EFFECT OF SOIL PRESENCE ON FLOW CAPACITY OF DRAINAGE GEOCOMPOSITES UNDER HIGH NORMAL LOADS

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ABSTRACT:

Extensive transmissivity tests are conducted under high normal loads to investigate the effect of soft boundaries over drainage geocomposites on the flow rates. Two geonet structures (tri-planar and bi-planar geonets), two types of soils (sand and clay), GCL, and a neoprene rubber are included in the tests. Long-term transmissivity tests under in-soil environment are also performed. Under high normal loads, the effect of sand layer density is found to be insignificant to the flow rate of both bi-planar and tri-planar geocomposites. The neoprene tested simulates well geotextile intrusion into the geonet's core space for sand layer, but significantly underestimates intrusion of geotextile for clayey soil. Due to the variable nature of both neoprene and soils, for performance transmissivity tests, site representative soils are strongly recommended. Under high normal loads, the reported default reduction factors for intrusion (1.5 to 2) are in agreement with the tri-planar geocomposites for sand layer; while the default reduction factors are not representative of the bi-planar geocomposite for all the boundary conditions. A reduction in the flow rate of geocomposites under sustained high loads occurs with respect to time especially for the bi-planar geocomposite. Long-term transmissivity tests for geocomposites and 10,000 hour long-term compressive creep tests for geonets are strongly recommended.

INTRODUCTION

Geocomposite drain systems consist of a geonet core with a geotextile laminated to one or two sides and are designed for in-plane flow over large surface area. Geocomposite drains are increasingly used in place of soil drains in civil and environmental applications. For instance, a geocomposite can function as a surface water removal layer in landfill final covers, a leachate collection layer over a liner systems or a leak detection layer between two barrier layers. The most critical engineering property of a geocomposite is its in-plane flow capacity under design loads and site specific boundary conditions. The design parameter used to quantify the in-plane flow capacity is either the flow rate per unit width or hydraulic transmissivity. Transmissivity is applicable to laminar flow conditions (ASTM D4716-95) and it is defined as

$$\theta = k_p \cdot t = \frac{q}{i}$$

(1)

Where

θ = hydraulic transmissivity (m^3/sec/m)
q = flow rate per unit width (m^3/sec/m)
k_p = in-plane hydraulic conductivity (permeability) (m/sec)
i = hydraulic gradient
t = geocomposite thickness (m)

It is more appropriate to present the flow rate or transmissivity in terms of m^3/sec/m (or gal/min/ft), not m^2/sec. The latter dimension has no physical meaning. Geocomposite drainage design by function is described by Koerner, (1997). More specific design issues for geocomposite drains are summarized by Richardson and Zhao (1998) for steep side slopes in landfill final covers, and flat slopes of landfill barrier systems by Zhao and Richardson (1998). In design by function approach, a drainage geocomposite must meet the following equation

$$FS = \frac{q_{allow}}{q_{req'd}}$$

(2)

where FS is the overall safety factor, q_{allow} is the allowable flow rate of the geocomposite, and $q_{req'd}$ is the required flow rate. The required flow rate can be determined from a water balance model such as the HELP model (Schroeder, et al. 1994) or other well-documented methods. The allowable flow rate of the drainage product can be determined from

$$q_{allow} = \frac{q_{ultimate}}{RF_{in} \cdot RF_{cr} \cdot RF_{cc} \cdot RF_{bc}} = \frac{q_{ultimate}}{\prod RF} \quad (3)$$

where $q_{ultimate}$ is the ultimate flow rate (index value) measured in accordance with ASTM D4716-95. If the test setup does not simulate the actual field conditions, reduction factors shall be applied. The following default reduction factors are suggested (Koerner, 1997):

- RF_{in} = reduction factor for elastic deformation, or intrusion of the adjacent geotextiles into the geonet's core space, 1.5 - 2.0 for landfill primary leachate collection layer.

- RF_{cr} = reduction factor for creep deformation of the geonet and/or adjacent geotextile into the geonet's core space, 1.4 - 2.0 for landfill primary leachate collection layer.

- RF_{cc} = reduction factor for chemical clogging and/or precipitation of chemicals in the geonet's core space, 1.5 - 2.0 for landfill primary leachate collection layer.

- RF_{bc} = reduction factor for biological clogging in the geonet's core space, 1.5 - 2.0 for landfill primary leachate collection layer.

- ΠRF = product of all relevant reduction factors for the site-specific conditions.

Geotextile intrusion into geonets under low normal pressure (up to 105 kPa (2180 psf)) was investigated by Hwu, Koerner and Sprague (1990). Under high normal loads, there are rather limited data available to verify the intrusion reduction factors. Obviously, intrusion reduction factors are a function of many variables such as types of geonet structures and polymer, overlying materials (sand, clay, or a GCL) above the geocomposite, normal pressure, seating time, and hydraulic gradient. This paper will focus on intrusion reduction factors under high normal loads only. Two types of geonet structures (bi-planar and tri-planar), two types of soils (sand and clay), GCL and a neoprene are included in the testing program to investigate reduction factors due to geotextile intrusion into the geonet core.

Due to the compressive creep nature of polymeric materials, in-plane flow capacity for geonet geocomposite drains under sustained compressive loads must be considered (Slocumb, Demeny and Christopher, 1986, Smith and Kraemer, 1988, Campbell and Wu, 1994, Fannin and Choy, 1995). To address long-term compressive stress on the geonet core of a geocompopsite, the design pressure on a geocomposite core is suggested by Holtz, Christopher and Berg (1997) to be limited to either:

(a) the maximum pressure sustained on the core in a test of 10,000 hour minimum duration or
(b) the crushing pressure of a core as defined with a quick loading test, divided by a safety factor of 5.

The transmissivity testing program is presented in the next section, followed by verification of intrusion reduction factors. The long-term transmissivity tests under in–soil environment and long-term compressive creep data are described in the next section. The paper is finished with concluding remarks.

TESTING PROGRAM

Transmissivity Testing Set-Up

The in-plane flow rate (transmissivity) of a geocomposite under different boundary conditions is determined by measuring the quantity of water passing through a specimen in a specific time interval in accordance with ASTM D4716. A specimen of 305 mm by 355 mm dimension is used. The flow capacity for each test is reported as a flow rate per unit width for the conditions examined. All values are corrected for water temperature. The transmissivity test set-up is shown in Figure 1. Various overlying materials can be placed on top of the drainage geocomposite, including sand, clay, neoprene and GCL. For soil layer preparation, the sand thickness is kept constant at 25 mm. Based on the desired degree of compaction, the amount of sand required is calculated and weighed. For instance, the transmissivity tests reported here need 4.15 kg of dry sand to achieve 95% compaction, and 3.3 kg of dry sand for 75% compaction. The sand is wetted with 10% moisture. The sand layer is then compacted to target thickness. The clay is handled with 2% moisture content to avoid "mud waves." Before performing the transmissivity tests with the GCL, the GCL is hydrated for 24 hours under 8 kPa (160 psf) pressure. The length of the neoprene was cut 2.5 mm at the two ends to avoid intrusion at the edges of geocomposite specimen.

Testing Materials

To verify the intrusion reduction factors of different geonet structures, two types of drainage geonets are tested: a bi-planar geonet and a tri-planar geonet. Bi-planar geonets consist of two layers of ribs superimposed over each other; while tri-planar geonets are comprised of two layers of inclined ribs separated by thick vertical ribs, creating a wide flow. Figure 2 shows the profiles of the two types of geonets with bi-planar geonet on the left and the tri-planar geonet on the right.

Geotextile-geonet-geotextile composites are used in the tests. Both bi-planar and tri-planar geonets have HDPE cores. Two layers of polypropylene non-woven geotextile are heat-bonded to the geonet by a lamination process. The geosynthetic clay liner (GCL) is made by a layer of sodium bentonite enclosed in two layers of woven geotextiles. The properties of the geosynthetic products tested are given in Table 1.

Table 1. Testing products: Bi-Planar, tri-planar geocomposites and a GCL.

Product	Thickness (mm)	Core Unit weight (g/m^2)	Geotextile Unit Weight (g/m^2)	AOS (mm)
Bi-planar geocomposite	6	900	180	0.13
Tri-planar Geocomposite	7.6	1600	270	0.15
GCL	5.2	5000	102	-

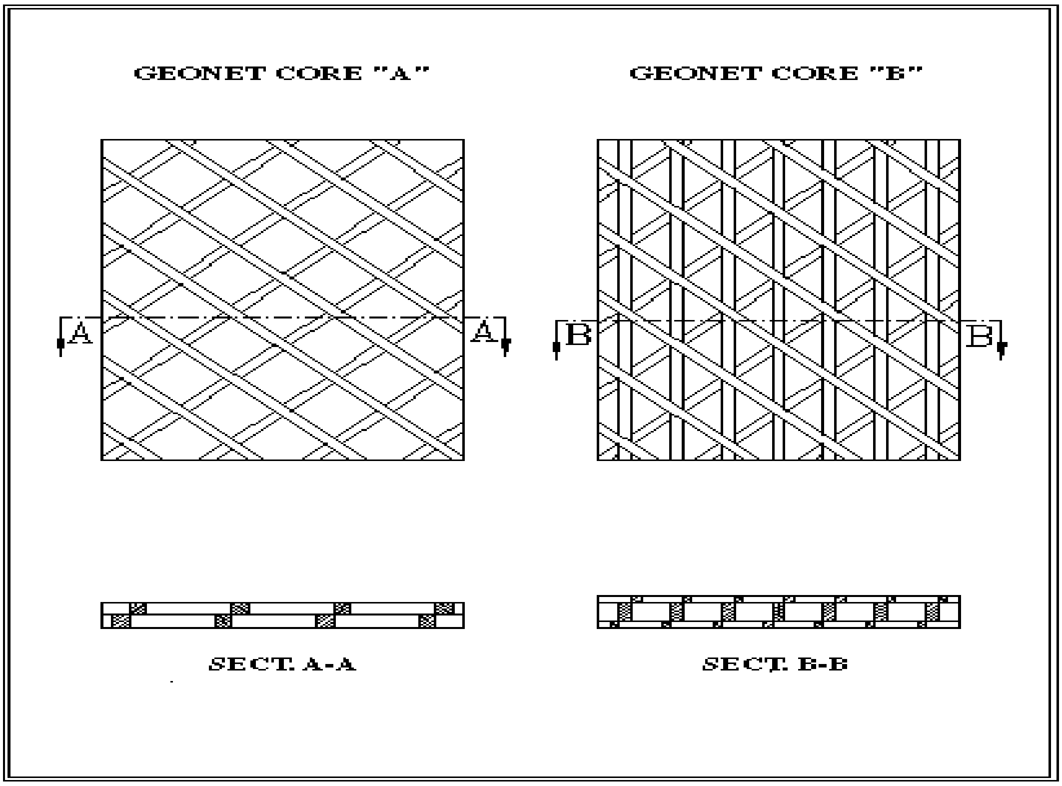


Figure 2: Profiles and cross-sections of a bi-planar and a tri-planar geonet

The neoprene is placed on top of the geocomposite to investigate the possibility of simulating real soil intrusion behavior. The neoprene has a nominal thickness of 10 mm per EN ISO129858 test method. The properties of the neoprene are listed in Table 2.

Table 2. Properties of the neoprene used in tests

Normal pressure (kPa)	2	20	200
Thickness (mm)	9.75	9.18	3.76
Thickness Retained (%)	97.5%	91.8%	37.6%
Density (g/cm3)			0.151
Hardness (Shore D)			2-5

Both sand and clay soils are included in the testing program. A sand layer is commonly placed over a geocomposite blanket in primary leachate collection applications as a protective/drainage layer. A compacted clay or GCL is typically used over a geocomposite in leak detection applications. The sand has a uniformity coefficient of about 2, proctor density =19 kN/m^3, and an optimal moisture content w = 15%. The sand is called Ticino siliceous sand, since it is dredged from the Ticino River in Italy. The gradation curve of the sand is shown in Figure 2. The clay used in the tests has plasticity index = 15, liquid limit =36, plastic limit = 21.

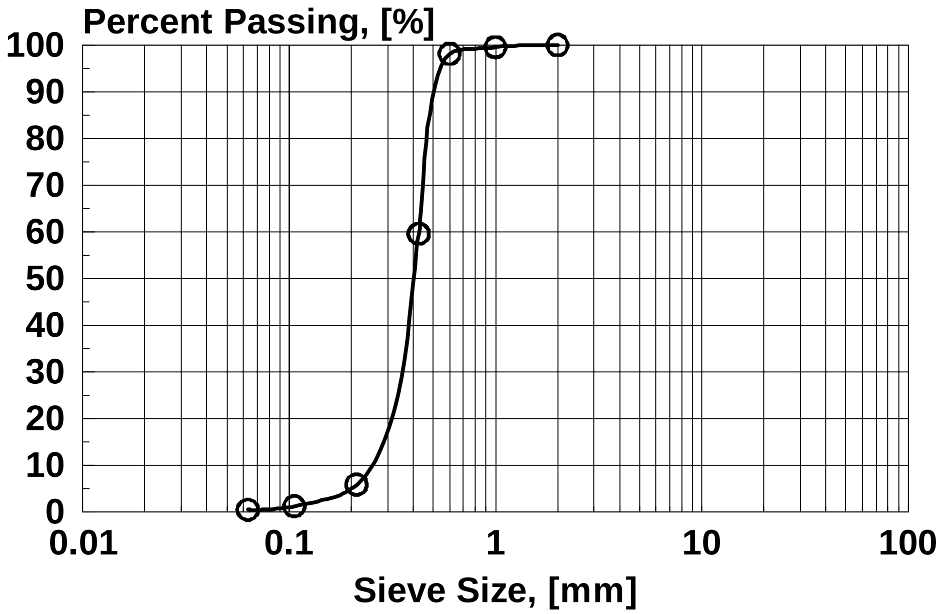


Figure 2. Grain size distribution of the sand

VERIFICATION OF REDUCTION FACTORS FOR INTRUSION

Bi-Planar Geocomposites

Transmissivity test results for the bi-planar geocomposite under different boundary conditions are listed in Table 3. The flow rate of the geocomposite tested between two steel plates is considered as the base for comparison. The retained flow rates of the bi-planar geocomposite under different testing boundary conditions are presented in Figure 3. Under 720kPa (15,000psf) normal load, the bi-planar geocomposite retains less than 25% of the flow rate when it is tested with either sand or clay. A significant reduction in flow rates due to geotextile intrusion into the geonet core is recorded. Under gradient of 0.1, the retained flow rate is very low, less than 10 percent.

Table 3. Table 5. Flow rates (m^3/sec/m) of the bi-planar geocomposite

Test boundaries	i = 1	i = 0.5	i = 0.1
Steel plate	3.32E-04	2.05E-04	5.62E-05
Neoprene	9.71E-05	3.32E-05	4.09E-06
Neoprene above and below	3.28E-05	1.58E-05	1.50E-06
Sand 95% compaction	7.92E-05	2.69E-05	4.09E-06
Clay	7.11E-05	2.57E-05	2.73E-06

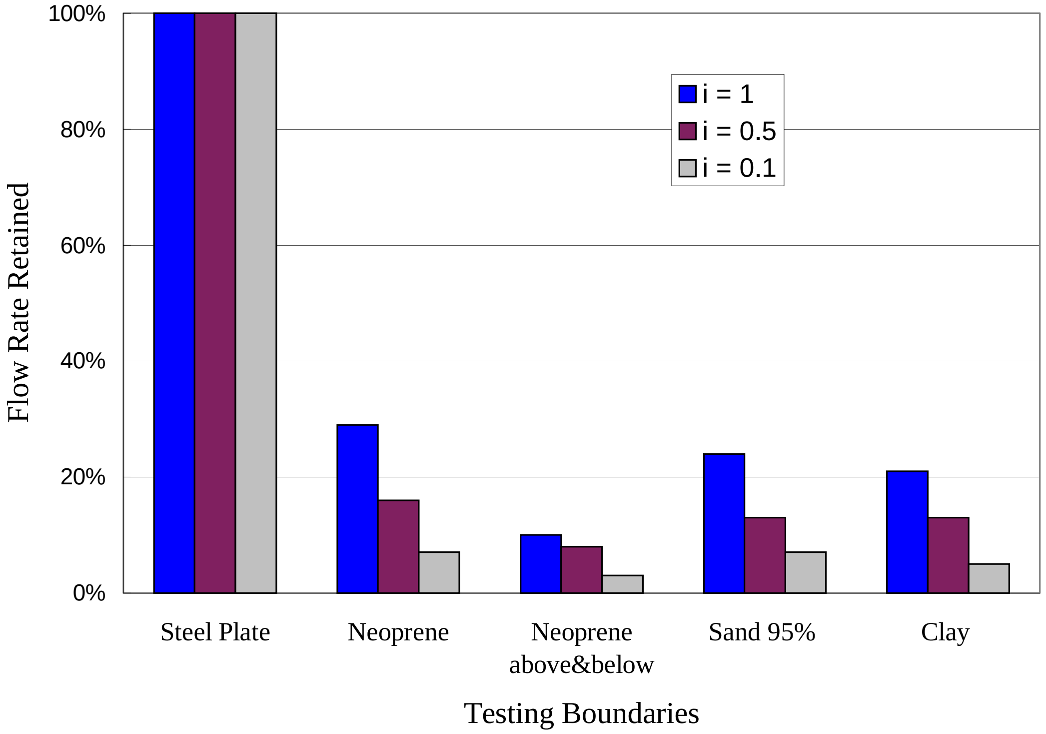


Figure 3. Flow rate percent for the bi-planar geocomposite under different boundaries

The reduction factors under different testing boundaries can then be calculated and presented in Table 4. Table 4 indicates that under normal load of 720kPa (15,000psf), the reduction factors with every overlying material are significantly larger than suggested default values in the range of 1.5 – 2. The presence of a soft material layer causes great geotextile intrusion into the geonet flow channel. The reduction factors are also found to be heavily dependent upon hydraulic gradient. At a low gradient, reduction factors are significantly larger than those at a higher gradient. Especially for clayey soil, the reduction factor is as high as 20. This is 10 times larger than the suggested default reduction factors. Neoprene is found to simulate sand behavior very well, but underestimate the reduction factors in clayey soils. Neoprene below and above the bi-planar geocomposite causes the greatest geotextile intrusion with a reduction factor as high as 37.5 at gradient 0.1. A soil layer above and below a geocomposite is not a typical application in landfill drainage systems, therefore, this testing boundary condition is not recommended.

Table 4. Reduction factors on the flow rate for the bi-planar geocomposite

Test boundaries	i = 1	i = 0.5	i = 0.1
Steel plate	1	1	1
Neoprene	3.42	6.17	13.74
Neoprene above and below	10.12	12.97	37.47
Sand 95% compaction	4.19	7.62	13.74
Clay	4.67	7.98	20.59

Tri-Planar Geocomposites

The flow rates of the tri-planar geocomposite under different boundary conditions are listed in Table 5. The corresponding flow rate percentage compared to that tested between two steel plates is presented in Figure 4. The reduction factors under different testing boundary conditions are listed in Table 6. Under all the testing conditions, the tri-planar geocomposite exhibits much less geotextile intrusion into the geonet's core space than the bi-planar geocomposite. This is mainly credited to the tri-planar structure. The middle flow plane contributes to the large flow rate of the tri-planar geonet; the top and bottom auxiliary planes accommodate the intrusion of geotextiles. The reduction factors of the tri-planar geocomposite with sand are in agreement with the suggested default values. The effect of soil compaction seems to be insignificant under high compressive loads. Clayey soil causes greater intrusion than sand. Neoprene simulates well the geotextile intrusion of a sand layer.

Table 5. Flow rates (m^3/sec/m) of the tri-planar geocomposite

Test boundaries	i = 1	i = 0.5	i = 0.1
Steel plate	1.27E-03	8.54E-04	3.50E-04
Neoprene	8.07E-04	5.13E-04	1.96E-04
Neoprene above and below	2.81E-04	1.28E-04	1.53E-05
Sand 95% compaction	1.00E-03	6.81E-04	2.69E-04
Sand 75% compaction	9.79E-04	6.55E-04	2.65E-04
Clay	4.92E-04	3.07E-04	9.71E-05

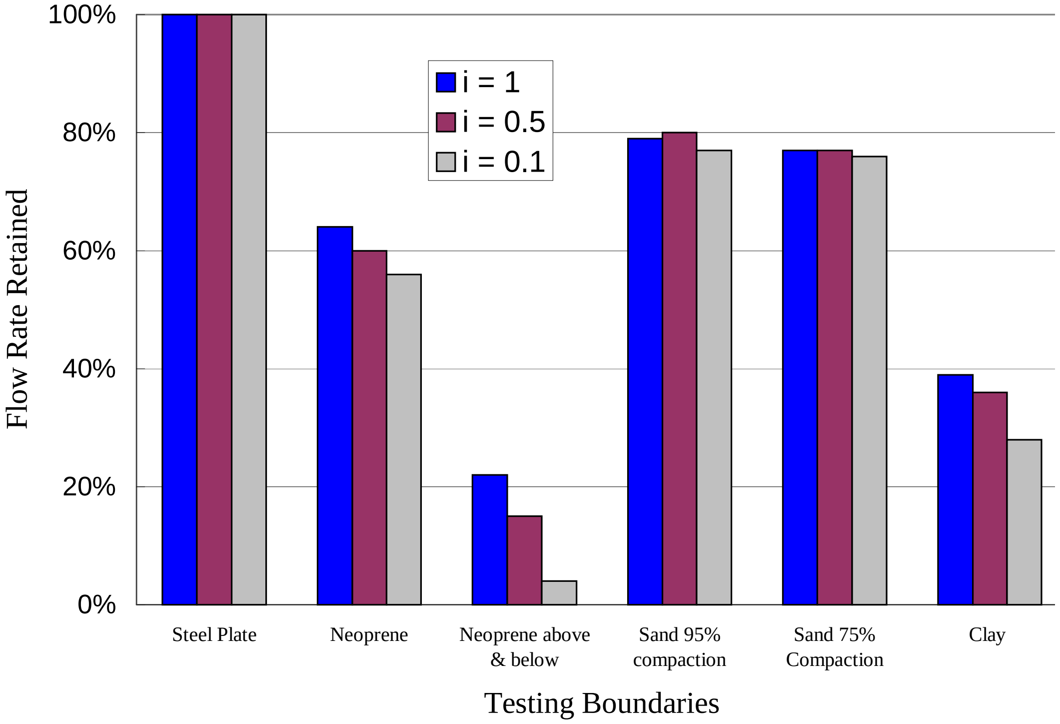


Figure 4. Flow rate percent for the tri-planar geocomposite under different boundaries

Table 6. Reduction factors on the flow rates for the tri-planar geocomposite

Test boundaries	i = 1	i = 0.5	i = 0.1
Steel plate	1	1	1
Neoprene	1.57	1.66	1.79
Neoprene above and below	4.52	6.67	22.88
Sand 95% compaction	1.27	1.25	1.3
Sand 75% compaction	1.3	1.3	1.32
Clay	2.58	2.78	3.6

Each transmissivity tests listed in the above tables is conducted with a 15 minute seating time. Therefore, the results are considered as short-term data. Figure 5 presents a limited data on the long-term flow rate of the tri-planar geocomposite with and without a GCL. The seating time is 100 hours with a gradient of 1 and a normal pressure 800kPa (16640psf). From which a long-term intrusion/creep reduction factor can be derived (see Figure 6). The long-term reduction factor for the tri-planar geocomposite with an overlying GCL is about 2.0.

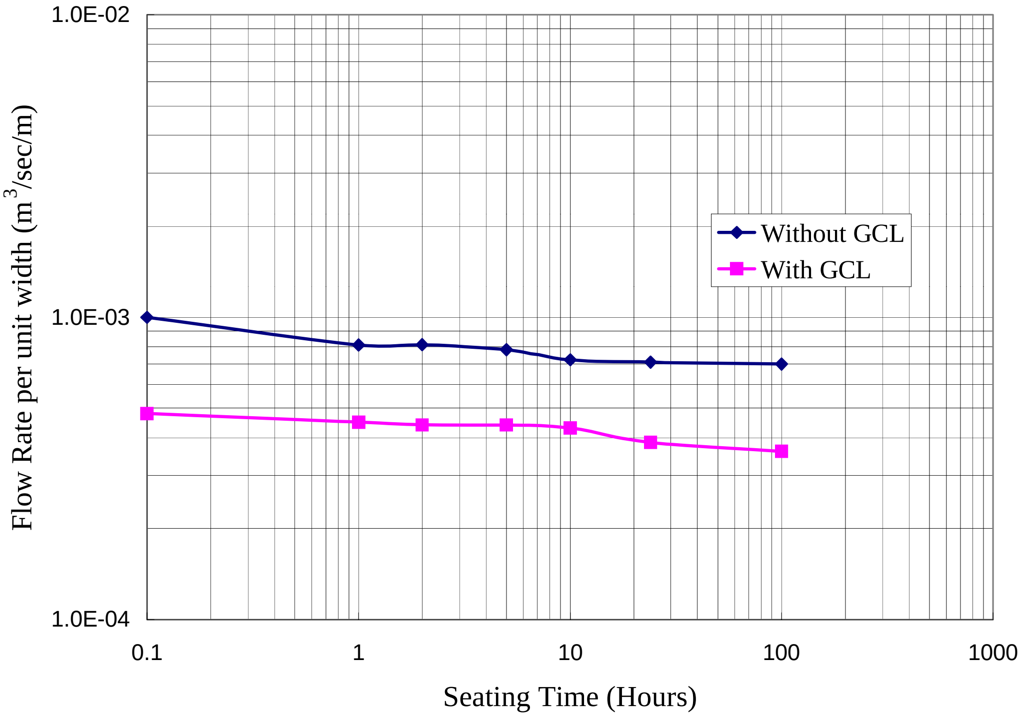


Figure 5. Flow rate for a tri-planar geocomposite with and without a GCL (After Montanelli and Rimoldi, 1995)

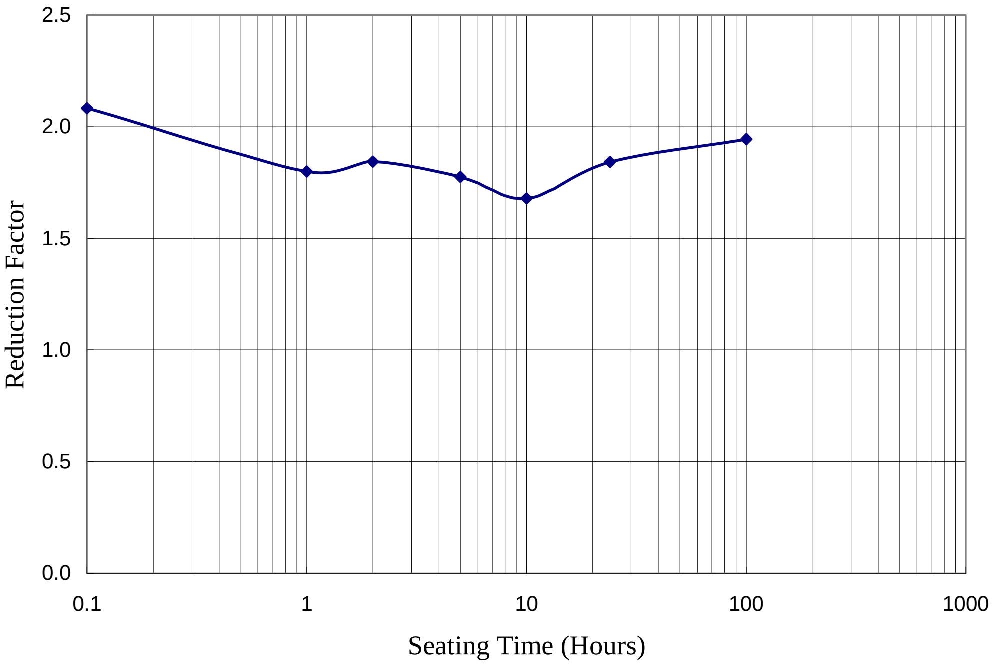
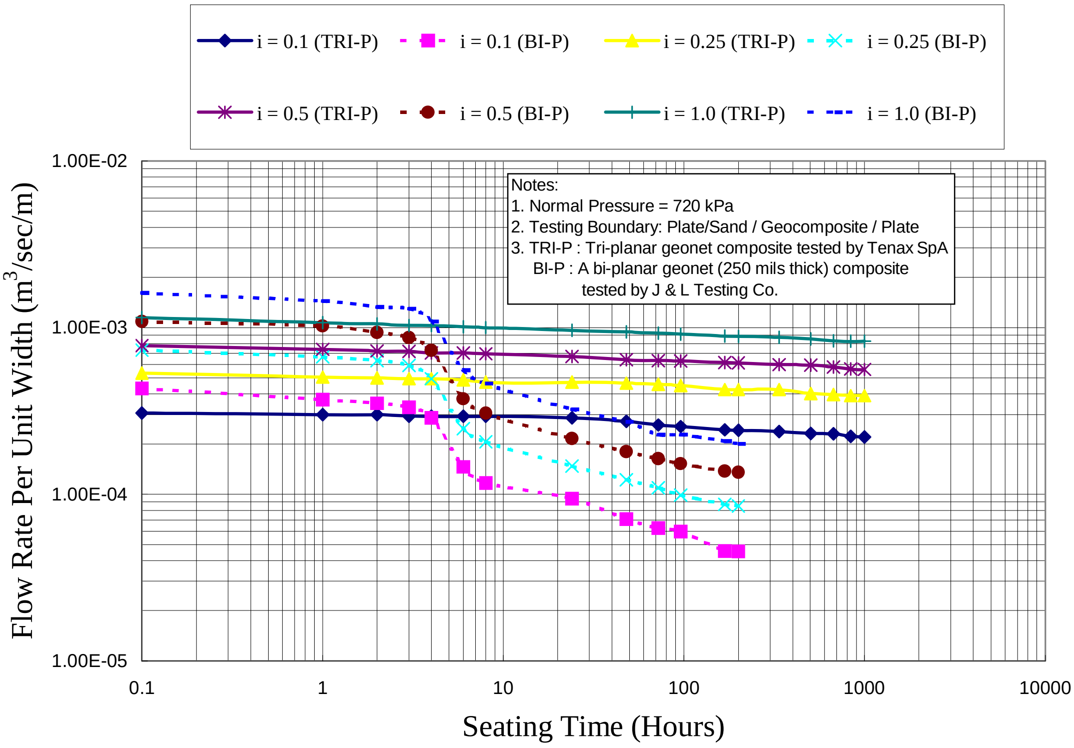


Figure 6. Long-term reduction factor of a tri-planar geocomposite with a GCL

LONG-TERM FLOW OF GEOCOMPOSITES UNDER IN-SOIL ENVIRONMENT

The long-term intrusion of the geotextile into the geonet core can be measured by transmissivity tests under sustained normal loads. Figure 7 presents the long-term flow rates for a tri-planar geocomposite up to 1000 hours and a bi-planar geocomposite up to 200 hours. Flow rates of both geocomposites experience reduction with time. The tri-planar geocomposite retains about 65% of its flow capacity after 1000 hours; while the bi-planar geocomposite losses almost 70% of the flow within the first 10 hours. The bi-planar geocomposite tested continues to experience flow rate reduction over extended time. The flow rate retained as a percentage of the initial value is presented in Figure 8.

Long-term flow capacity of a geocomposite is directly related to the compressive creep behavior of the geonet. An obvious correlation to the geocomposite long-term flow rate is the long-term compressive creep of the geonet. Figure 9 is a 10,000-hour compressive creep curve for the tri-planar geonet under sustained normal load of 1200kPa (25,000psf). The geonet retains over 65% of its initial thickness.



Notes:
1. Normal Pressure = 720 kPa
2. Testing Boundary: Plate/Sand / Geocomposite / Plate
3. TRI-P : Tri-planar geonet composite tested by Tenax SpA
BI-P : A bi-planar geonet (250 mils thick) composite
tested by J & L Testing Co.

Figure 7. Long-term flow rate for a tri-planar & a bi-planar geocomposite.

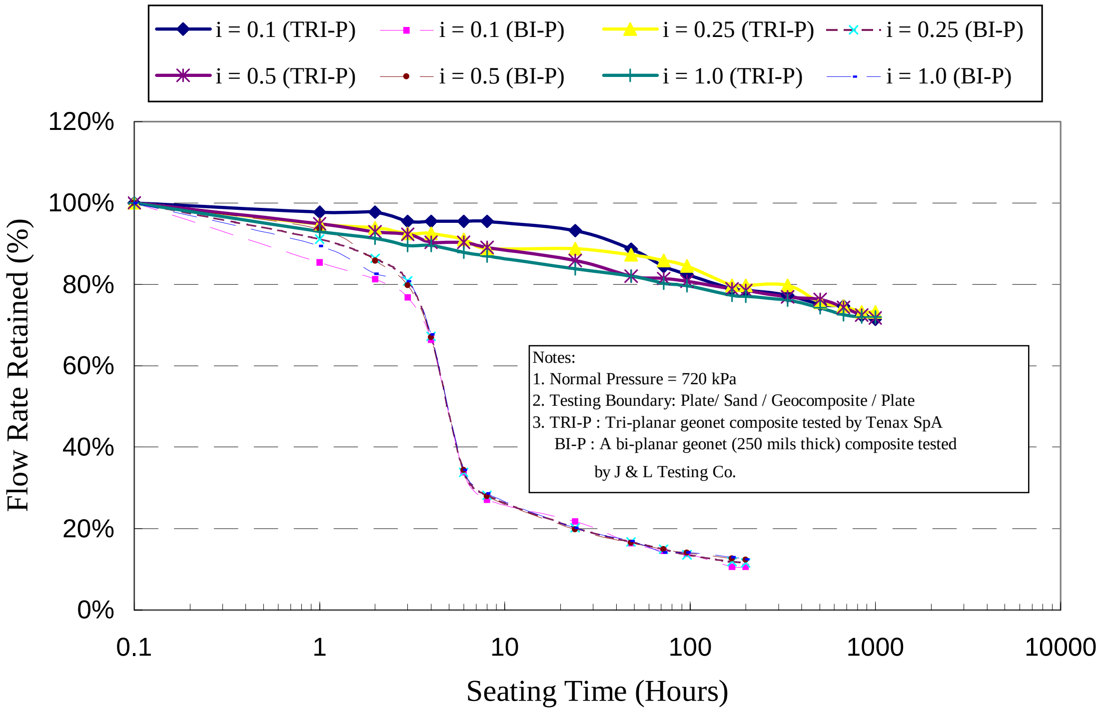


Figure 8. Long-term flow rate retained for a tri-planar and a bi-planar geocomposite.

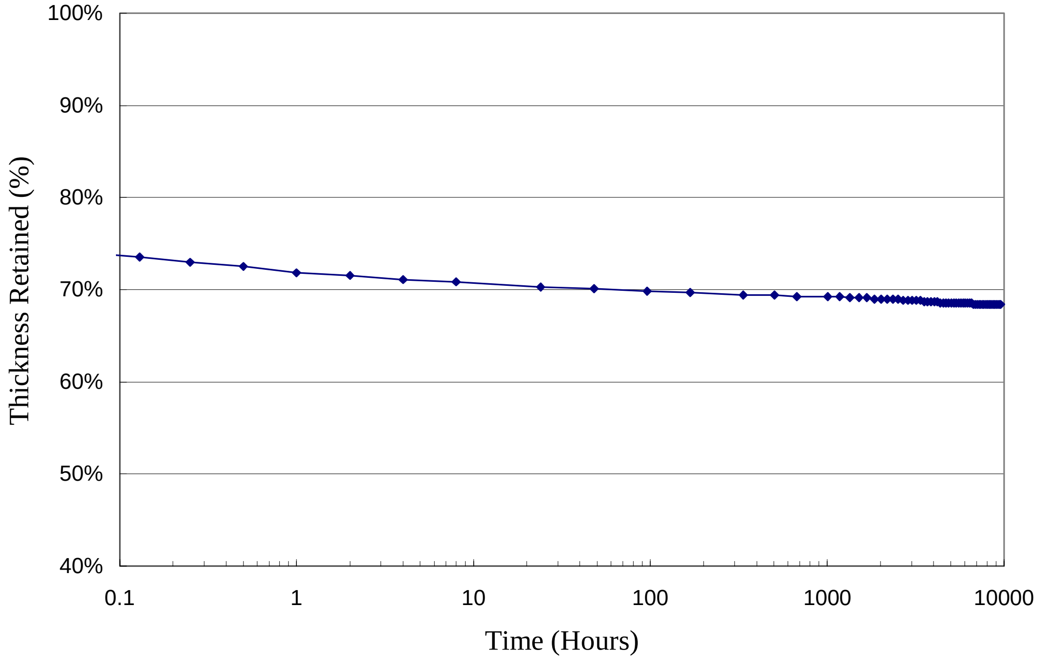


Figure 9. Long-term compressive creep curve for a tri-planar geonet (Normal pressure =1200 kPa (25,000 psf))

CONCLUDING REMARKS

Extensive transmissivity tests are performed under high normal loads to investigate the reduction factors of flow rate due to overlying material intrusion into the geonet core. Two geonet structures (tri-planar and bi-planar geonets), two types of soils (sand and clay), GCL and a neoprene are included in the tests. Long-term transmissivity tests under in-soil environment and long-term compressive creep test up to 10,000 hours are also conducted. The following conclusions can be drawn from the above-presented experimental results:

- Under high normal loads, the reduction factors for intrusion of the tri-planar geocomposite with sand layer are found to be in agreement with the suggested default value range (1.5 to 2). The default reduction factors are not representative of the bi-planar geocomposite. Reduction in the flow rate from the bi-planar geocomposite due to the presence of a clayey soil layer can be as large as 95 percent (corresponding reduction factor greater than 20).

- The effect of sand layer compaction effort is found to be insignificant to the flow rate of both bi-planar and tri-planar geocomposites under high normal loads.

- The neoprene tested can simulate the geotextile intrusion of the sand layer for both bi-planar and tri-planar geocomposites. However, the neoprene significantly underestimates intrusion of geotextile for clayey soil. Transmissivity tests with a neoprene above and below a geocomposite greatly reduce the flow rate, with a reduction factor as high as 38 obtained. Due to variations of both neoprene and soils, the use of real soils to conduct performance transmissivity tests is strongly recommended.

- A significant reduction in flow rate of geocomposites under sustained high loads occurs with respect to time especially for bi-planar geocomposites. Long-term performance transmissivity tests of geocomposites and long-term compressive creep tests of geonets are recommend.

It has been noticed that variation in transmissivity test results, especially under in-soil environment, is significant. Many factors, such as different transmissivity test equipment, different types of soils and preparation procedures, seating time etc., can contribute to this variation. Further research is needed to standardize the in-soil transmissivity testing procedure, conduct more comprehensive tests to advance the understanding of long-term behaviors of various geocomposites under different conditions.

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