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Update on designing with geocomposite drainage layers in landfills

Part 4 of 4: Geocomposite lamination specifications

By Richard Thiel and Dhani Narejo

A geonet drainage geocomposite consists of a polyethylene geonet core to which a geotextile—most commonly composed of polypropylene fibers—is heat-laminated on either on one or both sides of the geonet. There is some question in the industry as to what is an appropriate lamination strength between the geotextile and geonet components. Until recently, the field has supported a minimum average roll value (MARV) peel strength of 90 N/m (0.5 pounds per inch [ppi]) as being adequate to meet internal shear strength requirements. A previous *GFR* article ("Geocomposite drains: what the eye can't see beyond lamination" by Richardson and Boschuk) identified problems that occurred when too high of a lamination strength is specified and manufactured. That article showed how manufacturing attempts to achieve high peel strengths through extra heating, high pressures, and high tension during manufacturing resulted in large decreases in transmissivity and even broken cores on the final product. The article concluded that peel strengths on the order of 90 to 180 N/m (0.5 to 1.0 ppi)—tested per GRI-GC7—should provide adequate bonding and shear strength, and that going beyond that required peel strength was generally unwarranted and detrimental to the product.

Photo 1. Geocomposite internal failure on 2:1 slope (Exposed surface in center of photo is the delaminated geonet core).

This article, which concludes this mini-series on designing with geocomposites for landfills, takes a closer look at the suggested required minimum peel strength for geocomposites. Drawing on information gained from one case history plus laboratory test data (reported in more detail in Thiel and Narejo 2005), this article suggests a model whereby the lamination strength can be evaluated for slope and placement conditions. Also, it provides guidance for writing geocomposite specifications.

In general, the results of these evaluations suggest that the standard of 90 N/m (0.5 ppi) peel strength is too low for applications where internal shear strength is important.

Lamination process

The lamination process used to manufacture geocomposites involves heating the geonet surface with heated wedges or a gas flame, immediately prior to bringing it in contact with the geotextile(s) via two counter-rotating rollers. The lamination mechanism is such that the rollers then push the geotextile fibers into the partially molten polyethylene. When the polyethylene cools the fibers are mechanically locked into the outer surface of geonet. Therefore, although the lamination is thermally induced, the actual lamination strength could be considered mechanical in nature. Low temperatures and pressures during manufacturing will maintain maximum transmissivity but could result in weak lamination strength. Higher temperatures and pressures will increase lamination strength, but will reduce transmissivity and could even lead to damage of the geotextile and/or geonet core if excessive.

Case history

The case-history project required installing a geocomposite drainage layer as part of a landfill cap system on a 40 m long 2(H):1(V) slope. The design required placing a sand layer on top of the geocomposite to act as a filter/separator followed by the overlying vegetative layer. At the point that the sand layer was pushed approximately half way up the slope, the upper geotextile of the geocomposite was observed to tear. Delaminated areas became visible just above areas of the push. Upon returning to the site the next morning, the sand and the top geotextile on the drainage geocomposite had slid down-slope further and the geotextile had torn at the top of the slide (**Photo 1**), though no equipment had been active during the night.

In the authors' opinion, all aspects of the construction and installation procedures were performed in accordance with the specifications and standard industry practice. In this case, the sand was end-dumped at the toe of the slope and pushed up from the bottom of the slope using a Caterpillar® D6 low-ground-pressure (LGP) dozer, in accordance with the vast majority of construction projects in which soil is spread over geosynthetics.

Since the failure occurred internally within the geocomposite, one obvious question is whether the geocomposite lamination strength met the standard product specifications, or if it was non-conforming in any way. The relevant specification in this regard is the peel strength between the geotextile and geonet components of the geocomposite. The manufacturer's and project specification for this material was for an average peel

Figure 1. Plan view of dozer pushing sand up slope on top of geocomposite.

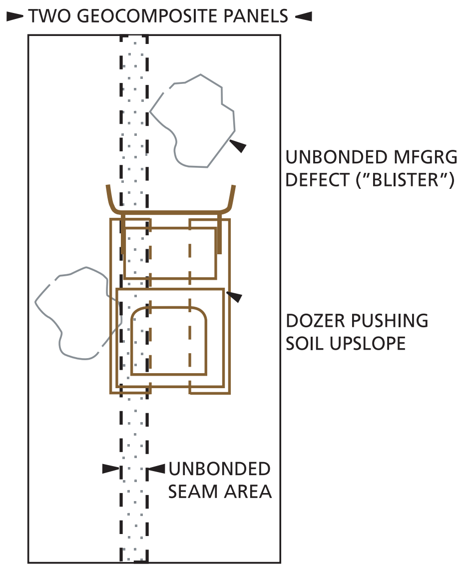
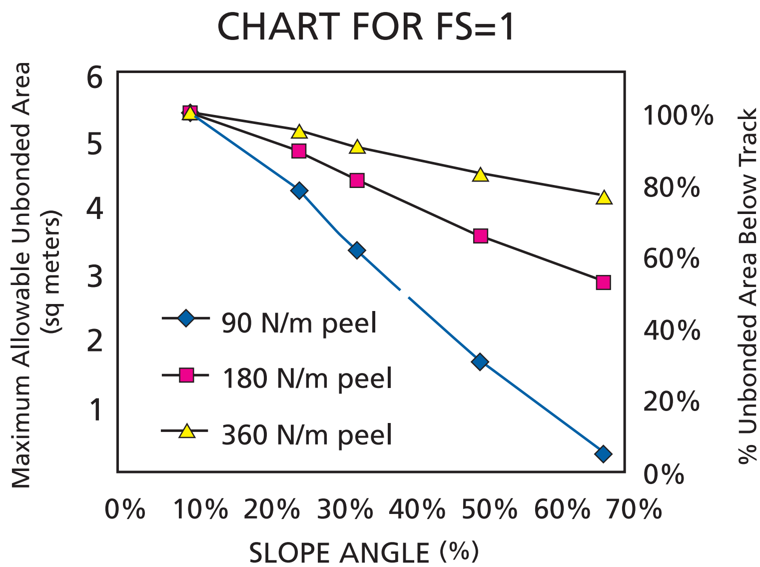


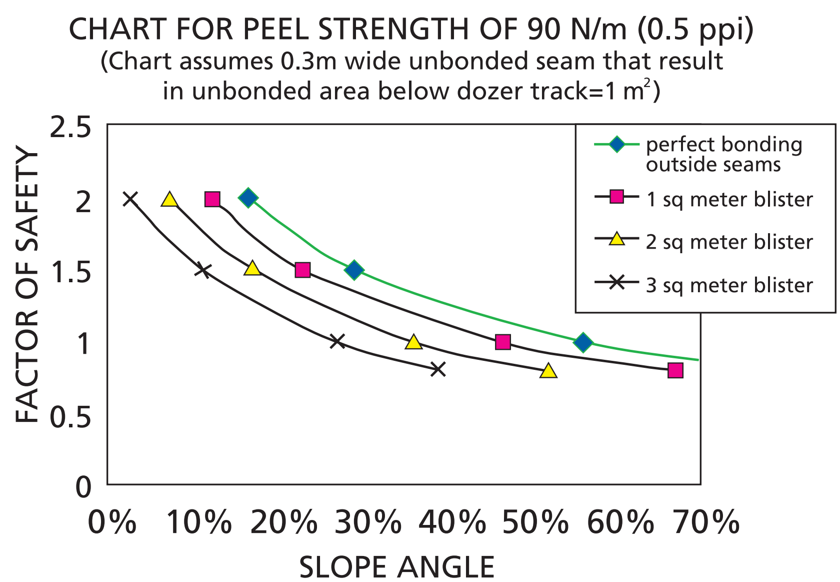
Figure 2. Maximum allowable unbonded area in geocomposite lamination below dozer track area for FS = 1.



strength of 180 N/m (1.0 pound per inch[ppi]). Conformance testing conducted by a third-party laboratory on samples taken from every 10,000 m^2 of the project's material indicated that the material met the specifications.

However, on-site inspection of the material as it was being deployed revealed a large variance in the degree of bonding between the geonet and geotextiles. Some areas were very difficult to peel apart, other areas were easier. Many areas of the panels displayed outright delamination between the geotextile and the geonet, which we termed "blisters." Many of the delaminated areas were relatively small, but some were significantly larger (e.g., greater than 1 m^2). Furthermore, the material supplied for the case history was manufactured with 0.3 m unbonded edges, such that a butted seam would result in a continuous unbonded zone 0.6 m wide from top to bottom of slope.

Figure 3. Chart for peel strength of 90 N/m.



The influence of construction equipment

So what happens on a slope as the dozer is working? There are cyclic impact-shear forces as the dozer accelerates and decelerates. If some of the area is not able to resist the full shear load, it transfers it to adjacent areas. The mobilization of the shear forces induces some shear strain, which is greatest in the areas where the shear strength is least (or zero). Thus, the bonded areas immediately adjacent to un-bonded areas will experience disproportionately higher shear stresses than the other bonded areas that are more uniform and remote from the unbonded areas. If the bond strength immediately adjacent to the unbonded area is weak, it may fail and become unbonded itself. Each pass of the dozer over this area may promote additional unbonding; thus, *progressive delamination* of the geocomposite may occur.

To set up the problem, imagine a plan view of a dozer pushing soil up a slope on top of a geocomposite (**Figure 1**). Potential unbonded areas below the footprint of the dozer could include the unbonded seam zone, plus any unbonded "blisters" that are of random size and location.

Strength and force evaluation

The question: What level of bond strength is necessary to prevent progressive delamination? To help answer this question, Thiel and Narejo (2005) describe shear-adhesion test data, plus direct shear test results provided by TRI Laboratories of Austin, Texas, that indicates that the amount of shear adhesion given by thermal bonding ranges from 0.11 to 0.15 kPa per N/m of peel (417–560 psf per ppi) under the low normal load range of veneer covers. For purposes of further evaluation in this article, the conservative lower end of the data was assumed to govern the relationship; that is, 0.11 kPa per N/m of peel (417 psf per ppi). Thus, a material that has 360 N/m (2 ppi) peel strength might be assumed to have 40 kPa (833 psf) adhesive shear strength due to the thermally-induced bonding.

In addition to the adhesion lent by thermally-induced bonding, a frictional component of the shear strength would be proportional to the normal load. At this point, it is not understood how the frictional shear strength is mobilized relative to the adhesive shear strength as the interface is deformed. For purposes of evaluation in this article of a veneer soil layer being placed on top of geocomposites on slopes, where the normal load under the cover soil and construction equipment might be on the order of 14–20 kPa (300–400 psf), we have assumed that the bonded shear strength is the sum of the adhesion at the rate of 0.11 kPa per N/m of peel plus a friction parameter of 20°, and that the unbonded shear strength is solely due to a friction parameter of 20°. The selection of 20° friction is taken from the TRI data (Thiel and Narejo 2005) for the secant friction angle of the large-displacement shear strength up to a normal stress of 240 kPa.

Regarding construction equipment loading, for purposes of this evaluation we will take as a constant that a specific size dozer is placing a 0.3 m (1 foot) thick layer of soil on a slope, pushing soil from the bottom to the top. Assume the unit weight of the soil is 1762 kg/m^3 (110 pcf). We assume the weight of the dozer is 16,330 kg (36,000 lbs.), the tracks are each 3.1 m (10.1 ft.) long and 0.85 m (2.8 ft.) wide. This is typical for a Caterpillar® D5 or D6 wide-track dozer, depending on the model and year of its manufacture. We will also assume that the maximum acceleration or deceleration force of the dozer equipment acting parallel to the slope, either due to sudden acceleration or sudden stopping, is 30% of gravity (Koerner and Soong 1998). Thus an additional force of 0.3 x 16,330 = 4899 kg (0.3 x 36,000 = 10,800 lbs.) would get transmitted in shear parallel to the slope under the footprint of the dozer.

The evaluation will focus on the forces acting under one of the dozer tracks. To approximate the loads acting at the geocomposite interface, which are 0.3 m below the dozer track, we assume that the normal load is distributed at a 1:1 slope away from the edge of the tracks (a very crude approximation of the Boussinesq theory). Therefore, 0.3 m below the bottom of the dozer track, we will assume that the effective footprint area where the dozer forces are acting will be an area of [(3.1 + 2x0.3) x (0.85 + 2x0.3)] = 5.4 m^2.

The factor of safety against sliding under the dozer track can be calculated using limit equilibrium as follows:

Equation 1

$$FS = \frac{\text{Resisting Stress}}{\text{Driving Stress}}$$

Equation 2

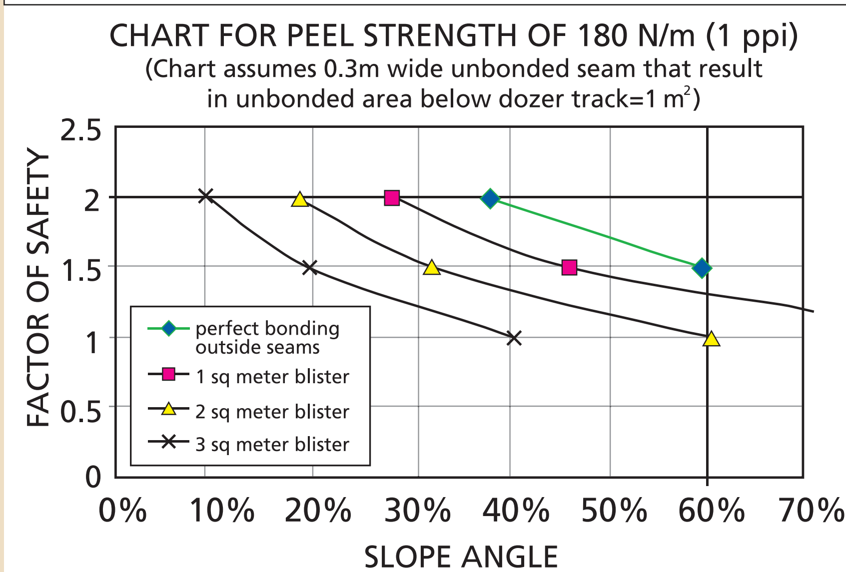
$$FS = \frac{C_a + [(h \times \gamma) + P]\cos\beta \tan\phi}{[(h \times \gamma) + P]\sin\beta + 0.3P}$$

Equation 3

$$P = \frac{W}{2(x + 2h)(\gamma + 2h)}$$

where: C_a = adhesion strength between geotextile and geonet due to lamination (kPa); h = soil depth (m); γ = soil unit weight (kg/m^3); P = vertical stress from dozer at geocomposites surface (kPa);

Figure 4. Chart for peel strength of 180 N/m.



β = slope angle; ϕ = friction between unbonded geotextile and geonet; x = width of track (m); and y = length of track (m); W = weight of the bulldozer (N).

By spreadsheet analysis of **Equation 2**, we could estimate what area below the dozer track needed to be bonded to achieve a balance in shear forces (FS = 1.0). The data was reduced to indicate a maximum allowable unbonded area for different slopes and assumed initial adhesion (peel) strength assuming the dozer weight and dynamic forces described above. **Figure 2** presents the results graphically for a factor of safety of 1.0.

Discussion

As expected, the results depicted in **Figure 2** indicate that the allowable unbonded area decreases with increasing slopes. Moreover, significantly less unbonded area is allowable as ply-adhesion strength decreases. Using **Figure 2** for FS = 1.0, the failure on the 2:1 (50%) slope could have been predicted. **Figure 2** suggests that if the local bonded peel strength were at the current industry-recommended minimum of 90 N/m (0.5 ppi), then an unbonded area as small as 1.7 m^2 (18 $ft.^2$) could result in failure. This amount of unbonded area directly below a dozer track would have occurred simply due to the edge seams!

Assuming a 3.1 m length of dozer track, the unbonded seam area under the track would have been [(3.1+ 2x0.3) x (2x0.3)] = 2.2 m^2. In some cases where the unbonded edge was noted to be 0.45 m, the unbonded area just due to the seam below a dozer track influence could have been as large as [(3.1+ 2x0.3) x (2x0.45)] = 3.3 m^2.

The current state-of-practice and general industry opinion has suggested that a 90 N/m (0.5 ppi) MARV peel strength is adequate for most applications. The results of the current evaluation, as depicted in **Figure 2**, suggest that even on slopes as flat as 4:1 (25%), progressive delamination could occur with equipment operations on the slope if unbonded areas on the order of 4 m^2 exist when the bonded peel strength is only 90 N/m (0.5 ppi).

The model results were graphically reformulated in terms of slope angle versus factor of safety for a given peel strength and standard unbonded seam width of 0.3 m, as well as for various blister sizes, as shown in **Figures 3 and 4**.

Note that if progressive delamination occurred due to equipment forces acting on slopes flatter than 3:1, it is quite likely that it would go unnoticed because the static factor of safety against sliding would still be greater than unity. This could have undesirable effects, however, for both final cover and bottom liner systems. If progressive delamination unknowingly occurred during construction of a final cover system, the cover would have a less robust seismic resistance, even if it were statically stable. If the slopes on which progressive delamination unknowingly occurred were for a landfill bottom liner or heap leach pad, then the future slope stability could be compromised. For example, it is reasonable that a designer could expect the internal geocomposite strength to have a secant friction angle to be much greater than some other interface that has a peak strength of, say, 22° friction under future anticipated normal loads of 500 kPa. If, however, progressive delamination unknowingly occurred during construction of the slope, the actual governing shear strength could be as low as 13° at very high normal loads (Thiel and Narejo 2005) along the unbonded geonet/geotextile interface, resulting in a less robust slope than designed.

The authors do not intend that **Figures 3 and 4** are definitive representations of what actually occurs in the field. At this point, however, we have at least one field failure and some lab testing indicating that this approach may be on the right track. Given the high levels of uncertainty regarding the actual distribution of shear stresses and dynamic forces that might occur in the field, combined with the inherent variability in the heat lamination process, the authors suggest that using a factor of safety greater than unity, such as 1.5, would be prudent to take into account these unknown factors until more is known about the specifics of the failure mechanics.

Recommendations

If lamination of the geotextile to the geonet is only for the convenience of installation, and the long-term integrity and shear strength of the lamination is not important, then it is beneficial to have the lowest peel strength that will just keep the materials together during deployment. The following recommendations apply only to those cases where it is considered important to preserve the bonding and shear strength of the geocomposite and minimize, to the extent possible, the amount of progressive delamination that may occur during construction:

- Slopes steeper than 20% are recommended to have a MARV peel strength of at least 180 N/m (1 ppi). This is a step up from the industry accepted minimum of 90 N/m (0.5 ppi).
- The maximum allowable unbonded width along the edges of the panels should be controlled and specified. The current industry standard is 0.15 m unbonded along each side.
- The maximum allowable size of unbonded areas should be specified and made part of the construction quality assurance (CQA) plan (e.g., maximum 1 m^2 blister, or as specified by the design engineer). For all recommendations regarding maximum allowable unbonded areas, the unbonded zone in the seam area must be accounted for by the designer; thus, a narrower unbonded width would be more favorable to the installation.
- Slopes constructed steeper than 33% (3H:1V) should be done with great care and caution because the slope angle may begin to exceed the residual shear strength of any number of interfaces, including the residual unbonded shear strength of the internal geocomposite interface.
- The maximum allowable size of the construction equipment allowed on the slope should be specified, and is recommended to be no larger than a Caterpillar® D6 with LGP tracks. Smaller equipment will produce less potential for delamination, and should be considered for slopes steeper than 33%.

• Soils should generally be pushed up from the bottom of the slope, and pushing from top-down discouraged except under special circumstances approved by the engineer, and where field tests are performed.
• Greater soil thickness is beneficial because it will spread out the equipment loads further. For example, spreading a 0.45 m thick lift would cause less potential for delamination compared to a 0.3 m thick lift. In general, the minimum lift thickness of soil placed over a geocomposite should not be less than 0.3 m. GFR

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The Designer's Forum column is refereed by Greg Richardson of G.N. Richardson & Associates, www.gnra.com.

See page 45 for more information.

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NOTE: If readers would like to provide feedback to this series of articles, please email them to richard@rthiel.com. If there is enough practical discussion regarding drainage systems in landfills, the authors would be happy to prepare a subsequent commentary article for *GFR*.

Coming in June

The June *GFR*'s Designer's Forum will address problems encountered during the closure of a Maryland landfill that predates our more thorough environmental regulations. Authored by Gregory N. Richardson, Ph.D., P.E., of G.N. Richardson & Associates and William E. Chicca of the Maryland Environmental Service (MES), problems related to the landfill's shape, slopes and original design are described; and a special focus is placed on the not-too-simple task of resolving the situation with current technology and practice.