MEMORANDUM

TO: All Solid Waste Landfill Facility Owners/Operators, Approved Health Departments, and Design Engineers

FROM: Doug Evans, Division of Solid and Infectious Waste Management (DSIWM)

SUBJECT: Advisory on Structural Integrity Considerations for Incorporating Geosynthetic Clay Liners In Solid Waste Landfill Facility Design

DATE: September 17, 1997

1.0 Introduction

Ohio's solid waste landfill regulations allow a geosynthetic clay liner (GCL) to be used in lieu of the recompacted soil barrier layer of the composite cap system or in lieu of a portion of the recompacted soil layer of the composite bottom liner system. Nevertheless, GCLs are a relative newcomer to the evolving field of waste containment, and significant concerns remain over their ability to be appropriately incorporated into waste containment designs. These concerns include inherent stability shortcomings, hydraulic equivalency, and long term performance. Many of these issues continue to be investigated by manufacturers and researchers alike who have, over time, offered changing, conflicting, and ambiguous information on GCLs, thus creating uncertainty regarding the appropriate use of these products.

Recent information suggests that there are special considerations which must be taken into account when utilizing a GCL in certain applications, including use on side slopes and in areas of landfills where localized non-uniform stresses may be encountered.

The purpose of this document is to provide owners, operators, and consultants with the detailed concerns that DSIWM has for the use of GCLs in solid waste landfill design, as well as specific recommendations to allay these concerns.

2.0 Background

Initially, issues regarding GCLs centered on hydraulic conductivity, equivalence to compacted clay liners, and internal shear strength. More recently, interface shear strength, bearing capacity, and overall long term performance have come to the forefront of concern. Ohio's solid waste regulations have addressed the hydraulic conductivity and equivalence issue by setting forth specific criteria regarding the thickness of clay

which a GCL can replace, based on its specific mass of bentonite. However, significant issues remain regarding stability and long term performance associated with use of GCLs in landfill design.

The use of a GCL is a double edged sword; the bentonite contained in the GCL provides low hydraulic conductivity, and yet it probably has the least shear resistance or bearing capacity of any soil. Add to this a significant number of engineering failures and a lack of long term performance data, and concern regarding designs incorporating GCLs is heightened. It is our thought that by sharing our concerns and recommendations with owners, operators, and consultants, that GCLs can be properly incorporated in landfill designs and a considerable amount of time and energy can be conserved by all involved in the DSIWM permitting process.

While the advantages of GCLs are numerous, they are beyond the intended scope of this advisory. This document is intended to make our concerns about GCLs known and to provide design and testing recommendations to alleviate these concerns. This document will explain DSIWM's concerns regarding GCLs in more detail, provide recommendations for incorporating GCLs in landfill design, and offer guidance for determining appropriate strength parameters to use in the necessary design calculations. The concerns contained in this advisory must be addressed by owner/operators proposing to use GCLs. The recommendations made in this document should be considered the preferred method for alleviating the listed concerns, but should not be interpreted as regulatory requirements. By following the recommendations of this advisory, owner/operators will benefit from a straightforward review which will be less likely delayed by revisions during the review process. Conversely, if alternative procedures are used to address the concerns outlined in this document, the alternative procedures will have to be evaluated on a case by case basis for their technical merit, and will probably result in a longer review period.

Please note that although this information is being provided to interested parties in a proactive effort to clarify regulatory concerns and expedite permit review, these issues are exceedingly complex and research is ongoing. Therefore, the information is subject to update and revision as more research is conducted and more issues arise.

For the purposes of this document, GCLs can be grouped into two broad categories, reinforced and unreinforced. Reinforced GCLs are basically comprised of three components, a bentonitic clay soil sandwiched between two geotextiles, with reinforcement to provide additional strength. The reinforcement is accomplished by intermittently stitching the three components together (stitch bonding), or by punching fibers throughout the three components (needle punching). Both types of reinforcement provide additional bonding and strength qualities to the product. Unreinforced GCLs consist of a bentonitic clay soil sandwiched between two geotextiles with no reinforcement, or bentonitic clay soil adhered to a geomembrane.

Stability characteristics are unique to each GCL. This is due to the differing geosynthetic components which are combined in individual GCLs and the methods by which the components are joined. Reinforced GCLs have greater shear strength characteristics than unreinforced GCLs. In addition, reinforced GCLs constructed with non-woven geotextiles are more stable over a larger range of applications than those constructed with a woven geotextile. This is because the woven geotextiles allow bentonite to extrude more readily than non-

woven textiles. The extruded bentonite essentially lubricates the interface(s) between the GCL and adjacent materials, greatly reducing the shear resistance of the composite system.

3.0 Regulatory Considerations

The following Ohio Administrative Code (OAC) references are useful for the purposes of this advisory.

The municipal, industrial, and residual solid waste (MSW, ISW, RSW) regulations require that a permit applicant demonstrate the stability of the landfill. OAC 3745-27-06(C)(4)(j) in the MSW regulations states;

> *"(C) The following information shall be presented in narrative form in a report divided according to paragraphs (C)(1) to (C)(9) of this rule.*
>
> > *(4) The following design calculations with references to equations used, showing site specific input and assumptions:*
> >
> > > *(j) Slope stability analysis".*

Requirements identical to these in the MSW rules are found in OAC 3745-29-06(C)(4)(j) and OAC 3745-30-05(C)(5)(j) for ISW and RSW facilities, respectively.

The MSW and ISW regulations require that a GCL be negligibly permeable to fluid migration and contain a specific mass of bentonite per area. OAC 3745-27-08(C)(3)(a) and (c) and OAC 3745-29-08(C)(3)(a) and (c) state, respectively, for the MSW and ISW regulations;

> *"(3) A Geosynthetic clay liner used in lieu of part of the recompacted soil liner pursuant to paragraph (C)(1)(j) of this rule, or in lieu of part of the recompacted soil barrier layer, pursuant to paragraph (C)(15) or (C)(16) of this rule, shall have the following characteristics:*
>
> > *(a) Be negligibly permeable to fluid migration; and*
> >
> > *(c) Have a bentonite mass per unit area of at least one pound per square foot".*

4.0 Concerns and Recommendations

DSIWM has two main areas of concern with incorporating a GCL in a landfill design:

- Defining performance standards which can account for uncertainties associated with the use of a relatively new and developing product without a proven long term performance record; and

- Determining accurate and appropriate design parameters to fully account for the exceptionally weak nature of hydrated bentonite.

These two main areas of concern have a number of specific concerns which are discussed in the following sub-sections.

4.1 Assuring Long Term Performance

Very little is known about the long term performance of GCLs. This issue is discussed at length in U.S. EPA's recently released *Report of 1995 Workshop on Geosynthetic Clay Liners*, dated June 1996, and also in the American Society for Testing and Materials (ASTM) Special Testing Publication No. 1308, *Testing and Acceptance Criteria for Geosynthetic Clay Liners*, published in January of 1997. Additionally, there appears to be a growing opinion among eminent researchers in the GCL arena that it may be more prudent to evaluate post-peak strength conditions than peak conditions. This is due to uncertainties surrounding the processes that may initiate deformations in composite lining systems during construction, waste placement, and the waste's subsequent settlement. These processes may result in the development of post-peak or residual shear strength conditions which are weaker than peak strength values.

Ohio EPA guidance document number 180, *Factors of Safety for Slope Stability Analysis*, dated November 24, 1995, explains the methodology that DSIWM uses for the selection of an appropriate recommended factor of safety for a solid waste landfill, based on imminent danger to human life or major environmental impact if the slope were to fail and the degree of certainty in the assumed parameters. However, the incorporation of a GCL in the solid waste landfill design adds an additional unknown to the factor of safety selection process. Therefore, due to uncertainties and a lack of long term performance data, DSIWM recommends designing for post-peak conditions with a 1.3 static factor of safety and a 1.1 dynamic factor of safety for designs incorporating GCLs, see Table 1.

Table 1

Recommended Minimum Factors of Safety

Post-Peak Static Stability [1,2]	1.30
Post-Peak Pseudo-Static Stability [2,3]	1.10

1. Potential pore water pressure build up in the drainage layer must be taken into account when investigating the stability of the final cover system. Consideration of seepage forces should include an investigation of the maximum pore water pressure that may build up in the drainage layer of the cover system based on the maximum fluid flux through the cover soils which could occur during saturated conditions and a major rain event.

   [Comment: Seepage forces are important because a significant number of landfill final cover failures have occurred across the nation due to inadequate design of the drainage layer. Drainage layers have been unable to adequately relieve the pore water pressure that can build up in cap systems during heavy downpours. The design inadequacies include underestimating the volume of water that can permeate through the cover soils during a major rain event and/or inadequate controls for keeping the drainage layer from becoming partially or completely clogged throughout the life and post closure of the landfill.]

2. Post-peak shear strength should be determined utilizing a shear displacement of at least 50 mm (2 in).

3. Should a deformational approach be chosen over a pseudo-static analysis, deformation in the composite cap system should not exceed 15 cm (6 in) and deformation in the composite liner system should not exceed 10 cm (4 in).

4.2 Accounting for the Weak Nature of Hydrated Bentonite

The bentonite component of the GCL usually controls the strength characteristics of the composite bottom liner and cap system. Hydrated bentonite has the lowest peak and residual shear strengths of any soil. Bentonitic soils also have an extremely high affinity for moisture and will wick significant amounts of moisture from even the driest subgrade. In other words, GCLs will hydrate. Bentonite's affinity for moisture results in extraordinarily large swell pressures which can cause the hydrated bentonite to extrude from the GCL into the interfaces between the GCL and adjacent materials, essentially lubricating these interfaces, thereby weakening the structural integrity of the composite system.

Hydrated bentonite also exhibits an extremely low bearing capacity. Thus localized non-uniform stresses can cause the bentonite in GCLs to flow or migrate away from higher stress concentrations allowing the GCL to thin in localized areas. This bentonite thinning results in GCLs no longer meeting the regulatory requirements on specific mass per unit area, and greatly increases fluid flux through the GCL.

It is the low hydraulic conductivity of hydrated bentonite that makes the GCL useful and it is also the hydrated bentonite that makes the GCL so weak. Focusing on the weakness issue, some designers have suggested encapsulating the GCL between two geomembranes to prevent hydration. While this will minimize widespread hydration, localized zones of hydrated bentonite and ensuing weakened conditions are still a possibility owing to imperfections in geomembrane installation. A U.S. EPA sponsored test section of an encapsulated GCL recently failed due to such localized zones of hydration.

4.2.1 Determining Shear Strength Characteristics

Many times in the past, slope stability calculations required in the permitting process have been submitted to DSIWM utilizing manufacturer-supplied generic shear strength data. While this data may be useful in preliminary design evaluations, it is inadequate for the stability calculations required in the DSIWM permitting process. Typically, manufacturer's data is accompanied by disclaimers which state that the information should not be relied upon to determine final design parameters and that project-specific shear testing should be conducted for this purpose. DSIWM emphatically recommends testing the shear strength of project-specific materials under appropriate conditions, including normal stress, moisture content, and shearing procedure.

Currently, no established or otherwise universally accepted test method exists for determining the internal shear strength and interface shear strength of a GCL. "Appropriate" shear testing has proven to be a highly subjective and controversial issue around the state and nation. This is to be expected when one considers the array of products, each with distinctively different characteristics, and the reality that any inaccuracies inadvertently introduced into sample selection, sample preparation, or actual shearing may falsely increase the measured shear resistance.

With this in mind, DSIWM is outlining some of the more pertinent aspects of shear testing a GCL and recommending the following specific testing procedures.

A. Sample Selection

Ideally the shear samples should be selected from rolls that are delivered to the site. However, this is often impractical. The next best alternative is to obtain identical product samples from another site. If either of the preceding options are unavailable, samples from the manufacturer may be used, if the manufacturer will certify that the samples are representative of materials shipped to the field. This is important because the amount of reinforcement can vary significantly in the manufacturing process.

B. Hydration

According to U.S. EPA (1996), GCLs will hydrate when placed in contact with typical construction subgrade soils and will probably hydrate significantly within the first few days (moisture contents as high as 50 % were measured after 10 days). Stark (1997a) reports that this hydration typically occurs under a free swell condition and that the swell pressure of a reinforced GCL can be on the order of 35 to 40 kPa (730 - 835 psf). A confining stress of

this magnitude, equivalent 2.1 to 2.5 m (7 - 8 ft) of soil, is typically never applied to a cap system and it is usually a number of weeks if not months before a confining stress capable of preventing GCL swell is applied to the composite bottom liner system. In addition, this swell pressure is capable of destroying the reinforcement of GCLs and/or forcing hydrated bentonite into the interfaces, thereby greatly decreasing the integrity of the bottom liner or cap system. Consequently, DSIWM recommends that project-specific GCLs and adjacent materials be allowed to fully hydrate, as a single unit, in a free swell condition until vertical expansion has essentially ceased (an inconsequential confining stress of no more than 0.5 psi to prevent sample deterioration or to provide a founding for displacement measurement is acceptable). The vertical expansion should be determined by monitoring vertical displacement until swelling has reached 100% primary as determined by ASTM 4546 and moisture samples should be taken from the hydrated GCL after the shear test to verify the degree of hydration.

C. Normal Stress

DSIWM recommends that project-specific materials including soils and geosynthetics be tested for internal and interface shear strength over the entire range of normal stresses which will be encountered in the particular design.

- For cap systems, this includes the low normal stresses associated with these applications and any additional stresses which may be induced by surface water diversion benches, roads, equipment, or other structures constructed above the composite cap system.

- For composite bottom liner systems, the range of normal stresses which needs to be evaluated can be extensive, varying from low values at the perimeter of the fill to extremely high values under the deepest areas of the fill.

D. Shear Displacement Rate

Gilbert et al. (1997) and Stark (1997) show that the rate of shear displacement can greatly affect the measured shear strength of GCLs. Shear strength values from tests using a displacement rate of 1 mm/min, the industry norm, have been shown to be in significant excess of those values using slower displacement rates. Stark (1997) reports that rates equal to or less than 0.04 mm/min (.0016 in/min) do not seem to have a detrimental affect on measured shear strength values of one reinforced GCL. Gilbert et al. (1997) and U.S. EPA (1996) recommend ASTM D-3080 for determining the appropriate direct shear rate. DSIWM recommends following the ASTM D-3080 procedure for determining the appropriate direct shear rate for GCLs; and that the direct shear rate should not exceed 0.04 mm/min.

E. Test Method

Currently the most common method used for determining internal shear strengths and interface shear strengths of GCLs is ASTM D-5321 utilizing a 300 mm square shear box. DSIWM recommends this procedure for determining the shear strength of Geosynthetic/Geosynthetic or Geosynthetic/soil interfaces, and the internal shear strength of GCLs.

4.2.2 Avoiding GCL Thinning

After GCLs have hydrated and stresses have been applied, the bentonite has been observed to migrate away from high stress concentrations, resulting in localized thinning of the GCL. This phenomenon is especially likely to occur in areas of composite bottom lining systems where non-uniform stress concentrations typically develop. This includes areas in the immediate proximity of wrinkles, in and around sumps, and beneath leachate collection piping. Thinning of the GCL due to migration of the bentonite has been observed at one facility here in Ohio.

One-dimensional compression tests show that the thickness of a hydrated GCL can decrease significantly due to bentonite migration. This phenomenon has been evidenced in exhumed GCLs and has been noted by numerous authors including Fox et al. (1997), Richardson (1997), Anderson (1996), Koerner and Narejo (1995), and Anderson and Allen (1995). According to Fox et al. (1997), bentonite migration seems to be more pronounced in unreinforced GCLs than in reinforced GCLs. Anderson and Allen (1995) and Anderson (1996) also show that the thickness of a GCL can be significantly reduced in the vicinity of a wrinkle in the overlying geomembrane due to hydrated bentonite flowing up into the air space of the wrinkle, which may change shape but does not necessarily disappear according to Koerner (1996).

Thinning of the GCL has serious implications for meeting the regulatory requirements, which include criteria for specific mass of bentonite per unit area and hydraulic performance. GCLs are allowed to replace a portion of the recompacted soil layer based on their hydraulic performance. However, the hydraulic performance or fluid flux through a GCL is directly related to the thickness or specific mass of bentonite per unit area. Thus, if the bentonite thins, the fluid flux through the GCL will increase, and the requirements for hydraulic performance and specific mass of bentonite per unit area may no longer be satisfied. It is therefore recommended that the sump areas and areas directly beneath leachate collection piping not incorporate GCLs, and that wrinkling of the geomembrane be kept to an <u>absolute minimum</u>. DSIWM recognizes that there will be design and construction difficulties associated with this recommendation and that there are alternative approaches. Unfortunately, insufficient information currently exists for DSIWM to make any other recommendation.

5.0 Concerns and Recommendations Unique to Unreinforced GCLs:

Unreinforced GCLs lack any added reinforcement to resist shear stresses, such as needle punching or stitch bonding. As a consequence, these products have internal shear strength and bearing capacity characteristics approximately equivalent to hydrated bentonite. USEPA (1996) comments that shear data on unreinforced GCLs show friction angles of about 10 degrees. Richardson (1997) estimates the bearing capacity of a

hydrated unreinforced GCL to be 40 kPa (825 psf) and the internal shear strength to be less than 5 kPa (100 psf) for low normal stresses such as those associated with caps.

For low normal stresses such as those in cap systems, unreinforced GCLs will hydrate fully under confining stresses significantly less than the swell pressure of the GCL. Furthermore, these products have a severely limited shear resistance which essentially corresponds to hydrated bentonite. These products may also undergo significant creep due to the time-dependent deformational characteristics of hydrated bentonite, resulting in extremely low post-peak or residual strength conditions. Additionally, the extremely low bearing capacity of unreinforced GCLs may result in thinning of the GCL from bentonite migration due to non-uniform stress concentrations, such as wheel loads, that may be applied to a cap during closure and post closure. For these reasons, it is recommended that composite cap system designs do not incorporate unreinforced GCLs and that unreinforced GCLs be restricted to use on bottom lining slopes of less than 10%.

6.0 Procedural Considerations

The recommended testing procedures and factors of safety for GCLs are a component of the slope stability analysis required in the DSIWM permitting process. The first Ohio Administrative Code cited in Section 3.0, Regulatory Considerations points out that a slope stability analysis is to be included in the narrative section of the permit to install application. This requirement applies to all permit applications or alteration requests proposing to use a GCL, initially; and may apply to alterations or other changes proposing to exchange one GCL for another. Additionally, this requirement may also apply to permit applications, alteration requests, or other changes already incorporating a GCL, but proposing to change materials or thicknesses of materials for individual components of the composite bottom liner and composite cap system, or any other circumstance that may cause uncertainty in the validity of previously submitted slope stability calculations.

The specific contents of a slope stability analysis can be sensitive to particular conditions present at an individual site and often need to be assessed on a case by case basis. However, in general, a slope stability analysis for a landfill should include the following:

A. The rationale, cross-sections, and plan views, for critical slope conditions* which may occur during the excavation and construction of the landfill**.

B. The rationale, cross-sections, and plan views, for critical slope conditions* which may occur during the operation and filling of the landfill**.

C. The rationale, cross-sections, and plan views, for critical slope conditions* which may occur during final closure and post closure care of the landfill.

D. The rationale for the selection of soil and geosynthetic strength characteristics, including detailed information from a site specific subsurface exploration, and detailed information from a project specific materials shear strength testing program.

E. A discussion of the methodology used for the determination of the factors of safety.

F. The physical calculations and/or computer output for the critical conditions of the excavation, intermediate or interim waste slopes, and final slopes.

* Determining critical slope conditions includes investigating both static and dynamic cases for both deep-seated and shallow failure surfaces for both rotational and translational modes of failure.

** Operational and construction practices can have a profound impact upon the integrity of the engineered components of waste containment facilities and should not be overlooked in the design process. Recommendations for operational and construction practices relating to geosynthetics have been provided in a previous memorandum titled *Unstable Slopes Advisory for Solid Waste Landfill Facilities*, dated December 2, 1996. Specific terms and conditions of a permit to install may be necessary in order to limit waste placement to a maximum slope height and inclination during the filling of a phase or unit to maintain the integrity of the engineered components of the landfill.

7.0 Summary

In summary, Ohio's solid waste regulations allow a GCL to be used in lieu of the recompacted soil layer of the composite final cap system or for a portion of the recompacted soil layer of the composite bottom liner system. However, any liner or cap system utilizing one of these products must perform adequately. DSIWM has significant reservations regarding the ability of GCLs to perform as safely and durably as compacted clay soils in some applications. These concerns are due to the inherent low strength characteristics of bentonitic soils and a lack of long term performance data on these products. The low strength characteristics of bentonite preclude GCLs from being used on some slopes and allow GCLs to thin when subjected to non-uniform stresses. In an effort to provide direction to interested parties in alleviating DSIWM's concerns and to expedite review of proposals incorporating these products, DSIWM offers the following recommendations:

- Project-specific geosynthetics and soils should be tested appropriately for internal and interface shear strengths over the entire range of normal stresses which will be encountered for a particular application, and the results incorporated into the required slope stability calculations.

- The recommended minimum factors of safety for GCLs are listed below and should be satisfied using a post-peak shear strength with a shear displacement of at least 50 mm (2 in).

Post-Peak Static Stability	1.30
Post-Peak Pseudo-Static Stability	1.10

- Prior to shearing, the GCL should be allowed to fully hydrate in a free swell condition until primary swell is complete. The moisture content should be verified upon completion of the shear test.

- DSIWM recommends that the rate of shear for direct shear tests on GCLs be determined using ASTM D-3080, and that it not exceed 0.04mm/min.

- DSIWM recommends determining internal and interface shear strengths of GCLs by ASTM D-5321 utilizing a 300 mm square shear box.

- Wrinkling of the geomembrane should be kept to an absolute minimum, and any sump areas and areas directly beneath leachate collection piping should not incorporate GCLs.

- Unreinforced GCLs should only be used on slopes with a grade of less than 10%, and should not be used in composite cap systems.

The recommendations made above apply to all permit applications or alteration requests initially proposing to use a GCL, and may apply to alterations or other changes proposing to exchange one GCL for another. Additionally, these recommendations may apply to permit applications, alteration requests, or other changes already incorporating a GCL, but proposing to change materials or thicknesses of materials for individual components of the composite bottom liner or composite cap system, or any other circumstance that may cause uncertainty in the validity of previously submitted slope stability calculations.

A substantial portion of the information contained in this advisory will be incorporated into a comprehensive policy statement on slope stability. A draft copy of the policy will be distributed to interested parties for review and comment. If you have any comments or questions concerning the information contained in this advisory or would like information regarding the forthcoming slope stability policy, please contact me at (614) 728-5371. If you would like to be included on the interested party list for the slope stability policy please fax me your name, address, company/affiliation, telephone and fax numbers at (614) 728-5315.

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Attachment: References

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