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Geosynthetics

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An example of a solution to the problem of high-stress rollover for biplanar geonets

New round-strand innovation in biplanar geonet structure

By Dhani Narejo and Mengjia Li

Background

The primary design property of drainage geocomposites is flow rate or transmissivity, which is measured in the laboratory according to ASTM D4716. The laboratory value is used to calculate the allowable flow rate according to GRI procedure GC8. The compressive creep of the polymeric core of the drainage geocomposite (i.e., geonet) along with long-term clogging must be considered when calculating the allowable flow rate. The expression that considers all these variables is as follows (per GRI GC8):

$$q_{all} = \frac{q_{100}}{RF_{cr} \, x RF_{cc} \, x \, RF_{bc}} \tag{1}$$

In **Equation 1**, q_{all} = allowable flow rate (ft^3/sec-ft), q_{100} = flow rate from a 100-hour test (ft^3/sec-ft), RF_{cr} = reduction factor for creep, RF_{cc} = reduction factor for chemical clogging, and RF_{bc} = reduction factor for biological clogging. GRI GC8 presents default values for RF_{bc} and RF_{cc}, while RF_{cr} is product specific and must be obtained from actual tests.

Since the late 1990s, there has been much interest in the creep testing of geonets and many articles have been published on this topic (for example, Thornton et al., 2000 and Narejo and Allen, 2004). Compressive creep is now recognized as an important factor in the selection of geonets for a specific project. Manufacturers are increasingly using creep data to demonstrate the performance advantage of their products.

Giroud et al. (2000) derived **Equation 2** to demonstrate the effect of thickness on the transmissivity of a geonet. The ratio of transmissivity after (θ_2) and before (θ_1) compression is a cubic function of the thickness after (t_2) and before (t_1) compression.

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$$\frac{\theta_2}{\theta_1} = \left[1 - \frac{\left(1 - \frac{t_2}{t_1}\right)}{n_1}\right]^3 \qquad (2)$$

For example, for a geonet with a typical original porosity (n_1) of 0.7, a 20% thickness reduction will lead to a 64% reduction in its transmissivity. Thus, it is critical not only to determine the creep reduction factor of a geonet under the long-term compressive load, but also to calculate the reduction in thickness.

Creep and structural stability of geonets

Most geonets have unique structural features that influence their stress-strain and creep behavior.

For conventional biplanar geonets the compressive stress-strain relationship is typically of the type presented in **Figure 1**. The peak short-term compressive stress is often referred to as layover, rollover, or structural collapse and depends primarily on the shape of the strands. This value is the peak compressive strength, or simply the compressive strength, of the geonet and varies from 5,000psf to 30,000psf for materials available in the market.

It was mentioned in the previous section that a creep reduction factor (RF_{cr}) for the drainage core is required for calculating the allowable flow rate. Creep tests are performed in the laboratory under constant compressive stress according to conventional creep or accelerated creep methods (Narejo and Allen, 2004). The stress in a creep test is only a fraction of the strength of the material tested.

For example, for the 22,000psf strength in **Figure 1**, the creep test may be set up at 10% (2,200psf), 25% (5,500psf), 50% (11,000psf), and so on, of the ultimate compressive strength. A graph with test results is expected to be of the type presented in **Figure 2**. Once the creep curve is established, the linear relationship on a semi-log scale is used to calculate a creep reduction factor, RF_{cr}, which can then be used in **Equation 1** to calculate allowable flow rate (Giroud et al., 2000).

To use this procedure, it is essential that the relationship between strain (or thickness retained) and time is linear, as is the case in **Figure 2**. More often, however, the creep test on conventional biplanar geonets results in creep curves of the type illustrated in **Figure 3**. This is especially the case when the test is performed without any historical data on the material being evaluated.

For the test in curve A, there is an abrupt drop in thickness at about an hour into the test while the same happens for curve B at about 800 hours into the test. The sudden change in the curve represents a rollover of the strands or structural collapse of the geonet, which is essentially the same as in a compression test **(see Figure 1)**.

TABLE 1 Specifications for the materials included in the test program

PROPERTY	TEST METHOD	VALUE	QUALIFIER
Polymer	—	HDPE	—
Thickness	ASTM D5199	200-330 mils	Range
Density	ASTM D1505	0.94 g/cm^3	Typical
Tensile Strength	ASTM D7179	30-85 lbs/in	Range

Although it is not possible to calculate a creep reduction factor from the data in **Figure 3**, the information can be used to set up the next test. For example, if curve B represents a test at 50% of the strength, the next test may be performed at 40% of the strength or lower.

The senior author has performed many tests of this type on many conventional biplanar geonets of different types. **Table 1** presents a few property values for the materials included in the test program. The resulting data is reproduced here in **Figure 4** (page 22) from a paper (Narejo and Allen, 2010) presented at the 9th International Conference on Geosynthetics in Brazil (May 2010). The best-fit equation to the data in the figure is as follows:

$$\frac{P}{S} = -\,0.028 \cdot \ln(t) + 0.68 \qquad (3)$$

Where P = applied compressive stress on geonet (kPa or PSF), S = peak short-term compressive strength (kPa or PSF) and t = time to structural collapse (hours). The above empirical relationship is used to set up creep tests on biplanar geonets so the layover does not occur prematurely, i.e., during a test before 10,000 hours are complete.

For example, suppose that the strength (S) of a geonet is 15,000psf. A 10,000-hour conventional creep test is scheduled on this geonet. The laboratory performing the test would like to prevent a layover of the geonet during the duration of this test. Substitute t in **Equation 3** with 10,000 hours. The result is stress of 6,330psf for the geonet considered for this test.

A design engineer would like this geonet to not fail during the active life of the landfill, which is estimated to be five years. Substituting t with 43,800 hours (five years) in **Equation 3** results in stress of 5,711psf.

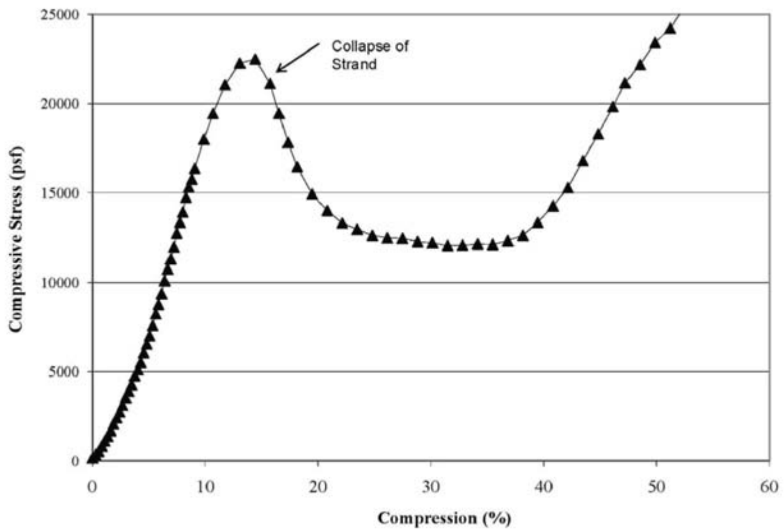


FIGURE 1 Compressive stress-strain behavior of biplanar geonets

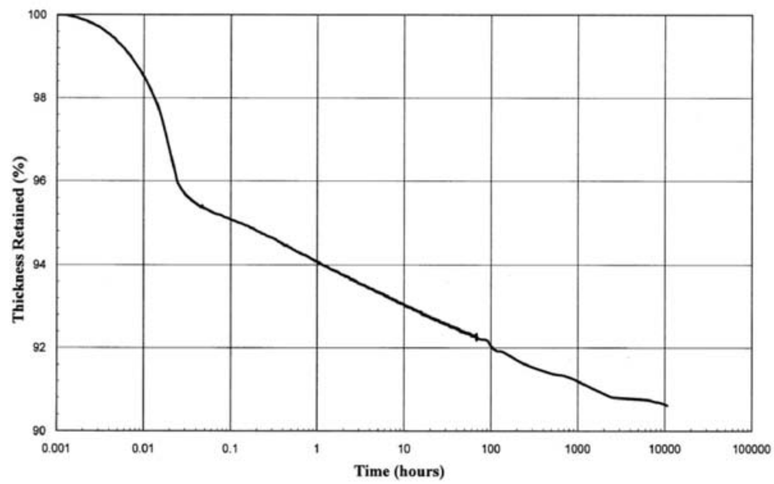


FIGURE 2 Example of a creep curve for a biplanar geonet

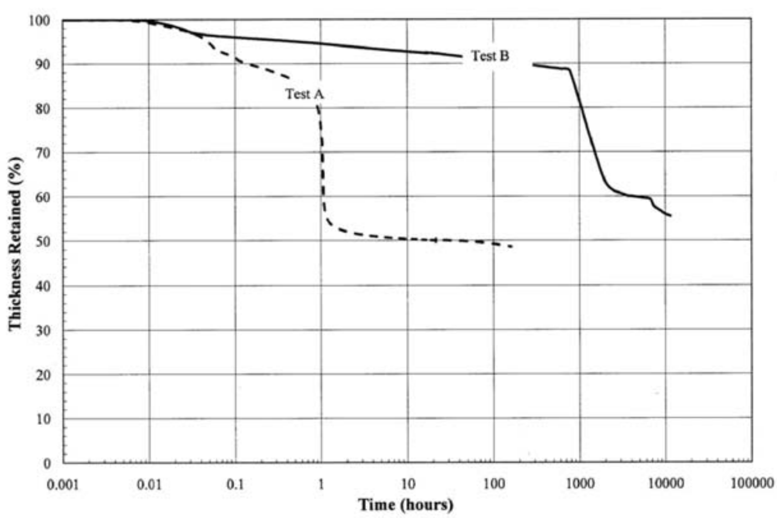


FIGURE 3 Creep failure in biplanar geonets

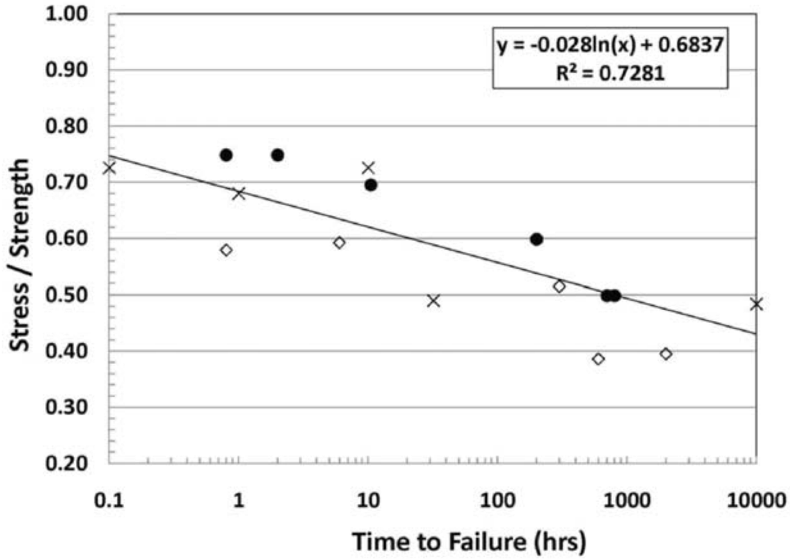
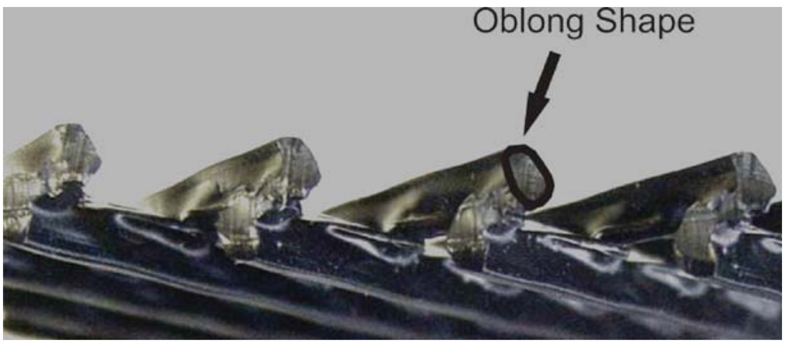
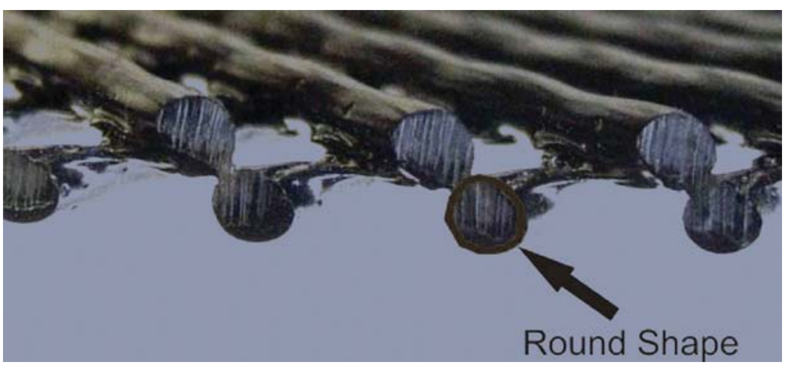


FIGURE 4 Time to failure obtained from creep tests on many biplanar geonets (Reference Narejo and Allen, 9th International Conference on Geosynthetics, Brazil, 2010)

FIGURE 5 Shape of geonet strands in biplanar geonets



(a) Standard biplanar geonet with oblong shaped strands



(b) Round strand biplanar geonet

Innovation in the structure of biplanar geonets

It is clear from **Figure 4** and **Equation 3** that projects with high overburden stress and long design life require the use of geonets with higher compression strength.

The maximum strength of standard biplanar geonets is around 25,000psf and can be increased to 30,000psf with some adjustments in the manufacturing process. There are many landfill cells in the U.S. where overburden stress exceeds 15,000psf and active design life can be 30 years.

The creep data we have accumulated points to a concern with the structural stability of the geonet at high overburden stress and long design life. Fortunately, many alternative materials are available with little or no impact on the cost.

Figure 5(a) presents the traditional oblong-shaped structure of biplanar geonets. In **Figure 5(b),** the shape of the strands was changed by changing the die through which the strands are extruded. The new shape is approximately rounded as opposed to the oblong shape of the conventional biplanar geonets.

The stress-strain behavior in compression for the round-strand geonet is presented in **Figure 6** (page 25). The stress-strain curve indicates a small change in slope at around 55,000psf but nothing of the nature in **Figure 1**.

It is neither collapse of the strands nor a sudden flattening. Essentially, the rollover of the strands that is typical of conventional biplanar geonets has been eliminated with the new shape of the strands. Not surprisingly, the creep curve in **Figure 7** (page 25) for the round strand product is linear on a semi-log scale showing no layover even at 25,000psf.

Designing for structural capacity

This section relates mostly to conventional oblong-strand biplanar geonets, for which a procedure is presented to prevent a structural failure.

For low-stress applications, such as landfill covers, the overburden stress is much lower than the strength of the most commercially available products, including most biplanar products. Therefore, the strength of the material or creep is not an important design consideration.

For landfill liner systems, strength or structural design should be performed explicitly in addition to the hydraulic design. The structural design of geonets is equivalent to the structural design of plastic pipes.

Although GRI procedure GC8 includes the effect of creep on allowable flow rate, it does not prevent a structural collapse of the geonet structure under load. In fact, a structural capacity design is necessary to ensure that the creep reduction factor used in **Equation 1** is valid for the product and site under consideration.

Moreover, although the hydraulic design may indicate adequate flow rate for the specific project, the strength of the material may be too low to prevent structural failure. **Equation 3** can also be expressed as:

$$P = S\left[0.68 - 0.028 \cdot \ln(t)\right]$$

One or more partial reduction factors are required to calculate the allowable pressure on a geonet based on the above empirical equation. An interim reduction factor, RF_{im}, is proposed until additional data on this topic is available. With the reduction factor, the above equation can be written as:

$$P_{allow} = \frac{S}{RF_{im}}\left[0.68 - 0.028 \cdot \ln(t)\right] \quad (4)$$

A value of 1.2 is proposed for the interim reduction factor. Required stress can be calculated from the following equation:

$$P_{req} = \gamma\ x\ h \quad (5)$$

Where, P_{req}= design stress (psf), γ = waste density (pcf), and h = height of waste (ft). A factor of safety against structural failure of a conventional oblong-strand biplanar geonet can then be calculated by comparing **Equations 4** and **5**.

$$FS = \frac{P_{allow}}{P_{req}} \quad (6)$$

A factor safety of 1.5 is recommended in **Equation 6**, based on the authors' understanding of the uncertainty involved in these calculations. The authors also note that a factor of safety of 2 is typically used in drainage calculations where there is significantly more uncertainty than in the structural design presented in this article.

For a specific project, several biplanar geonets can be evaluated until an adequate factor of safety against structural failure is achieved. In those cases, when it is not possible to achieve the required factor of safety with conventional oblong-strand biplanar geonets, another type of structure or round strand biplanar geonet should be considered. The procedure is demonstrated in the examples below.

Examples of calculations

Example 1— A landfill cell is being designed with a maximum waste height of 45ft. The density of the waste is estimated to be 75lbs/ft^3. The active life of the cell is five years, at which time the cell is scheduled to receive a final cover.

After the cover liner system, the leachate generation is expected to be negligible. A conventional biplanar geonet with a compression strength of 20,000psf is considered as a leak-detection material. Determine a factor of safety against structural failure of this geonet.

Solution— The following information has been given in the problem:

- cell height = h = 45ft
- waste density = γ = 75lbs/ft^3
- design life = t =5 years = 43,800 hours
- compression strength = S = 20,000psf

Substituting the values in **Equation 4** with RF_{im} being 1.2, one obtains P_{allow} of 6,345psf. The required strength is obtained from **Equation 5** as 3,375psf. Then the factor of safety is obtained from **Equation 6** as 1.9, which is acceptable as it is greater than 1.5.

Then the next step in the design process would be to determine a factor of safety for flow rate based on GRI GC8 and the site-specific design information. A creep reduction factor will be required for use in **Equation 1** that can be obtained from actual creep tests.

Example 2— A landfill cell is designed with a maximum waste height of 200ft. The waste density in the cell is estimated to be 70lbs/ft^3. The active life of the cell is 20 years, at which time the cell will be closed with a final cover system.

Within five years of final cover, the leachate generation within the cell is estimated to drop to zero for all practical purposes. A standard biplanar geonet with peak strength of 25,000psf is considered. Calculate a factor of safety against structural failure of this geonet.

Solution— The following information has been given in the problem:

- waste height = h = 200ft
- waste density = γ = 70lbs/ft^3
- design life = t = 25 years = 219,000 hours
- compression strength = S = 25,000psf

Substituting the values in **Equation 4** with RF_{im} equal to 1.2, one obtains P_{allow} of 8,392psf. Required stress is calculated from **Equation 5** to be 14,000psf.

By substituting the values of the allowable and required stress in **Equation 6**, we

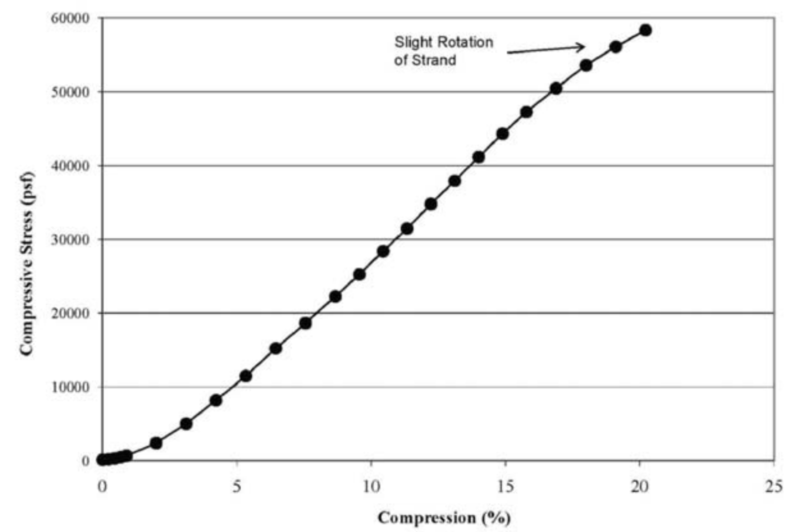


FIGURE 6 Compressive stress-strain curve for modified round-strand biplanar geonet

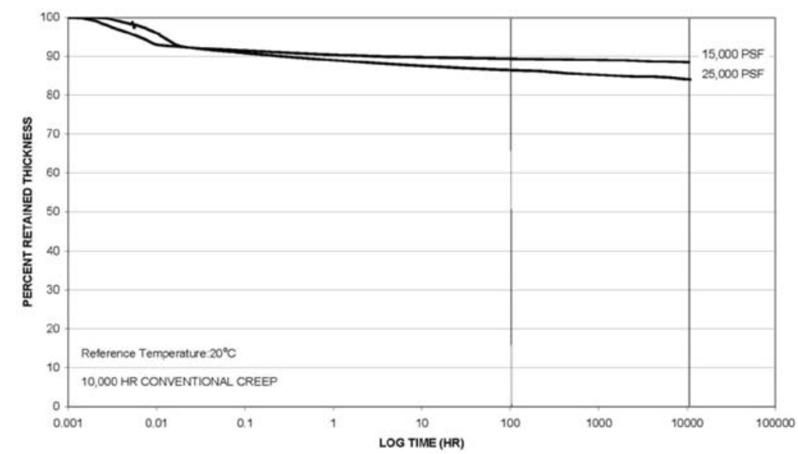


FIGURE 7 Creep behavior of modified round-strand biplanar geonet

obtain a factor of safety of 0.59 against the structural failure of the geonet. As such, the geonet under consideration is not adequate.

Alternatively, the geonet in **Figure 5(b)** with round strand or another material with high compression strength can be considered for this project.

Limitations of the structural design procedure

The procedure for calculating the factor of safety against structural failure of conventional oblong-strand biplanar geonets presented in previous sections is based on laboratory creep testing.

During the creep tests, the geonet test specimen is sandwiched between plates; in the field, the boundary conditions can be geotextile (bonded or unbonded), geomembrane (smooth or textured), and soil (cohesive or noncohesive with a filter geotextile). The steel-geonet boundary conditions represent the geonet-geomembrane interface very well. This interface is not common in landfill base liner systems.

A new type of round-strand biplanar geonet shows no rollover of the strands.

To the author's knowledge, there has been no published information on the effect of the boundary conditions on the creep of geonets. Creep tests in isolation (between steel plates) are simple to perform and are often the only tests for which any data is available.

It is possible that the soil-geocomposite interface would prevent the layover of the strands. In that case the procedure presented here is conservative but may significantly underpredict the structural capacity of conventional biplanar geonets.

Until additional information on the effect of the boundary conditions is available, the procedure presented here should be used as a tool to gain understanding of the nature of the geonets rather than selection or rejection of a particular geonet.

The procedure illustrates well that the long-term structural capacity of conventional biplanar geonets is significantly lower than the peak strength. Designing these materials close to their peak strength may lead to a strand layover during the service life.

Summary

Conventional biplanar geonets have strands that are oblong shaped. In a compression test, the oblong strands result in a stress-strain curve with a distinct peak. At this peak, there is a sudden collapse of the strands followed by significant strain or compression with constant stress or even with a drop in stress.

The stress at which rollover occurs is known as peak strength or rollover strength of biplanar geonets. Not all geonets have the rollover of the strands. In fact, a new type of round-strand biplanar geonet shows no rollover of the strands.

A procedure for structural design of conventional oblong-strand biplanar geonets was presented in this article. This procedure was based on creep testing of biplanar geonets.

The use of this procedure ensures that the maximum stress on a biplanar geonet is lower than the stress at which structural failure would occur over the design life of the drainage geocomposite. The creep data shows that the allowable compressive stress on an oblong-strand biplanar geonet should be much lower than its peak compressive strength.

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