Destructive and Nondestructive Testing of Geosynthetic Clay Liner (GCL) Panel Seams

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ABSTRACT

Geosynthetic clay liner (GCL) panel separation of the overlapping edges has occurred in five known situations when they have been placed beneath geomembranes exposed to the atmosphere. Exposure time varied from 15 mos.-to-5 years and the separation distances varied from loss of overlap to as much as 1.2 m. Of course, any amount of physical separation challenges the concept of a composite liner and should be avoided. The current thinking to prevent panel separation when exposed conditions are necessary is a mechanical bonding (or “seaming”) of the initial overlaps. This paper will first address manufacturing of seven different seaming types, aka, procedures. It then introduces seam strength testing methods for GCL seams.

The testing methods described herein can be conducted in the laboratory as destructive tests and/or in the field as nondestructive tests. Both types can be conducted on GCL seams irrespective of how the seams were made in the field. The destructive test method is used to determine the ultimate tensile strength of the GCL seams. It is straightforward and follows similar procedures of geomembrane seam testing in shear. Results can then be compared to the unseamed GCL’s wide width tensile test results and thus a seam efficiency can be calculated.

In determining the in-situ GCL seam strength, numerous trials in gripping and evaluating representative samples of different thickness, geometry, and stiffness were performed. The resulting recommended field test places the GCL seam in a shear mode such that the applied force is less than the ultimate strength in a manner similar to conventional nondestructive geomembrane testing.

1. BACKGROUND

On at least five occasions, exposed geomembranes have been cut open for various reasons and the underlying GCL panels were seen to be physically separated from one another, see Figure 1 after Koerner and Koerner (2005). This is obviously of concern since composite action of a geomembrane/geosynthetic clay liner is dependent upon full coverage of both materials.

a) Loss of initial overlap ~ 150 mm (Daniel and Koerner, 1995)
b) Separation of GCL panels ~ 200 mm (California, 2004)
A series of papers describe this phenomenon in the open literature. They are as follows (Thiel, et al. 2005; Thiel and Richardson, 2005; Thiel and Thiel, 2009; Thiel and Rowe, 2010; Rowe, et al. 2010) describing the possible phenomenon and suggesting that GCL overlap seaming would be a mitigating or even eliminating if certain precautions are taken.

This activity prompted research into various methods of GCL seaming (which is the focus of this paper) and the subsequent destructive and nondestructive evaluation of the possible types of GCL seams.

2. INTRODUCTION

At the outset, it should be mentioned that the delivered rolls of GCL’s should be in protective wrappings and stored at the site until immediately before placement. Placement should be according to the project’s plans and specifications and observed by the site inspection CQC and CQA personnel, see EPA (1991 and 1993) and Daniel and Koerner (1995).

Overlapping of the GCL’s so as to form seams should be completed according to manufacturer’s specifications. The seaming procedures and inspections should be part of the CQA Plan. Bentonite may be needed for water tightness, depending on the manufacturer’s recommendation. If bentonite is used, the amount must be specified and verified as part of CQA monitoring activities. Obviously adding bentonite in paste or powder form to the area to be bonded will compromise most seaming methods and must be considered accordingly.

It also must be recognized that this discussion about seaming GCL’s is predicated on proper preparation of the GCL overlapped surfaces to be seamed. Seaming should not take place during precipitation events or where the GCL has been hydrated on-site. In addition, in the area to be seamed, soil debris and foreign matter must be removed from the opposing surfaces of the GCL in the regions where the actual seaming is to be performed.

In the sections to follow the following seven types of GCL panel seaming are illustrated and described.

- Thermal fusion methods
  - manual hot air
  - automated hot air
  - manual hot iron
  - manual propane torch
- Adhesive bonding
- Double sided tape
- Sewing

3. THERMAL FUSION

The original approach toward seaming GCL panels was made by Rick Thiel who observed that all geosynthetic installers had hand-held hot air blowers used to tack geomembrane sheets together. Field trials using the same device on bonding
the opposing geotextiles on GCL’s followed accordingly. Hot air is introduced into the area to be bonded, held sufficiently long to melt some of the opposing geotextile fibers and is immediately followed by a light pressure such as dragging a sandbag behind the fiber melting process. This initial field approach led directly toward our investigation of four different types of thermal fusion; manual hot air, automatic hot air, hot iron and propane torch. It should be noted that Wayne and Sinclair (1994) experimented with thermal seaming of thick nonwoven geotextiles and GCL’s are obviously similar in this regard.

All four are accomplished by overlapping the GCL’s the appropriate distance and applying heat to the seamed area, then dragging a sand bag over the area to press the seam together immediately after the heat source is applied. In general, the rate of seaming (speed), temperature and normal pressure can be controlled with automated devices. This is not the case with hand held devices. It is apparent that the automated device creates a more consistent and continuous seam as compared with the hand held options, however, there can be no waves or wrinkles in either of the overlapping GCL edges unless the device starts to slip and overheats the geotextile(s). This is oftentimes difficult to achieve.

GCL panels are generally overlapped 75 mm and shingled downgradient like a roof. Typically the device being used is inserted into the area to be bonded and moves along briskly to avoid burning through the geotextiles of the GCL. The four different thermal fusion methods are shown in Figure 2.
4. ADHESIVE BONDING

In order to demonstrate the viability of adhesive bonding, some bench-scale tests were performed using different adhesives. The objective was to identify an adhesive with suitable strength properties to bond GCL panels to one another. The glues investigated were wood glue, liquid nail (a common construction adhesive) and an eurethane foam adhesive, see Figure 3. GCL panels approximately 300 mm wide and 1.5 m long were overlapped and bonded together with each adhesive. The overlap distance was approximately 75 mm. Each adhesive was placed in an approximate 12 mm wide bead within this overlap zone. The panels were pressed together by hand and then were allowed to dry for 24 hours without confining pressure. It was reasoned that if the bond strength was found to be similar to the strength of GCL, then the bond could be judged as adequate for allowing stress transfer from one panel to another. It is important to recognize that the overlays to be bonded must be completely dry. Wayne, et al. (1990) experimented with different adhesive bonding of geotextiles and found this to be the case.

Figure 3. Various types of adhesives used for bonding GCL panel overlaps.
5. DOUBLE-SIDED TAPE

This type of seam is very similar to the glued seam, however, it offers more control but at a higher price. Many 150 mm wide products are available for placement of household carpeting. The association of a carpet to either woven or nonwoven geotextile is obvious. The area to be bonded needs to be clean, dry and overlapped properly. The procedure is to fold back one side of the GCL by about 150 mm so the underside is facing up. Next, peel off a section of tape long enough to span the area to be bonded. Then press the sticky side of the tape to the lower GCL, about 25 mm inside the edge. Peel off the waxy paper from the top of the tape, exposing the sticky surface under it. Immediately fold the edge of the upper GCL back down and apply pressure on the overlap. Several different two sided tapes are shown in Figure 4 along with a resulting seamed GCL.

![Image of double-sided tapes](image_url)

**Figure 4.** Several double-sided tapes for bonding GCL panels.

6. SEWING

When GCL connections are a critical part of project design, sewing may be an option. GCL sewn seams are possible but it is more difficult than geotextile seams due to the multiple plys of geosynthetic in question and dealing with the granular or powderd bentonite of the GCL. Broken needles simply must be anticipated and dealt with in a systematic manner on site.

In some applications, sewing is used as a means of eliminating the expense of large overlaps. Normally, a sewn seam will require only a few millimeters of GCL from each direction, compared to an overlap which may use as much as 300 mm. If an application requires stress transfer from one GCL roll to another, sewing might become necessary. As the strength required across the seam increases, details of the sewn seam, such as seam type, sewing equipment, and sewing thread become more important.

There are three sewn seam types that could be considered for GCL’s; prayer, “J”, and butterfly. Each of these seam types can be sewn with varying threads, stitch types, varying numbers of stitch lines and number of stitches per inch of seam. The easiest and most common seam type is the prayer seam. For optimum strength and seam efficiency, a “J” type seam is sometimes used but now sewing is through four layers of material, as it also is with the butterfly seam. Thus, only prayer type sewn seams are evaluated in this study. Also, two stitch lines are sometimes required when a high degree of seam integrity confidence is necessary. However, most GCL applications probably only warrant one stitch line.

Sewing machinery is divided into two categories. The first is portable and hand-held equipment. These hand-held machines sew one stitch line and, depending on the manufacturer utilize either a lockstitch (two-thread stitch) or chain stitch (single-thread stitch). Lockstitches are more resistant to unraveling. Field-sewn seams requiring two stitch lines will need two passages with a lightweight sewing machine. Figure 5 shows field sewing of thick needle punched nonwoven geotextiles (similar to GCL’s) and the resulting laboratory-made GCL sewn seam.

When high seam strengths are required, or when heavier GCLs are sewn, a higher-powered sewing machine must be used. This is required for the needle to penetrate both GCL’s, and to accommodate a larger needle to carry the sewing thread. These machines normally are tractor-mounted and come with both single-head and double-head connections. Lightweight sewing threads are made from nylon, polypropylene or polyester. The selection is based on the project specific requirements such as anticipated environment exposure and service life.
7. LABORATORY DESTRUCTIVE TESTING OF GCL SEAMS

This test method is designed to determine the value of GCL seam strength in the laboratory in either shear or peel modes. That said, the peel tests were problematic and only shear tests are reported. In this shear test, a 100 mm wide GCL seam specimen was mounted into full width grips and tensioned until failure is reached. Failure can occur within the GCL sheet material, or the seam; see Figure 6. The value reported is the maximum force per unit width, e.g., kN/m.
c) Progressive failure during a GCL seam test

Figure 6. Destructive testing of a GCL seam specimen.

The tensile testing machine needed to properly conduct the test is a constant rate of extension (CRE) type described in ASTM Specification D76.

The grips required are full specimen width and shall be at least 25 by 100 mm, with appropriate clamping power to prevent slipping or excessive damage to the GCL’s. Testing specimens are to be cut from GCL coupons by a sharp die 100 mm wide by approximately 200 mm long.

The moisture content of the bentonite within the GCL was considered and of the various options (dry, as received, or saturated) it was decided to use the as-received material. The moisture content of the GCL will affect seam strength. Of course, this decision must ultimately be left to the various parties involved in the process.

Ultimately, the following test procedure was decided upon. (It has been temporarily written as a draft GRI test method.)

(a) Five (5) test specimens were die cut randomly distributed across locations on the seam sample.
(b) Grip separation, (distance between the leading edge of grip faces) at the start of the test was 50 ± 3 mm plus the seam width.
(c) The test speed for the CRE machine was 50 mm/min.
(d) Specimens were centrally located in the clamps as shown in Figure 6. The specimen length was made parallel to the direction of application of force.
(e) Each specimen in the CRE machine was tested until it ruptured completely. In all cases, maximum tensile force of the GCL seam was recorded. In any case where specimen slippage in the clamps was experienced, or for any reason attributable to faulty operation, results were discarded and another test specimen was tested.
(f) At the conclusion of each test the tensile strength was calculated by dividing the load read directly from the testing machine readout by the width of the specimen expressed in strength units of kN/m.

Results for four types of thermal fusion as well as gluing, double sided tape and sewing (as described in the companion paper) are presented in Table 1. Here the unseamed GCL tension baseline strength is given so as to compare the various types of seaming methods to it. It is seen that the glued (i.e., epoxy bonded) seam has, by far, the greatest seam strength as compared to the GCL sheet tension strength. It is actually greater, i.e., 128%. The other seam shear strengths range from 31% to 87% of the unseamed GCL sheet tension strength. It should be noted that the most common field seaming method to date is a fusion test using a hot air gun. Its efficiency is 52% but its standard deviation is the highest of the seven seam types.
Table 1. Results of laboratory shear testing of double nonwoven GCLs made by different seaming methods compared to the unseamed GCL tension strength.

<table>
<thead>
<tr>
<th>Test Number</th>
<th>GCL Tension Strength</th>
<th>Thermal Fusion Seams</th>
<th>Glued (urethane) Seam</th>
<th>Double Sided Tape Seam</th>
<th>Sewn Seam</th>
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<tbody>
<tr>
<td></td>
<td>kN/m</td>
<td>kN/m</td>
<td>kN/m</td>
<td>kN/m</td>
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<tr>
<td>1</td>
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<td>6.1</td>
<td>4.9</td>
<td>4.0</td>
<td>3.7</td>
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<tr>
<td>2</td>
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<td>8.4</td>
<td>4.7</td>
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</tr>
<tr>
<td>3</td>
<td>11.4</td>
<td>8.8</td>
<td>6.3</td>
<td>5.1</td>
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</tr>
<tr>
<td>4</td>
<td>10.0</td>
<td>4.7</td>
<td>3.3</td>
<td>3.3</td>
<td>4.2</td>
</tr>
<tr>
<td>5</td>
<td>12.6</td>
<td>8.1</td>
<td>5.3</td>
<td>1.9</td>
<td>3.2</td>
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<tr>
<td><strong>Average</strong></td>
<td><strong>10.7</strong></td>
<td><strong>6.8</strong></td>
<td><strong>5.6</strong></td>
<td><strong>3.8</strong></td>
<td><strong>3.3</strong></td>
</tr>
<tr>
<td></td>
<td><strong>kN/m</strong></td>
<td><strong>kN/m</strong></td>
<td><strong>kN/m</strong></td>
<td><strong>kN/m</strong></td>
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<tr>
<td>Std. Dev.</td>
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<td>1.6</td>
<td>1.9</td>
<td>1.3</td>
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<tr>
<td>Efficiency (%)</td>
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<td>64</td>
<td>52</td>
<td>36</td>
<td>31</td>
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</tbody>
</table>

Note: The values in this table are for these laboratory tests only. Site-specific and product-specific evaluations will take precedence in all situations.
8. FIELD NONDESTRUCTIVE (NDT) TESTING OF GCL SEAMS

The field NDT test for GCL seams is intended for construction quality control (CQC) and construction quality assurance (CQA) purposes. In this context it should be performed by CQC personnel and observed by CQA personnel in exactly the same manner as NDT geomembrane testing such as air pressure testing or vacuum box testing. Results can be compared to the unseamed GCL tension test or to a statistically obtained set of destructive tests based on a particular seam type conducted in the laboratory.

The test apparatus developed for this NDT method consists of two parts; (i) implement head or “spike plate” and (ii) a luggage scale/hand weighing balance. The latter should operate under a spring load. There are many commercially available devices of this type. It should have the capabilities of measuring the tensile force, with a load cell having an adequate load capacity, to cover the full range of GCL’s and seam types to be tested. The device should have a visible readout. The spike plate shall be sufficiently wide to grip a 100 mm wide section and with appropriate detail to prevent slippage. Details of the suggested gripping plate are shown in Figure 7. Such plates are also commercially available but must be bent as shown, so as to avoid load eccentricity during pulling. It should be noted that this is the exact type of spike plate used in laboratory direct shear testing of GCL’s, see Fox, et al. (2002) and GRI-GCL4 (2006).

![Diagram of GCL gripping assembly for nondestructive GCL field seam evaluation.](image)

a) Detailed perspective of spike plate used to grip the nonwoven geotextile of GCL’s

![Plan view of spike plate tooth layout.](image)

b) Plan view of spike plate tooth layout

Figure 7. GCL gripping assembly for nondestructive GCL field seam evaluation.
Since the force measured will be used to calculate strength, a representative unit must be selected. A minimum gripping plate width of 100 mm should be used. There should be multiple specimens tested in the direction of concern. Test conditions would ideally be 20 ± 2°C, however, the field temperature will govern. The test temperature and site conditions must be reported accordingly.

The following test procedure was decided upon. It is illustrated in Figure 8 and has been temporarily written as a draft GRI test method.

(a) Calibrate and balance the load cell prior to mounting the assembly.
(b) Mount the spike plate assembly to the upper geotextile of the overlying GCL of the seam.
(c) Apply a 2 kg weight to the horizontal portion of the spike plate assembly.
(d) Pull the luggage scale handle to the desired shearing force and maintain it for five seconds.
(e) Record the behavior of the seam during this time interval, e.g., no movement, partial separation, full separation.
(f) Repeat above procedure five times at closely spaced intervals along the GCL seam and report accordingly.
9. SUMMARY AND CONCLUSIONS

The paper describes seven techniques that have been shown to create GCL overlapping panel seams. When seaming GCL’s in the field one should report ambient conditions when the seams were made. The condition of the subgrade beneath the area being seamed should be reported. The method of cleaning of the surfaces should be described and if a rub sheet is used during the seaming process it should be noted. Complete identification of the field seaming system used, including material, methods and seaming rate should be documented. Any unusual conditions with respect to personnel and equipment should be described and documented.

This paper also describes two GCL seam testing protocols; (i) a laboratory destructive shear test to determine the strength of GCL seams, and (ii) a field nondestructive shear test to assess the adequacy of GCL seams to a given or specified value. Both test methods are occasioned due to a few cases of GCL panel separation in the field when an exposed geomembrane was placed above. The entire issue can, of course, be avoided by timely cover of the geomembrane but this is sometimes not expedient or even possible. In such cases, GCL panel seaming is a possible solution to which this paper on destructive and nondestructive testing is directed.

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