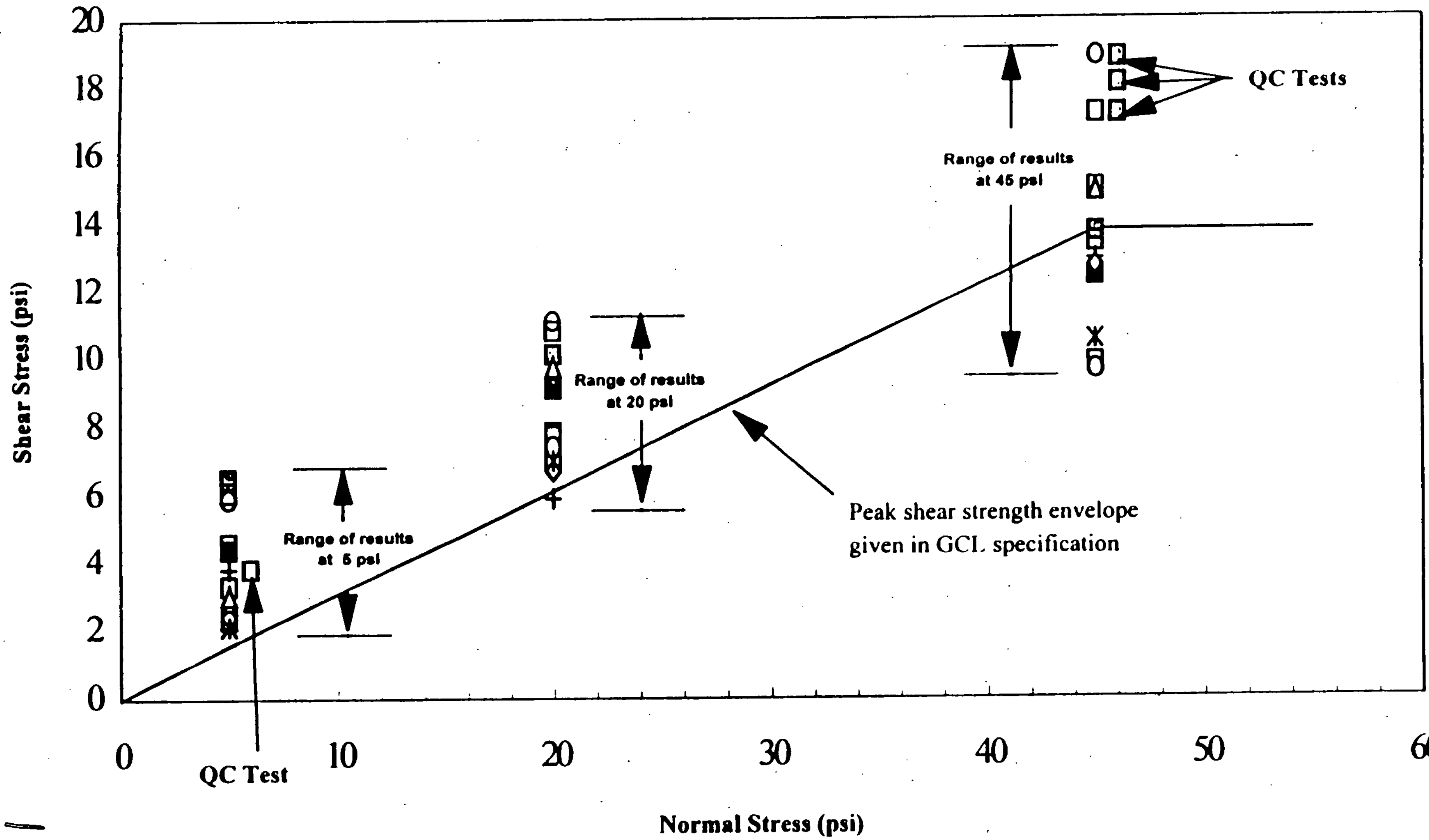


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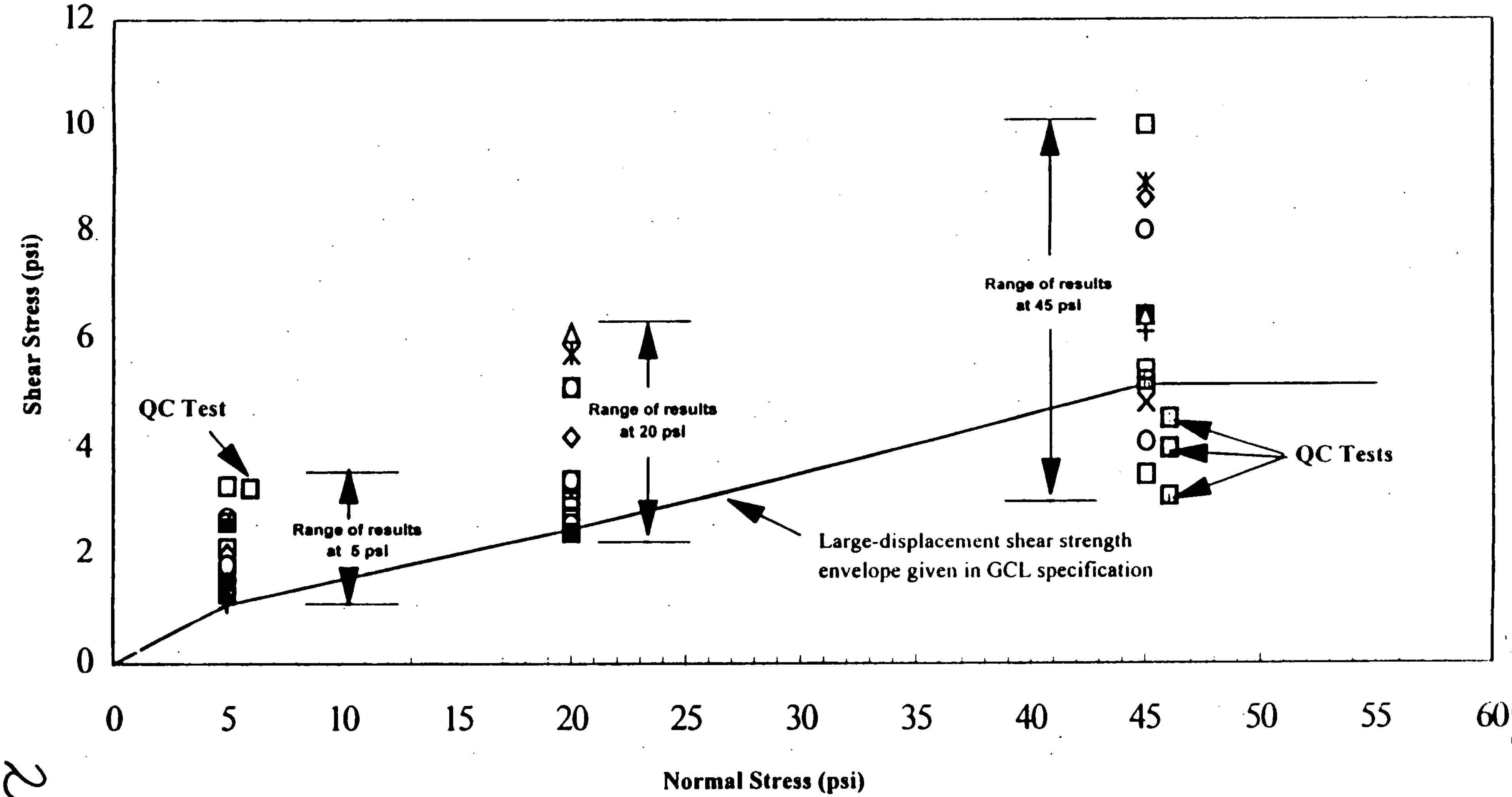
**Figure 5**
**Results from Conformance Testing Program**
**GCL and GCL Interfaces**
**Large-Displacement Strengths**



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2. Slope Stability Analysis. Two slope stability cases that were included in the OSDF design calculations will be reanalyzed using the measured peak and large-displacement strength envelopes established in Step 1. The two slope stability cases are from section 3.3 of the design calculations and are the most critical cases with respected to peak and large-displacement GCL shear strength. The first case involves interim slopes of impacted material[1]. This case will be reanalyzed using the measured peak shear strength envelopes to compute a slope stability factor of safety (FS), $FS_{peak}$. The second case involves final slopes of impacted material[2]. This case will be reanalyzed using the measured large-displacement shear strength envelopes to compute a slope stability factor of safety, $FS_{LD}$. The reanalyses will use the same geometry and material properties as the design calculations, with the exception that GCL shear strengths will be defined by the measured envelopes.

3. Evaluation. Compare the slope stability factors of safety computed in Step 2, $FS_{peak}$ and $FS_{LD}$, to baseline factors of safety. The baseline factors of safety have been obtained by using the shear strength envelopes defined in the specification and reanalyzing the same two slope stability cases described in Step 2. The baseline factors of safety are 1.9 for the peak strength case and 1.6 for the large-displacement strength case. The GCL is in compliance with the shear strength requirements of the specification if the computed internal and interface factors of safety are greater than or equal to the baseline values. The comparison of factors of safety will be made to the nearest 0.1, the same level of significance used in section 3.3 of the OSDF design calculations. Specifically, the GCL is in compliance if the following two conditions are satisfied:

$$FS_{peak} \geq 1.9$$
$$FS_{LD} \geq 1.6$$

1. The first case consists of the most critical interim slope (3H:1V) of impacted material that can potentially exist in the OSDF. The detailed analysis for this case is presented on pages 23 to 26 of section 3.3 of the design calculations, and is there identified by the title "OSDF Interim Conditions - Peak Short Term" and the file name "CASE5B".

2. The second case consists of the most critical final slope of impacted material that will exist in the OSDF. The detailed analysis for this case is presented on pages 31 to 34 of section 3.3 of the design calculations, and is there identified by the title "OSDF Final Long Term - Large Disp." and the file name "CASE7B".

Attachment [illegible]

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*David E. Daniel*
*Civil Engineer*
*906 W. Clark Champaign, Illinois 61821*
*217-398-0053 (Telephone & Telefax)*

October 5, 1997

Mr. Uday Kumthekar
Flour Daniel Fernald, Inc.
P.O. Box 538704
Cincinnati, OH 45253

Re: Purchase Order 98SC00020

Dear Mr. Kumthekar:

I have completed my review of GeoSyntec Consultants' draft RCI report concerning interpretation of the results of shear strength tests performed on samples of the geosynthetic clay liner (GCL) material. You requested that I provide a letter of assessment of the GeoSyntec report and its conclusions. You asked that I address the GeoSyntec procedure, methodology, and technical basis for acceptance of the GCL. This letter report summarizes the results of my evaluation.

By way of background, it might be useful to provide a brief summary of my involvement with GCLs. I have been working with GCLs for approximately 10 years. I was the principal investigator of the first EPA-sponsored study of GCLs and the organizer of all three EPA-sponsored workshops on GCLs. My students and I were among the first to measure and document the shear strength characteristics of GCLs and to report the results in the engineering literature. I co-authored EPA's technical guidance document on construction quality assurance for landfills, which includes a chapter on GCLs. Over the past several years, I have taught a series of continuing education courses on geosynthetic clay liners, which have been attended by about 1,000 engineers, scientists, and regulators. My current position is professor and head of the Department of Civil Engineering at the University of Illinois. I have been a registered professional engineer for 20 years and have consulted on approximately 200 landfill and waste containment/remediation projects. Because of my long-term involvment with GCLs and with landfill design/construction, I feel comfortable providing the assessment that you requested.

In developing my assessment, I reviewed background information, reports, and results of computer analyses provided by GeoSyntec Consultants. One of these reports is, "Final Report, Soil-Geosynthetic Interface Direct Shear Testing," dated March 1997. This report describes how GeoSyntec tested GCLs in the laboratory and established the criteria for the specification that was prepared for this project. GeoSyntec has extensive experience with GCLs. The report exhibits a high level of understanding of the key issues concerning strength testing of GCLs and GCL interfaces. The 12-inch by 12-inch shear box that GeoSyntec used for laboratory testing is a state-of-the-art shear box. The testing program was designed to test multiple potential failure surfaces to be certain that the critical failure surface (the one that yields the lowest strength) was tested. The normal stress used in the testing program was varied over the range of normal stress that is expected in the field. The shear displacement rate was varied to examine the impact of this important testing variable. The conditions of soil compaction for interface shear testing were also varied in an attempt to be sure that the testing program captured the most critical condition that yielded the lowest potential shear strength. The program of testing, and interpretation of test results, included peak strength and large-displacement conditions.

Based on the results of the laboratory testing program and analysis of slope stability, a specification was developed for GCLs to be used on the project. The specifications detail how the laboratory shear tests are to be performed and interpreted. A key element of the specification is the requirement that minimum shear strengths be achieved for normal stresses of 5, 20 and 45psi. The specification was crafted in this manner to take into account the curved nature of failure envelopes for GCLs. Failure envelopes for GCLs are typically curved, and requiring that shearing strengths be evaluated at different normal stresses is appropriate.

The intent of the GCL strength specification is to ensure that the factors of safety calculated for slopes will be no less than those assumed in the design phase. Slope stability analyses were performed using a computer program to calculate factors of safety for various slope conditions and failure surfaces. The computer program that GeoSyntec used is the same one that we use here at the University of Illinois to teach graduate students how to perform slope stability analyses. I did not personally check any of GeoSyntec's calculations, but I can state that the methodology is typical of good engineering practice in the industry. The computer program was used to analyze a large number of potential failure surfaces and to identify the most critical surfaces. The minimum factors of safety for the most critical failure surfaces were found to be 1.9 for peak shear conditions on interim slopes and 1.6 for large-displacement conditions on final slopes. The GCL specification was developed to ensure that the material delivered to the job site would produce slopes with factors of safety no less than these design values.

The selection of an appropriate factor of safety for design of slopes is normally based on engineering judgment, taking into account factors such as variability of materials, variability of test results, uncertainties related to construction, and other factors that are not easily quantified. There is no one factor of safety, or set of factors of safety, that every engineer uses because circumstances are different for every project. Instead, engineering judgment is used to take into account project-specific factors and to select an appropriate factor of safety for design. The factors of safety that GeoSyntec employed for this project are conservative, but not overly conservative, and are typical of values that are used in the industry for this type of project.

The approach that is presented in the draft RCI for evaluation of GCL materials involves the following steps. First, direct shear tests are performed on a sample of GCL material. Next, for each GCL sample, the factor of safety is calculated for the most critical failure surfaces. Finally, the calculated factors of safety are compared with the minimum design values of 1.9 for peak shear conditions on interim slopes and 1.6 for large-displacement conditions on final slopes. If the slope stability analyses for a particular GCL sample indicate that the calculated factor of safety meets or exceeds the design values, then the GCL material is considered to be in compliance with the shear strength requirements of the specification.

In my opinion, the approach described in the draft RCI is reasonable. The intent of the GCL strength specifications is to ensure that GCL materials will have shear strengths that produce factors of safety that are no less than those assumed in design. The most direct way to check for compliance with the design intent is to calculate factors of safety from the results of laboratory shear tests for the most critical slopes. For this reason, the approach that is described in the draft RCI is reasonable and appropriate. The approach goes straight to the bottom-line question of whether the GCL shear strength tests are consistent with the minimum factors of safety that were used for design of slopes.

The draft RCI describes how the results of laboratory shear test results are to be interpreted. For each sample, interface and internal shear tests are required, and the strengths that are evaulated are the lowest strengths from the two series of tests. In my opinion, this is a prudent approach with GCLs but is not unreasonably conservative. I believe that this prudence in the interpretation of individual test results adds even more credibility to an already highly credible approach.

In summary, my assessment of the draft RCI report is that the procedure described for interpretation of GCL shear strengths is fundamentally sound, technically defensible, and appropriate. I did not identify any flaws in the methodology. For these reasons, I recommend that you accept the procedure described in the draft RCI.

Please feel free to contact me if you have any questions.

Sincerely,

David E. Daniel