# Lamination Strength Requirements for Geonet Drainage Geocomposites

Richard Thiel[1] and Dhani Narejo[2]

[1] Richard Thiel, Vice President of Engineering, Vector Engineering, 143E Spring Hill Dr, Grass Valley, CA 95945, phone 530-272-2448, fax 530-272-8533, email richard@rthiel.com
[2] Dhani Narejo, Product Manager – Drainage, GSE Lining Technology, Inc., 19103 Gundle Road, Houston, TX 77073, phone 281-230-5855, email: dnarejo@gseworld.com

## Abstract

There is some question in the industry as to what is an appropriate lamination strength between the geotextile and geonet components of a drainage geocomposite. A recent slippage along this internal interface during soil placement on a 2:1 slope provided evidence that delamination of this interface is a potential issue. Drawing on information gained from this case history plus laboratory test data, this paper suggests a model whereby the lamination strength can be evaluated for slope and placement conditions, and provides guidance for writing geocomposite specifications.

## Introduction

A geonet drainage geocomposite consists of a geonet core to which is heat-laminated to a geotextile either on one or both sides. Geotextiles used are almost invariably nonwoven needlepunched (NW-NP) of either polypropylene (PP) staple fiber or PP continuous filament type. The properties of both the core (such as structure, thickness, mass, etc.) and the geotextile (such as apparent opening size) can be varied to meet site-specific filtration and transmissivity performance requirements. Geonet geocomposites are used extensively as drainage layers for water, leachate and gas conveyance in landfills as well as numerous other applications.

The lamination process used to manufacture geocomposites involves heating the geonet surface immediately prior to bringing it in contact with the geotextile(s) via two counter-rotating rolls as illustrated schematically in Figure 1. The source of heat is either electrically-heated wedges touching the geonet surface or a gas flame hitting the geonet. The lamination mechanism is that the geotextile fibers are then pushed by the rollers 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 actually lamination strength could be considered mechanical in nature. The amount and distribution of heat, the temperature of surroundings, air-circulation, and roller pressure can affect the quality and uniformity of bonding between the geotextile and the geonet. The drainage and shear performance of the geocomposites can also be affected by the lamination process. Low temperatures and pressures 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.

Landfill liner and cover systems almost always consist of large spatial areas with slopes ranging from almost flat to as high as 30% (18 degrees). Even steeper slopes are encountered but to a much lesser extent. The interface-shear strength as well as internal adhesion strength (i.e., lamination strength) of drainage geocomposites is an important consideration for many designs.

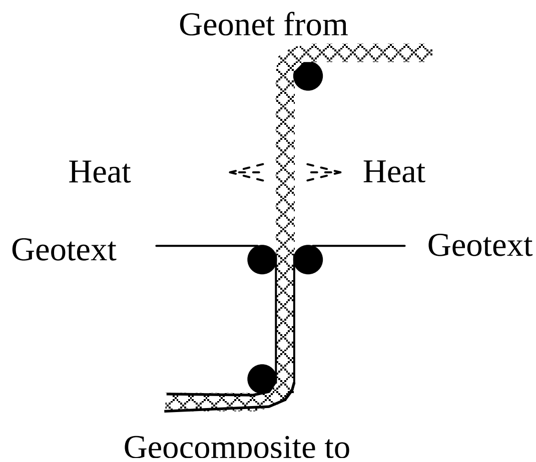


**Figure 1. Schematic of geonet-geotextile lamination process.**

## Case History

The 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. A schematic of the slope involved is presented in Figure 2.

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. Some trenches were hand dug to investigate. Some trenches showed nothing unusual, others exhibited wrinkling and delamination. Construction was continued with more caution, and 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 geocomposites had slid down-slope further and the geotextile had torn at the top of the slide as shown in Figure 3, though no equipment had been active during the night. The following additional observations were made prior to and immediately after the failure:

- Thickness of sand layer ranged from 2 plus feet near the toe of slope to 1.5 feet thick near mid slope.

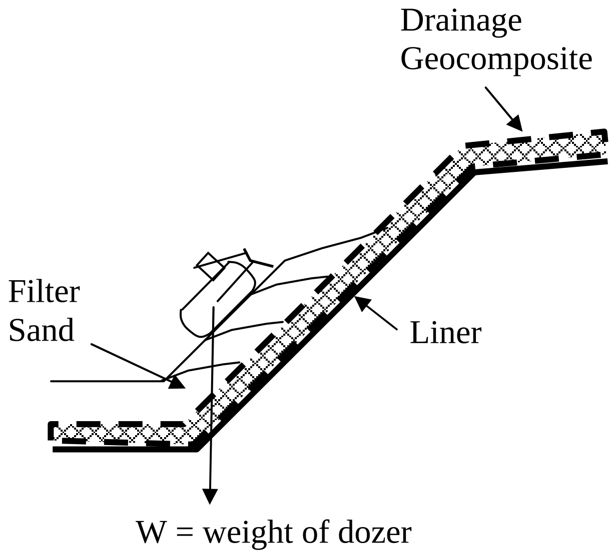


**Figure 2. Placement of sand on the 2:1 slope over geocomposite.**

- As the filter sand was being placed on the composite, the CQA and construction personnel could hear popping sounds coming from the geocomposite. The sound became audible before the first tear was observed, but they did not initially know what the sound meant. Eventually it became apparent that the sound was due to the active delamination of the geotextile from the geonet.

**Figure 3. Geocomposite internal failure on 2:1 slope (Exposed surface in center of photo is the delaminated geonet core).**

- “Excessive” tension in the geocomposite was observed above the sand placement location.
- There were several smaller localized failures while sand was being pushed up on the composite prior to the main failure involving a much larger area.
- As is the industry practice, the geocomposite panels were supplied with the edges unbonded for a distance of 0.3 m (12 inches), and in many cases were 0.45 m.
- The as-delivered geocomposite rolls had several areas of varying dimensions where the geotextile was un-bonded. A review of the manufacturer’s specifications showed that up to 10% un-bonded areas could be expected for that particular product in addition to the edges.

In the author’s 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 heat bonding met the standard product specifications, or if it was nonconforming 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 specification for this material was to have an average peel strength of 179 gm/cm (1.0 pound per inch[ppi]). Conformance testing conducted by a third-party laboratory on samples taken from every 10,000 $m^2$ of material produced for this project indicated that the material supplied for the project met the specifications. Of 6 samples taken, the minimum peel strength measured was 268 g/cm (1.5 ppi), and the average was 465 gm/cm (2.6 ppi).

As noted earlier, on-site inspection of the material as it was being deployed revealed large variance in the degree of bonding between the geonet and geotextiles. Some areas were very difficult to peel apart, and other areas were easier. Some areas of the panels displayed outright delamination between the geotextile and the geonet. The delaminated areas were generally relatively small (e.g. a 0.6m × 0.6m unbonded area, or ‘blister’, was considered insignificant relative to the unbonded area of the seam), but in some cases were large enough for the CQA firm to reject the material.

Given the results of the conformance testing, general observations of the material on the slopes, the context of the nature of geocomposite materials as they are manufactured, and the test results on the samples displaying poor lamination, it could be stated that the geocomposite material generally met and exceeded the specifications relative to heat bonding and peel strength, although it was also noted that the manufactured product contained a high variability in peel strength.

## 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 the greatest in the areas where the shear strength is the 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 un-bonded areas. If the bond strength immediately adjacent to the un-bonded area is weak, it may fail and become un-bonded itself. Each time the dozer passes over this area may promote additional un-bonding, and thus progressive delamination of the geocomposite may occur. The question is: what level of bond strength is necessary to prevent progressive delamination? To help answer this question, additional laboratory testing was performed.

## Laboratory Testing

***Relationship between Ply-Adhesion and Shear-Adhesion***. There are currently the following three tests available for measuring ply-adhesion strength between geotextile and geonet components of a geocomposite: (i) GRI GC7, (ii) ASTM D413, and (iii) ASTM F904. The test methods differ in the speed, size of specimen and interpretation of the test results. The direction of applied force is in a "peel mode" in all three tests as illustrated in Figure 4(a). The data reported in this article was obtained using GRI GC7 as this procedure uses a larger specimen size than the other two procedures (10 cm by 20 cm vs. 2.5 cm by 20 cm). The procedure requires peeling approximately 10 cm (4 inches) of composite test specimen at a speed of 30.5 cm per minute (12 inches per minute). The resulting load vs. distance curve shows a number of peaks and lows as the geotextile is separated from the net. The average of the load taken between 2.5 and 7.5 cm of separation is divided by the width of the test specimen (10 cm) to report an average ply-adhesion strength value in grams/cm or ppi. Further details of the procedure can be found in the GRI standard GC7.

The shear-adhesion test is a non-standard test that loads the geocomposite components in a shear mode as illustrated in Figure 4(c). Chiado and Walker (1993), who reported initial results using this method, used the same test specimen size as a wide width test (ASTM D 4595), i.e., 20 cm x 20 cm (8 inches x 8 inches) and a strain rate of 10% per minute. Koerner (2001) used the same test speed and specimen size as GRI procedure GC 7 (i.e., specimen size = 10 cm by 20 cm and speed = 30.5 cm/minute). One of the objectives of the current study was to develop a relationship between the ply-adhesion strength and shear-adhesion strength. The authors used the same specimen and speed for the shear-adhesion test as was used by Koerner.

The shear-adhesion test being discussed obviously has some potential drawbacks in that the shear stress distribution over the area of the sample is unknown. Stresses may be concentrated toward the leading edge of the sample. Therefore, any correlations and conclusions drawn from the test data may tend more towards index relationships than performance relationships.

In order to develop a relationship between ply-adhesion and shear-adhesion, it is necessary to have a range of samples with different adhesion strengths. Since commercial products are typically around 180-360 gm/cm (1 to 2 ppi) ply-adhesion strength, additional geocomposite samples were manufactured by either varying the amount of heat during the lamination process or by using different strength adhesives in the laboratory. The result was drainage geocomposite samples with ply-adhesion strengths ranging from 35 grams/cm (0.2 ppi) to 900 grams/cm (5 ppi). The type of geonet used in the study was a 5 mm (200 mil) thick geonet manufactured by GSE Lining Technology, Inc. The geotextile used in the geocomposite was a 200 gm/m$^2$ NW-NP type manufactured by GSE Lining Technology, Inc.

Six test specimens – three for ply-adhesion and three for shear-adhesion – were cut from a candidate material sample. The ply-adhesion tests were performed according to GRI method GC 7. To perform shear adhesion tests, approximately 5 cm of the test specimen was delaminated manually at the top and the bottom as illustrated in Figure 4. This left an area of 10 cm by 10 cm to be sheared during the test. The material was placed within opposite grips of a tensile tester as indicated in Figure 4. Notice that the geotextile and geonet are within two different grips and the specimen is loaded so as to separate it in a shear mode. The tests were performed at a speed of 30.5 cm/minute. The failure occurred either by material shear or by the tensile breakage of one of the components. In this article no data of the latter type is included, i.e., only that data where the geocomposite delaminated is considered. The peak de-lamination load was divided by the area of the test specimen to obtain shear-adhesion strength in kPa.

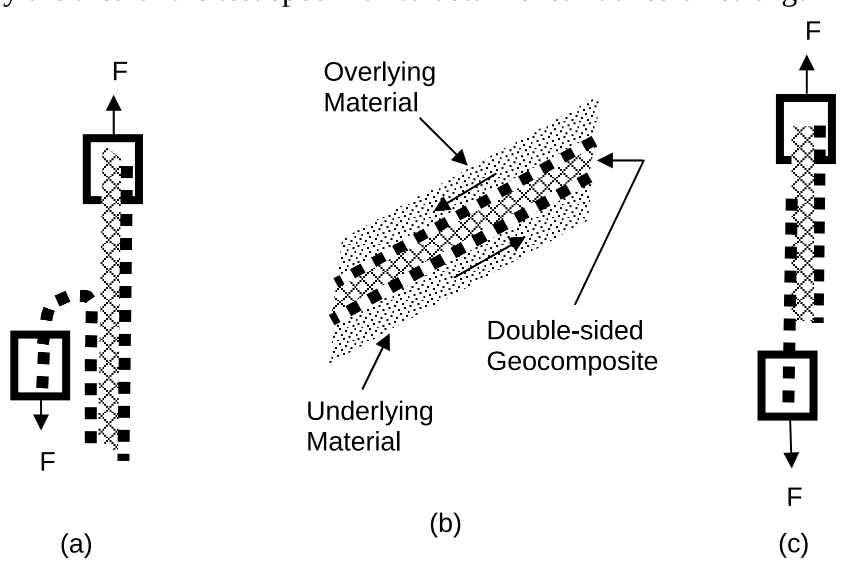


**Figure 4. Schematics of ply-adhesion and shear-adhesion tests.**

The data presented in Figure 5 shows an approximate linear relationship between ply-adhesion strength and shear-adhesion strength. It is obvious from the figure that more samples are needed to better define the relationship. For the materials tested and the test conditions explained earlier, shear-adhesion strength in kPa is found to be approximately equal to 0.11 times ply-adhesion strength in gm/cm:

$$\text{Shear-adhesion (kPa)} = 0.11 \times \text{Ply-adhesion (gm/cm)}$$

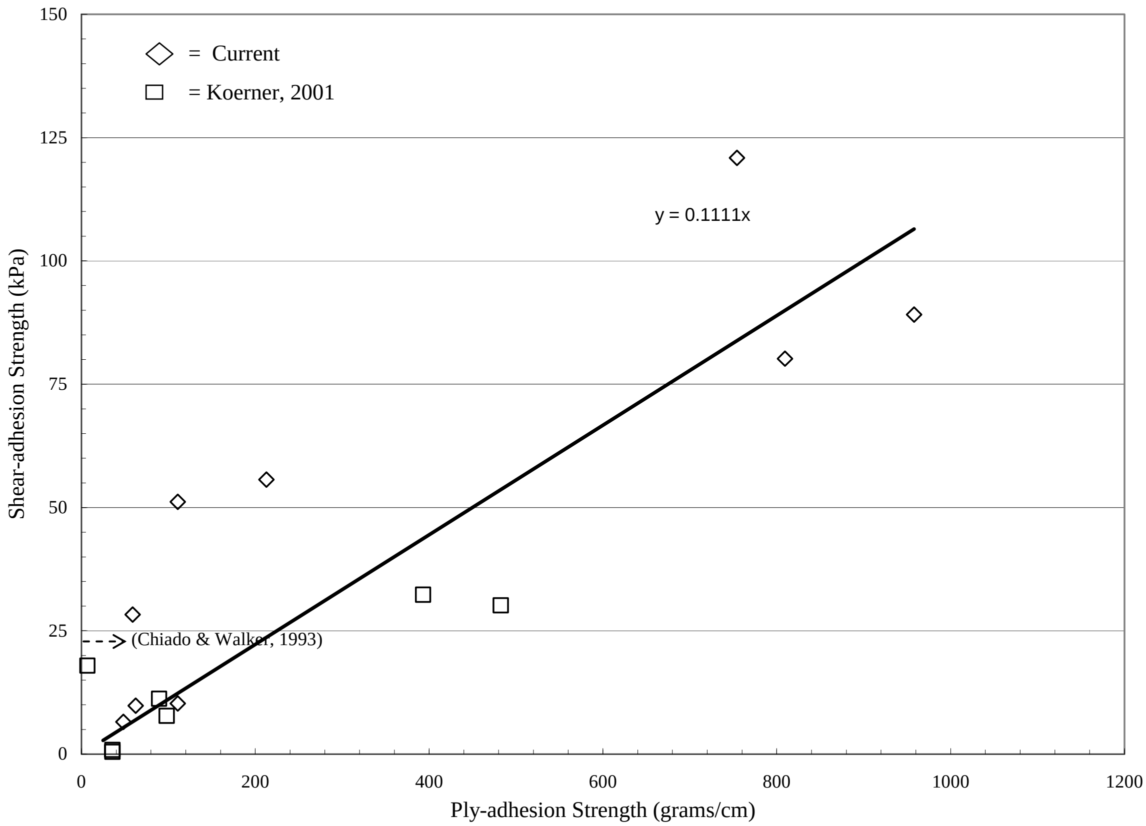


**Figure 5. Relationship between ply-adhesion and shear adhesion tests.**

***Direct Shear Testing***. Direct shear testing might provide a more direct, performance-based method to evaluate the lamination strength. TRI Laboratories provided data to the authors where direct shear tests were conducted on a geocomposite material that had an approximate average peel strength of 360 gm/cm (2 ppi). Their results, presented graphically in Figure 6, were obtained in a manner that tested specifically only the geotextile/geonet interface of concern. Under a 9.6 kPa (200 psf) normal load, the peak shear strength of the bonded geotextile/geonet interface was 54 kPa (1132 psf). The large displacement strength was 7.2 kPa (151 psf), from which it could postulated that 47 kPa (981 psf) of shear adhesion was due to the heat bonding. Since the material provided an index peel strength of 360 gm/cm (2 ppi), we might for the moment suggest that bonded shear adhesion was added in the proportion of 0.13 kPa per gm/cm of peel strength (490 psf per ppi). Using similar calculations for TRI's results under a normal load of 24 kPa (500 psf) indicated that the bonded shear adhesion was added in the proportion of 0.15 kPa per gm/cm of peel strength (560 psf per ppi). Interestingly these results are in approximate agreement with data presented in Figure 5 based on non-standard shear-adhesion testing (0.11 kPa per gm/cm) where there was zero normal load.

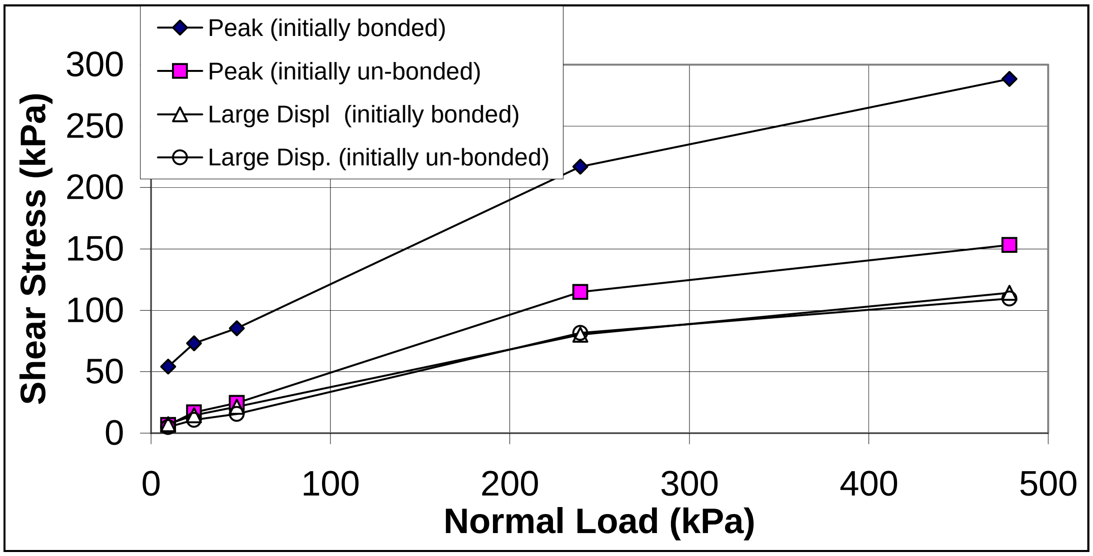


**Figure 6. Internal Shear Test Results for Bonded and Unbonded Geocomposites (compliments TRI Laboratories).**

Thus, from the new shear-adhesion test data reported in this paper, plus the direct shear tests performed by TRI, we have indications that the amount of shear adhesion given by thermal bonding ranges from 0.11 to 0.15 kPa per gm/cm of peel (417 to 560 psf per ppi) under the low normal load range of veneer covers. For purposes of further evaluation in this paper, we assumed the conservative lower end of the data governs the relationship, that is, 0.11 kPa per gm/cm of peel (417 psf per ppi). Thus a material that has 360 gm/cm (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, there is also a frictional component of the shear strength that would be proportional to the normal load. The TRI tests of the unbonded interface between geotextile and geonet shown in Figure 6 indicate that the shear strength envelope is substantial curved, with secant friction angles on the order of 30° for normal loads in the 10 kPa (200 psf) range, dropping to 13° under a normal load of 500 kPa (10,000 psf). These values are based on very limited testing, and could vary substantially depending on the specific materials being tested.

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 paper 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 conservatively assumed that the bonded shear strength is the sum of the adhesion at the rate of 0.11 kPa per gm/cm 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 for the secant friction angle of the large-displacement shear strength up to a normal stress of 240 kPa.

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 meter (10.1 feet) long and 0.85 meter (2.8 feet) wide. This is typical for a Caterpillar® D5 or D6 wide-track dozer, depending on the model and year of its manufacturer. 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 × 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 0.3m 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, 0.3m 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 + 2×0.3) × (0.85 + 2×0.3)] = 5.4 m$^2$.

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

$$\boldsymbol{FS} = \frac{\textbf{Resisting Stress}}{\textbf{Driving Stress}} \tag{1}$$

$$\boldsymbol{FS} = \frac{\boldsymbol{C_a} + [(\boldsymbol{h}\times\boldsymbol{\gamma}) + \boldsymbol{P}]\cos\boldsymbol{\beta}\tan\boldsymbol{\phi}}{[(\boldsymbol{h}\times\boldsymbol{\gamma}) + \boldsymbol{P}]\sin\boldsymbol{\beta} + 0.3\boldsymbol{P}} \tag{2}$$

$$\boldsymbol{P} = \frac{\boldsymbol{W}}{2(\boldsymbol{x}+2\boldsymbol{h})(\boldsymbol{y}+2\boldsymbol{h})} \tag{3}$$

where: $C_a$ = adhesion strength between geotextile and geonet due to lamination (kPa); $h$=soil depth (m); $\gamma$ = soil unit weight (kg/m$^3$); $P$ = vertical stress from dozer at geocomposites surface (kPa); $\beta$ = slope angle; $\phi$ = friction between unbonded geotextile and geonet; $x$ = width of track (m); and $y$ = length of track (m).

By spreadsheet analysis of Equation 2, and varying the amount of areas assumed to be bonded vs. un-bonded below the dozer track footprint, we could estimate what percentage of the area below the dozer track needed to be bonded to achieve a balance in shear forces (FS = 1.0). We also performed the calculation so that the factor of safety against progressive delamination would be 1.5. 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. Figures 7 and 8 presents the results graphically for factors of safety of 1.0 and 1.5. The intent of this exercise was to use the results to help develop guidance in preparing specifications regarding geocomposite material properties and installation requirements.

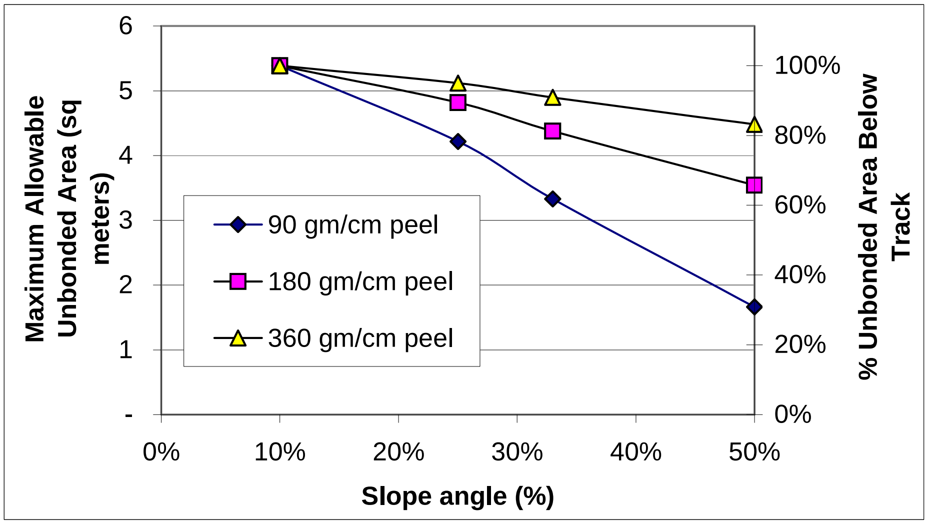


**Figure 7. Maximum allowable unbonded area in geocomposite lamination below dozer track area for FS = 1.**

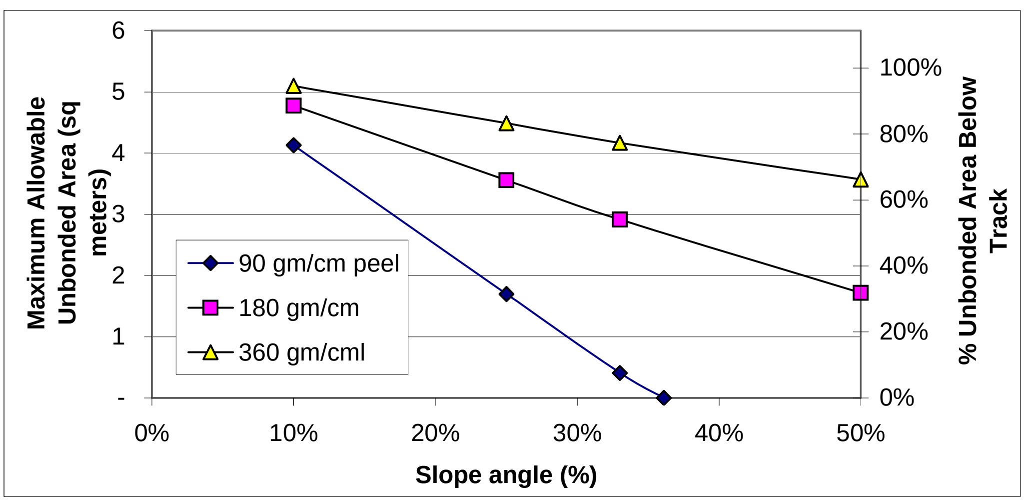


**Figure 8. Maximum allowable unbonded area in geocomposite lamination below dozer track area for FS = 1.5.**

**Discussion**

As expected, the results depicted in Figures 7 and 8 indicate that the allowable unbonded area decreases with increasing slopes. Moreover, significantly less unbonded area is allowable as ply-adhesion strength decreases. Using Figure 7 for FS = 1.0, the failure on the 2:1 (50%) slope could have been predicted. Figure 7 suggests that if the local bonded peel strength were at the current industry-recommended minimum of 90 gm/cm (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 influence would have been $[(3.1+ 2\times0.3)\times(2\times0.3)] = 2.2$ $m^2$. 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 $[(3.1+ 2\times0.3) \times (2\times0.45)] = 3.3$ $m^2$.

The current state-of-practice and general industry opinion has suggested that a 90 gm/cm (0.5 ppi) MARV peel strength is adequate for most applications. The results of the current evaluation, as depicted in Figure 7, 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 gm/cm (0.5 ppi). Furthermore, if a factor of safety of 1.5 against delamination is desired during construction, then Figure 8 suggests that 90 gm/cm peel material would not be appropriate for any slopes 4:1 or steeper simply because the typical unbonded seam area of 1.7 $m^2$ would exceed the allowable unbonded area shown on that graph. Figures 7 and 8 suggest that even geocomposite material with a peel strength of 360 gm/cm (2 ppi) has limitations for allowable unbonded areas on steep slopes. Smaller construction equipment, narrow unbonded seam edges, or higher peel strengths could be used to improve the factor of safety against progressive delamination.

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 (secant friction angle from Figure 6 for large-displacement shear strength at normal load of 480 kPa) along the unbonded geonet/geotextile interface, resulting in a less robust slope than designed.

The authors do not intend that Figures 7 and 8 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, as suggested by Figure 8, would be prudent to take into account these unknown factors until more in 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:

- The maximum allowable unbonded width along the edges of the panels should be controlled and specified. The current industry standard is 0.3 m unbonded along each side.
- The maximum allowable size of unbonded areas should be specified and made part of the CQA plan. For all recommendations regarding maximum allowable unbonded areas, the unbonded zone in the seam area must be included, and thus a narrower unbonded width would be more favorable to the installation. In making calculations of unbonded areas, the calculation shall be made for an assumed dozer track influence area of 3.6m long × 1.5m wide, translated or rotated in any orientation. For example, if a seam is 30m (100 ft) long and the unbonded width along the seam is 0.3 m (one ft) wide, and next to the seam there is a "blister" with dimensions of 0.6m × 0.6m, then the calculation of unbonded area for purposes of potential delamination is $(1.8\times2)\times(0.3\times2) + (0.6\times0.6) = 2.5\ m^2\ (28\ ft^2)$.
- Slopes steeper than 20% are recommended to have a MARV peel strength of at least 180 gm/cm (1 ppi).
- If a MARV peel strength of 90 gm/cm (0.5 ppi) is used for slopes between 10% and 20%, the maximum allowable unbonded area is recommended to be specified less than 2 $m^2$ (20 $ft^2$). Note that with 0.3m unbonded seam edges on the rolls, having the seam edges overlapped approximately 6 cm would barely meet this criteria, not allowing for any additional 'blisters'.
- If a MARV peel strength of 180 gm/cm (1 ppi) is specified, then the maximum allowable unbonded area for slopes between 20% (5:1) and 33% (3:1) is recommended to be 3 $m^2$ (30 $ft^2$).
- Slopes constructed steeper than 33% 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% (3:1).
- Materials 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.

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