Effect of sustained loading on structural stability of biplanar geonets

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ABSTRACT: A method for preventing the structural failure of biplanar geonets during their service life is presented. This method is based on compression strength and compression creep testing of biplanar geonets in a laboratory. Compression strength of many biplanar geonet samples was determined according to ASTM D 6364. Several compression creep tests were then performed on each sample of geonet by varying the applied stress. The ratio between the test stress and compression strength was found to have a linear relationship with the time-to-failure on a semi-log scale. The resulting best-fit equation was then used to propose a method for calculating a factor of safety against structural failure. The paper proposes the use of this method along with the hydraulic design to prevent structural failure of geonets over the service life of a project.

1 INTRODUCTION

Drainage geocomposites are commonly used as planar drainage materials in large and complex structures. Some of the major market segments where drainage geocomposites are routinely used include mining, landfills, buildings and highways. The basis of the design in most cases is the flow rate or transmissivity measured in the laboratory according to ASTM D 4716 or another equivalent procedure. The procedure for the design typically involves a comparison of the allowable flow rate value with the required flow rate value to calculate a factor of safety for drainage. Often a factor of safety of 1.5 for drainage is considered adequate but a value of 2 or 3 is also used by designers.

All geonets have a specific structure that is based on particular style, product grade and manufacturing process. Most geonets are quite compressible due not only to the structure but also due to polymers – base material from which all geonets are manufactured. Some geonets collapse at a certain normal compressive stress. When the stress in the field is very low, as in landfill covers and green roofs, there is little concern with the strength of the drainage core of the geocomposites. On the other hand, when the stress is high, as in landfill liner systems and heap leach pads, the applied load can cause a sudden collapse of the geonet structure. This collapse is of concern as it can lead to a sudden decrease in flow rate due to the closing of the geonet structure.

A design procedure that would prevent structural failure of the geonet over the service life of a project would be very useful for design engineers. The author presented such a procedure for biplanar geonets which was developed on the basis of compression creep tests (Narejo 2007). A simple method was suggested by the author in that paper which stated that the maximum service load on a biplanar geonet should not exceed 50% of the strength in order to avoid a structural failure during service life. There are new biplanar geonets which do not exhibit structural collapse. These new products have round strands and the relationship between compressive stress and strain is linear. The recommendations presented here, and those by Narejo (2007), are too conservative for round strand biplanar geonets and should not be used. It is the author's estimate that over 80% of all the drainage geocomposite by volume utilize a conventional biplanar core. The data and recommendations in this paper are applicable only to this overwhelming majority of geonet materials.

2 PROBLEM STATEMENT

Drainage geocomposites are almost always used in a project under overburden stress. The overburden stress can vary in projects from 10 kPa to 1500 kPa, and even higher in a limited number of cases. Laboratory compression tests on drainage cores are not routinely performed by manufacturers and the test is neither part of the manufacturing quality control procedure nor is the value considered in design. Manufacturers do not even publish the compression data for their geonets in their data sheets. When the test is performed according to ASTM 6364 or another equivalent method, each type of geonet core structure exhibits a different type of the stress-strain curve. A typical curve is presented in fig. 1 for conventional biplanar geonets since these are the only materials to which this paper is applicable. The reader may note that a peak stress is reached after which there is a sudden drop in stress and significant deformation at a lower stress. This peak stress is referred to in this paper as the strength of the geonet and the collapse is referred to here as the structural collapse. The curve is characteristic of the oblong-shaped structure of the conventional biplanar strands. The products with robust, rounded oblong shape, result in a higher value of the strength, while the products with lighter and elongated oblongs result in a lower value of strength.

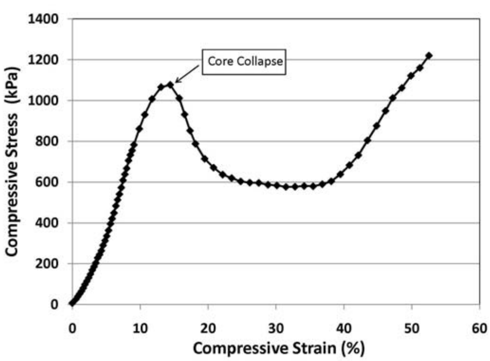

Figure 1 – Typical compression behavior of conventional biplanar geonets.

The compression response of the geonets in the field is unknown at this time as no largescale instrumented field tests have yet been performed and no excavations of large structures have occurred. There are no published case histories showing that geonets are vulnerable to structural failure in the field under loads beyond the peak strength. The author’s hypothesis is that the field stress-strain response of the geonets under comparable boundary conditions is the same as that measured in the laboratory. In the laboratory, the tests are run under a steel plate-geonet-steel plate set-up. A comparable condition in the field is geomembrane – geonet – geomembrane and geomembrane - geocomposite-geomembrane. The effect of soft boundary conditions (e.g., soil – geocomposite - geomembrane) on the stress-strain behavior of geonets is unknown at this time. It is the author’s assumption that the laboratory test conditions of the geonet sandwiched between steel plates are the worst-case conditions.

Design procedures use creep reduction factor to account for the effect of time on the flow rate. For example, GRI procedure GC8 recommends dividing the laboratory flow rate value by a creep reduction factor. However, the use of creep reduction factors in flow rate calculations without an accompanying strength design can be quite misleading. Under very high normal stresses, creep reduction factor can be very low which may imply that either the structure has a very high resistance to compression, or that the structure has already failed in compression, and the low creep reduction factor denotes the creep value postfailure. The procedure for structural design of conventional biplanar geonets suggested here is intended to prevent the structural failure of conventional biplanar geonets.

3 MATERIALS

The overall structure of drainage cores of conventional biplanar geonets included in the test program is presented in fig. 2. As was mentioned earlier, the spacing and shape of the strands vary significantly depending on the manufacturer and the grade of the material. Nevertheless, all variations have the similar stress-strain behavior as in fig. 1. In order to ensure that a broad range of materials is tested, the test program used three different grades of materials. These three different grades are identified in Table 1. The properties in Table 1 are nominal values, meaning that the actual test values may vary depending on the batch and the manufacturer. The materials represent the entire spectrum of conventional biplanar geonet, ranging from the materials used for low flow and low stress conditions, to those for high flow and high stress conditions.

4 CREEP AND CREEP FAILURE TESTS

Compression strength test was performed on candidate material sample according to ASTM D 6364.

Five specimens were tested across a roll width and the average of these five values was calculated. Once an average value of compression strength was obtained, the candidate test sample was ready to be tested for compression creep. An arbitrary value of compression stress was applied on the test specimen and maintained to such time when either 10,000 hours of maximum test duration was reached or a structural collapse of the material occurred. The creep tests were performed either according to conventional creep test methods or accelerated test method. The details of the conventional and accelerated test methods can be found in Narejo and Allen (2004), Thornton et. al (2000) and many other publications on the topic of compression creep. Approximately 50% of the data reported in this paper is from accelerated test method and the rest is from conventional method.

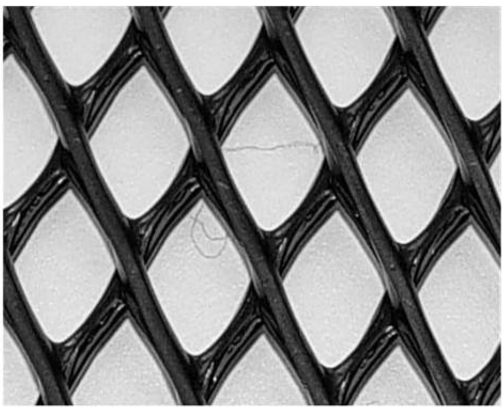

Figure 2 – General shape of biplanar geonets.

Table 1 – Materials evaluated for this paper.

Materials	Thickness (mm)	Mass (g/m^2)	Compression Strength (kPa)
A	5.0	730	718
B	6.4	1024	955
C	7.6	1560	1435

Note: All values are nominal.

When a test lasted up to 10,000 hours, the resulting creep curve is of the type presented in fig. 3. The reader may note that the curve is linear on semi-log scale, i.e., there is no structural collapse of the material up to the maximum test duration. This is a valid creep curve for this specific material and a creep reduction factor can be calculated from this curve according to equations presented by Giroud et al. (2000). For the purpose of this paper, the data in fig. 3 is of little use as there is no specific failure time, that is, time to failure is not known. However, if the stress on this same material is increased, a point is reached where the curves of the type in fig. 4 result. It is not possible to calculate a creep reduction factor from the data in fig. 4 as the relationship between time and strain (or thickness retained) is nonlinear. For the purpose of this paper, the data in fig. 4 is of high value as the time to structural failure is now known. The time to structural failure is around 1 hour in test A and 900 hours in test B.

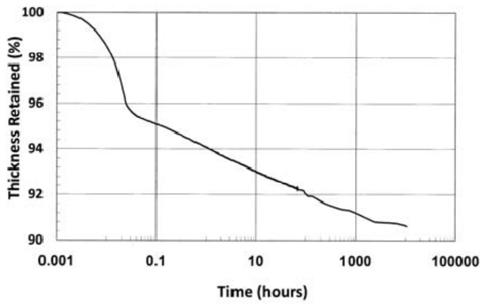

Figure 3 – Compression creep curve for a geonet.

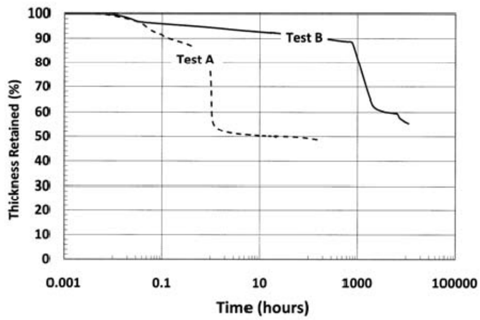

Figure 4 – Time-to-failure curves for a geonet.

The stress at which a creep test was performed was divided by compression strength of the sample. For example, if the compression strength of a particular sample is 800 kPa and the creep test was performed at 600 kPa, the resulting ratio is 0.75. This ratio was then plotted against time to failure. The resulting figures for materials A, B and C are fig. 5, fig. 6 and fig. 7, respectively. The figures show a good relationship between the ratio of stress/strength and time to failure, as can be judged by the R_2 value. The relationship between stress/strength ratio and time-to-failure is of the following type:

$$y = -a \cdot \ln(x) + b \qquad (1)$$

Where,
y = ratio of stress over strength,
x = time-to-failure (hours),

a = regression constant, and
b = regression constant.

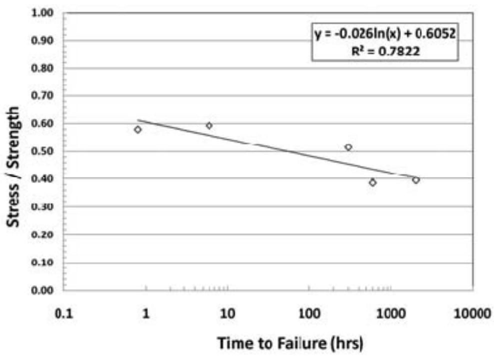

Figure 5 – Relationship between time to failure and stress for material A.

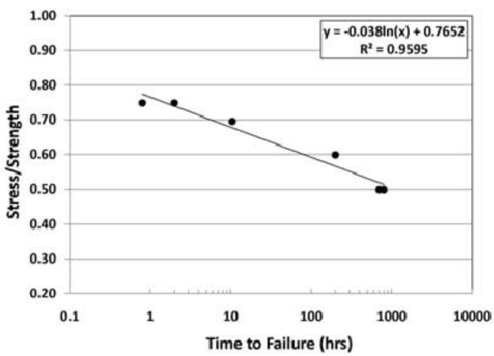

Figure 6 – Relationship between time to failure and stress for material B.

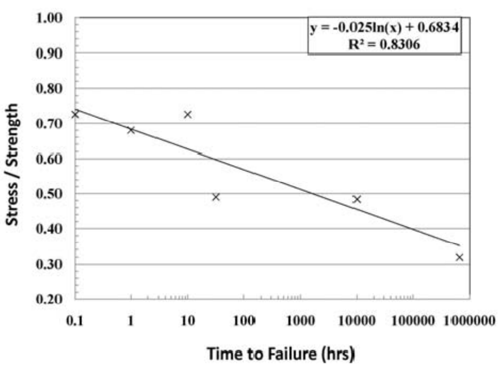

Figure 7 – Relationship between time to failure and stress for material C.

The coefficients "a" and "b" are given in the regression equations in fig. 5 through 7 for materials A, B and C, respectively. The author expected coefficients "a" and "b" to vary systematically as the mass/unit area of the geonet was increased from 730 to 1560 grams/m2. An improvement in time-to-failure with an increase in mass would indicate that the stability of the strands improves as the ribs are made sturdier. In order to determine whether there is indeed a systematic variation in time-to failure for three different grades of materials, the data in figures 5, 6 and 7 was plotted together on one plot in Figure 8. It may be noted from fig. 8 that most of the data for material B plots above that for material A. But then materials C (refer to Table 1) plots both above and below materials A and B.

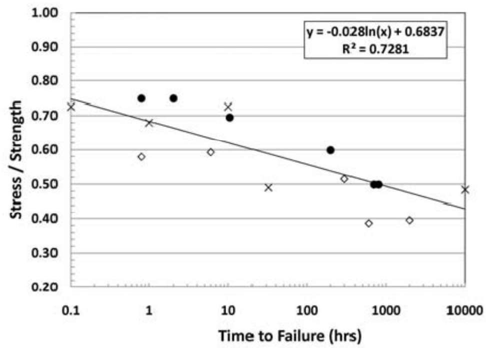

Figure 8 – Combined plot for all three materials.

The best-fit equation for the data in fig. 8 is reproduced here as:

$$y = -0.028\ln(x) + 0.68 \qquad (2)$$

Assume S = strength (kPa) and P = Stress (kPa), and t = time to failure (hours). Then Equation 2 can be written as:

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

Interpretation of Equation 3 is fairly straightforward. Given the strength of a conventional biplanar geonet, time to failure can be calculated for a specific overburden stress. For example, assume that a geonet with compression strength of 150 kPa is being considered for a project where maximum overburden stress will be 15 kPa. Substituting P equal to 15 kPa and S = 150 kPa in Equation 3 results in time to failure, t, of 917,200,580 hours or 105,000 years. If the same material is used in a different application where overburden stress is 75 kPa, the time to failure is 600 hours.

Equation 3 can be re-written as:

$$P = S[-0.028\ln(t) + 0.68] \qquad (4)$$

Two types of boundary conditions can be expected in the field: soft and hard. Soil geocomposite interface is a good example of the soft boundary conditions. On the other hand, geomembrane-geonet and geomembrane-geocomposite are examples of hard boundary conditions. Equation 4 was derived assuming that boundary conditions are hard. The author expects the equation to be conservative for soft boundary conditions. Other conditions that can influence time to failure include temperature, lamination process and the type of polymer. Equation 4 can be modified to calculate allowable stress on a geonet or geocomposite as follows:

$$p_{allow} = \frac{S}{R_f}\left[-0.028\ln(t) + 0.68\right] \quad (5)$$

Where R_f = reduction factor to account for several discrepancies between the test program and the field conditions. An interim value of 1.5 is proposed for R_f until additional tests are completed on the materials.

A site-specific value of the stress on a geocomposite can be calculated as:

$$p_{req} = \gamma \quad h \quad (6)$$

Where p_{req} = site-specific pressure (kPa), γ = unit weight of overburden material (kN/m3) and h = height of overburden material (m).

A factor of safety against structural failure of a biplanar geonet with conventional structure can be obtained as:

$$FS = \frac{p_{allow}}{p_{req}} \quad (7)$$

The methodology for preventing the structural collapse of geonets presented in this section is intended for use in association with the hydraulic design. In absence of this structural design, the hydraulic design can be misleading as the loads on the material could exceed long-term strength.

5 LIMITATIONS

The methodology presented above is based on laboratory testing. There are several aspects of the actual projects that are not represented by the laboratory testing. The procedure presented in this paper needs to be modified further to account for the field conditions. The following are some of the variables that are not completely accounted for in the method presented in this paper:

• The procedure is based on testing at 20 degrees Celsius whereas the field temperature can be much higher.

• All testing was performed with geonet steel plate boundary conditions. The field boundary conditions include soilgeocomposite. The effect of the field boundary conditions needs to be investigated.

• This method is applicable only to conventional biplanar geonets. The method should be extended to other geonet structures by conducting additional testing.

5 CONCLUSIONS

A procedure for calculating the factor of safety against structural failure of conventional biplanar geonets with oblong-shaped strands was presented above. This procedure was developed on the basis of creep testing of materials wherein the boundary conditions were steel plate – geonet – steel plate. The effect of the boundary conditions on the method presented here is currently being investigated. The equations presented here will be modified as further information becomes available.

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