FILTRATION BEHAVIOR FOR A SOIL-NONWOVEN GEOTEXTILE COMPOSITE SUBJECTED TO VARIOUS LOADS

Cho-Sen Wu[1], Y. S. Hong[2] & J. H. He[3]

[1] *Dept. of Civi. Engr. Tamkang University. (e-mail: cswu@mail.tku.edu.tw)*
[2] *Dept. of Civil Engr. Tamkang University. (e-mail: yshong@mail.tku.edu.tw)*
[3] *Dept. of Civil Engr. Tamkang University.*

Abstract: The load type influence on the filtration behavior of a soil-nonwoven geotextile composite is studied and the results presented in this paper. The soil-geotextile composite was formed by inserting a piece of nonwoven geotextile between a 5-cm thick soil and a layer of steel beads. Three load types, sustained load only, cyclic load only and cyclic load acting on a composite subjected to a sustained load, were applied to the composite prior to the filtration test. The frequency of the cyclic load was 0.1 Hz and 5000 cycles of repeated load was applied. Following the completion of a specific type of loading, water was allowed to flow through the composite from the soil into the drainage layer with various hydraulic gradients. A stable flow rate corresponding to each hydraulic gradient was measured and an averaged permeability value evaluated using Darcy’s law to represent the filtration characteristics of the soil-geotextile composite.

The initial void ratio of the soil was controlled to 0.63 for all tests. However, the normal load caused soil compacting. The test results revealed that the void ratio was decreased almost linearly with the increase in total load. For the composite subjected only to a sustained load, greater sustained load induced greater seepage flow. For the composite subjected to a cyclic load while a specific sustained load was applied, greater cyclic load induced larger amounts of seepage flow. For the composites subjected to the same total load, the composite subjected to half value of the sustained and cyclic loads produced the largest seepage flow. The composite subjected to full value of the sustained load produced the least amount of seepage flow.

Keywords: dynamic loads, filter testing, laboratory test, nonwoven geotextile, permeability.

INTRODUCTION

Geotextiles are used to wrap roadway drainage systems or placed horizontally between subgrade fine soils and subbase aggregates. Geo-composites are made with a core of quasi-rigid plastic sheet protected by a geotextile on one or both sides. They are used as edge drains on highways, airfields or railroads. Geotextiles in these applications act as filters or separator when subjected to earth pressure and dynamic or impact loads caused by highway vehicles, railroads or landing aircraft. The success of these applications relies on the retention and permeability capabilities of the geotextiles and prevention of undue clogging when geotextiles are subjected to in-plane stress/strain and dynamic load. The in-plane strain may change the geotextile pore size and fine particles may be pumped out by the dynamic load action. Thus, current filter criteria may not warranted, because they are based on the pore size and permeability of the plain geotextile and the clogging potential evaluation for a soil-geotextile system when no load, cyclic or static, is applied.

Some studies consider the migration of “fines” that have passed into and through the fabric under dynamic loads (Bell et al. 1982; Hoare 1982; Floss et al. 1990). Laboratory tests were conducted to study the change in permeability and clogging of a soil-geotextile system while subjected to dynamic load (Saxena and Hsu 1986; Lafleur et al. 1990, 1996; McMorrow 1990; Narejo and Koerner 1992). The effect of tensile strain on the filtration characteristics of geotextiles was studied (Fourie and Kuchena 1995; Fourie and Addis 1997, 1999; Wu et al. 2008). While an in-plane tensile load, biaxial or uniaxial, was applied to the geotextile, filtration opening size as well as the permeability of the geotextile was changed. Permeability test results using nonwoven and woven geotextiles showed dramatic decreases in flow rate with relatively small increases in tensile stress (Fourie and Addis 1997). Tensile stresses of less than 3% of the ultimate tensile strength of the geotextile resulted in decreases in flow rate up to 80% compared with the unstressed specimens (Fourie and Kuchena 1995). Fourie and Addis (1999) reported that a biaxial load has the opposite influence on the opening size of thick and thin woven geotextiles. Wu et al. (2008) illustrated from experimental test results conducted on two woven and two nonwoven geotextiles that the pore size and the mean flow rate through the plain geotextiles increased with the increase in tensile strain. In this study, different load types were introduced to distinguish the effect between the in-plane strain and cyclic load on the permeability change of a soil-geotextile composite.

EXPERIMENTAL PROGRAM

Descriptions of apparatus and experimental procedure

The experimental work consists of running a filtration test on a soil-geotextile system using a permeameter. The chamber of the permeameter is made of two 10-cm diameter acrylic tube sections. A cap is secured on the top of the chamber leaving holes for water inlets, vent valve and load piston to be extruded out of the chamber. A porous steel plate is placed on top of the soil to transmit the applied load. A clamp made of two steel rings with an internal diameter of 100 mm is secured between the two sections. A layer of test soil is filled between the porous plate and the clamped geotextile. A perforated plate is used to support stainless steel beads which are placed beneath the geotextile to drain water from the soil and geotextile. A schematic diagram of the test apparatus is presented in Fig. 1.

The soil-geotextile system was a composite of soil, geotextile and drainage material. The apparatus is arranged by allowing the clamped geotextile specimen to be inserted between a 5 cm high soil layer and a layer of steel beads 15.85 mm in diameter. The steel bead layer is introduced as drainage material downstream from the water flow. The steel beads are arranged in a specific pattern such that the opening area for water flow is the same for each test and the contact area between the geotextile and drainage layer will not be a variable for the seepage flow (Wu et al. 2006). Five centimeter soil thickness is chosen to ensure that the normal load applied on the top of the soil could be transmitted fully to the inserted geotextile. The geotextile was clamped using two steel rings with an internal diameter of 100 mm. The clamped geotextile specimen was then cut free from the remaining sheet at the outer edge of the clamping ring, leaving a circular geotextile secured by the clamp.

A series of wet sieving tests were applied to the clamped geotextile to determine the pore size distribution (Wu et al. 2008). The clamped geotextile specimen was then placed in the permeameter to carry out the filtration test. Prior to the filtration test the soil-geotextile system was subjected to a specific type of normal load. Three types of loads, sustained load only, cyclic load only, and cyclic load acting on a system subjected to a sustained load, were introduced to the geotextile system. Sustained and cyclic loads were applied to the top of soil through a piston. Following the completion of normal loading, water was allowed to flow through the composite using hydraulic gradients of 1, 5 and 10. The three hydraulic gradients were designated as low, medium and high hydraulic gradients, respectively. The hydraulic gradient application started from a hydraulic gradient of 1 and ended with hydraulic gradient of 10. The subsequent hydraulic gradient was applied to the system as the discharge flow from the previous hydraulic gradient reached a relatively stable value. For all tests in this study, the elapsed times for stable seepage flows were 1100, 1000 and 1000 minutes for hydraulic gradients of 1, 5 and 10, respectively. The flow rates at various elapsed times were measured. The measured flow rate was divided by the combined thickness of the soil and geotextile and referred to as the averaged permeability of the soil-geotextile composite.

A total of 10 tests were carried out to study the load type influence on the filtration characteristics of a soil-geotextile system. The load conditions and test results are tabulated in Table 1.

Materials used

The soil used had a specific gravity of G_s = 2.60, d_{50} = 0.19 mm, the maximum and minimum unit weight of the soil are γ_{max} = 17.66 kN/m^3 and γ_{min} =12.75 kN/m^3, respectively. The unit weight for the soil filled in the permeameter was γ = 15.30 kN/m^3. The particle size distribution curve of the test soil is shown in Fig. 2. The pore size distribution of the test geotextile was determined using the procedure described in Wu et al. (2006) and shown in Fig. 2. The mass per unit area of the geotextile used is 210 g/m^2, the effective opening size is 0.112 mm. The permeability of the test soil was evaluated using the gradient ratio test apparatus.

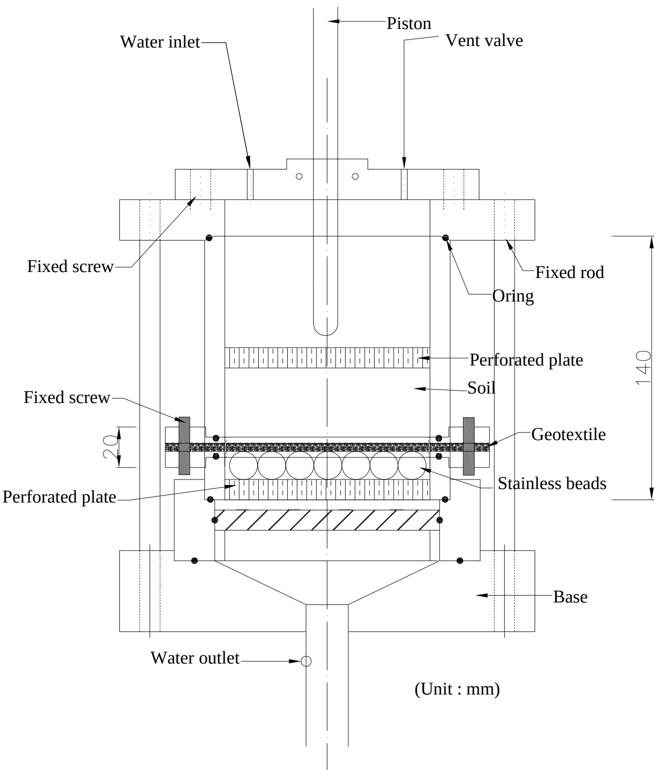


Figure 1. Schematic diagram of apparatus

Table 1. Experimental test results

Sustained load (kPa)	Cyclic load (kPa)	Soil settlement (mm)	Soil loss (g)	Void ratio	Averaged permeability (10^{-3} cm/sec)		
					i =1	i =5	i =10
0	0	0.00	2.92	0.63	1.518	1.246	0.935
0	24.5	0.38	0.76	0.61	1.588	1.444	1.126
0	98	1.73	2.10	0.57	2.426	1.859	1.587
0	196	3.43	3.62	0.52	2.835	2.284	1.965
24.5	0	0.28	1.26	0.62	1.805	1.432	1.135
98	0	1.94	3.08	0.57	2.235	1.609	1.281
196	0	2.95	2.92	0.53	2.468	1.625	1.369
49	49	2.02	2.57	0.56	3.189	2.863	2.232
98	24.5	2.48	2.68	0.55	2.664	2.610	2.318
98	98	3.36	2.61	0.52	4.032	3.264	2.540

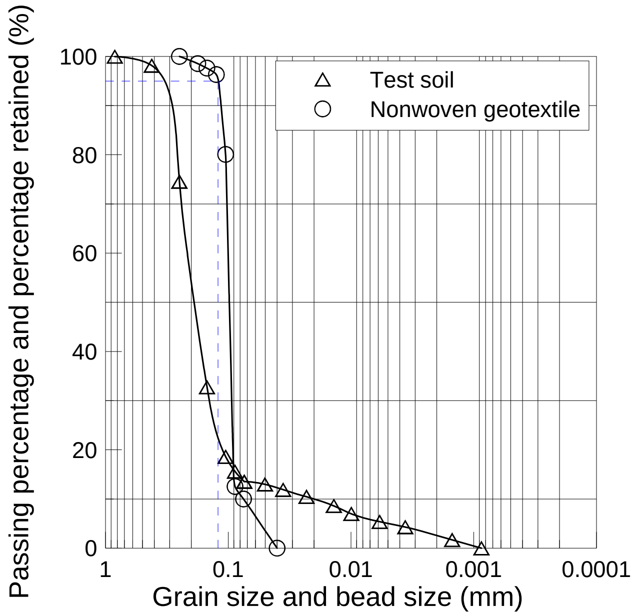


Figure 2. Particle size distribution of the test soil and pore size distribution of the test geotextile

EXPERIMENTAL RESULTS

Permeability of the pure soil and the unload soil-geotextile system

The gradient ratio test has been widely used to evaluate the clogging potential of a soil-geotextile system. Test results from this method identify the relative permeability between the soil layers at different positions. One of the advantages of the GR test is that it can evaluate the conductivity of the soil along the seepage path by measuring manometer water levels on the permeameter wall. The results can be used to assess the cause of water flow changes. The GR value is defined as the ratio of permeability between a lone soil layer and soil-geotextile layer. The permeability for the soil layer between 2.54 cm and 7.54 cm above the geotextile was adopted to represent the hydraulic conductivity of the soil alone. The permeability for the combination of the 2.5-cm soil thickness above the geotextile and the geotextile thickness represents the hydraulic conductivity of the soil-geotextile layer. Using the soil layer permeability as the reference, changes (increase/decrease) in the GR value are attributed to piping/clogging in the soil-geotextile layer. Therefore, this test method provides a good approach to determine the permeability of pure soil free of interference from the downstream material.

Figure 3 depicts the GR test results, the GR value and the permeability value of the soil alone and soil-geotextile layers are presented. The permeability value of the soil alone under different hydraulic gradients (i = 1, 5 and 10) ranges between 0.0014 and 0.0015 cm/sec, which indicates that permeability for the test soil has a stable value and is not significantly affected by the hydraulic gradient. The permeability value of the soil-geotextile layer decreases from 0.001 cm/sec for low hydraulic gradient (i =1) to 0.0005 cm/sec for high hydraulic gradient (i =10), which indicates that clogging or blinding may occur in the soil-geotextile layer while the system is subjected to high hydraulic gradient. This results in an increase in the GR value as shown in Fig. 3. By applying a normal load onto the top of the soil the thickness of the soil layer (about 12 cm) was found to hinder full normal load transmission to the geotextile. For a 12 cm height dry soil specimen placed onto a geotextile sheet, only 20-29% of the normal load applied on the soil top was transmitted to the geotextile for normal loads ranging between 100 and 1000 kPa. The greater the normal load the higher was the transmission percentage. Therefore, the GR test apparatus was excluded from running the load test due to difficulty in transmitting a full normal load to the geotextile.

The filtration test was conducted on the same soil and geotextile using the present apparatus. The variation in the averaged permeability value for the soil-geotextile composite with elapsed time using the load test apparatus is also plotted in Fig. 3. The averaged permeability value decreases with the elapsed time and reaches stable values for different hydraulic gradients. The stable averaged permeability values of the soil-geotextile composite are 0.0015, 0.0012, and 0.0009 cm/sec, respectively for low, medium and high hydraulic gradients. This result shows clogging or blinding at the soil-geotextile interface, which coincides with that obtained from the GR test.

By averaging the permeability values for the soil-geotextile layer (the combined 2.5-cm soil length and geotextile thickness) and the soil alone layer (2.5 cm) from the GR test, the averaged values are 0.0013, 0.001, and 0.00095 cm/sec. respectively for low, medium and high hydraulic gradients. These values are close to those obtained from the load test apparatus conducted on the 5-cm thick soil and geotextile.

Permeability of the system subjected to various sustained loads

Variations in the averaged permeability value with elapsed time for systems subjected to various sustained loads are presented in Fig. 4. The sustained loads are 24.5, 98 and 196 kPa. The result for a soil-geotextile system free of load is used as the reference. While the water flowed through the composites with low hydraulic gradient, the permeability values for all composites decreased with elapsed time for the first very short period of time. After that the permeability value trend was dependent on the magnitude of the sustained load. For the composite subjected to high normal load (98 and 196 kPa), the permeability value increases with elapsed time to a stable value close to or higher than the initial value. For the composite subjected to low or free of normal load (0 and 24.5 kPa), the value continued to decrease with elapsed time and reached a stable value. The filtration behavior for composite subjected to low sustained load is similar to that of the soil-geotextile layer in the GR test.

For all sustained load tests, the averaged permeability values decreased with the increase in hydraulic gradient. At a specific hydraulic gradient, the averaged permeability value of the soil-geotextile composite increased with the increase in sustained load. Variations in the averaged permeability value with sustained load for soil-geotextile composite under various hydraulic gradients are presented in Fig. 5. Subjecting soil-geotextile composites to a greater sustained load results in higher averaged permeability values. However, the increased trend subsides at high sustained load, especially for systems subjected to high hydraulic gradient.

System subjected to various cyclic loads

Two series of cyclic load tests were conducted to study the influence of cyclic loads on the soil-geotextile composite. A series of cyclic load tests was carried out on soil-geotextile composites free of sustained loads while the other series was conducted on soil-geotextile composites subjected to 98 kPa sustained loads. Cyclic loads of 24.5, 98 and 196 kPa were applied to soil-geotextile composites free of sustained load while 24.5 and 98 kPa were applied to soil-geotextile composites subjected to 98 kPa sustained load. The variations of averaged permeability value with elapsed time for composites under all types of load combinations are shown in Fig. 6. All test results show that a greater hydraulic gradient produces smaller averaged permeability values. For composites subjected to specific sustained loads and hydraulic gradients, the averaged permeability value increases with the increase in cyclic load. The relationship between the averaged permeability value and cyclic loading are presented in Fig. 7. Note that, for systems subjected to identical cyclic loads, the systems tested under 98 kPa sustained load produced greater averaged permeability values than those tested free of sustained loads.

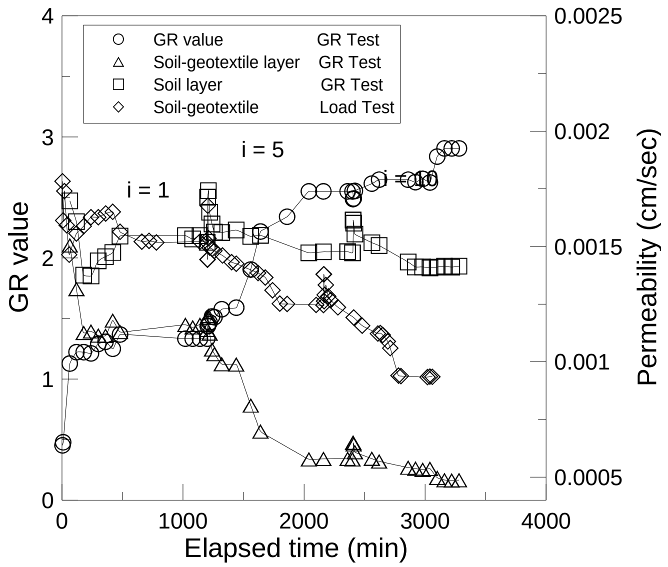


Figure 3. GR value and permeability of soil and soil-geotextile layers

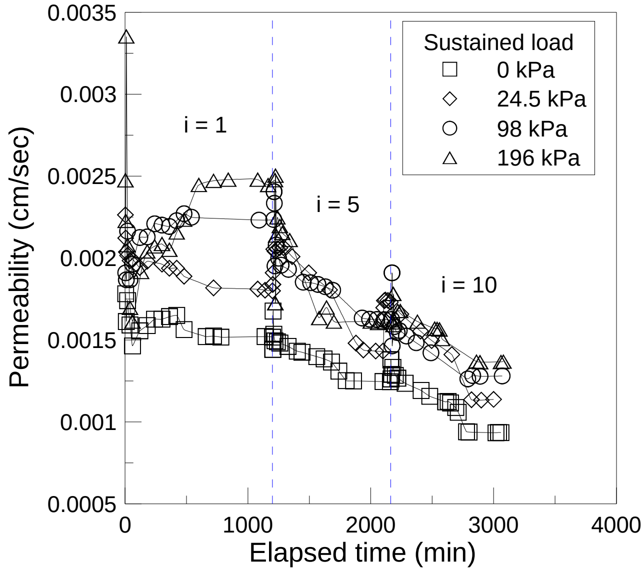


Figure 4. Variation of the averaged permeability with elapsed time for system subjected to various sustained loads (no cyclic load)

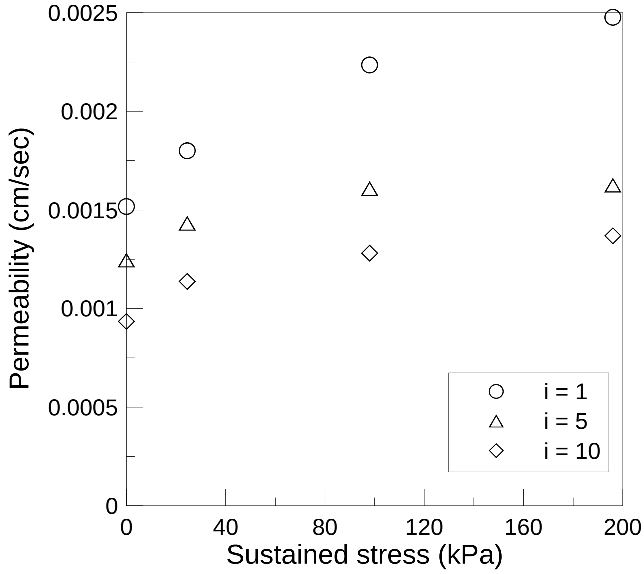


Figure 5. Relation between the averaged permeability and sustained load

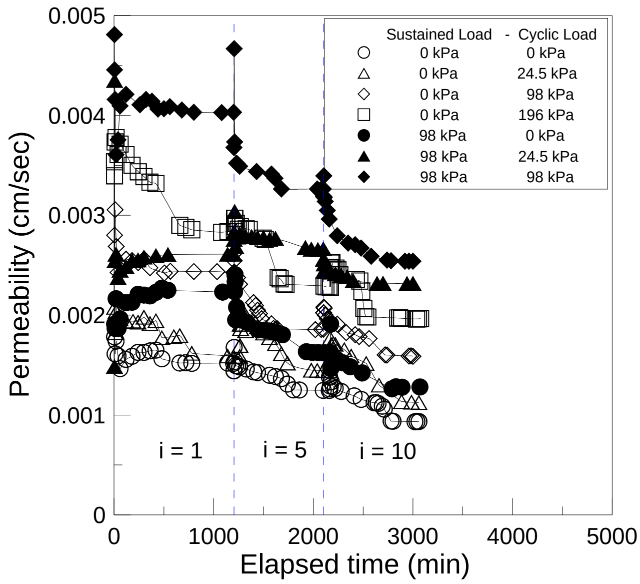


Figure 6. Influence of cyclic load on the averaged permeability for systems subjected to different sustained loads.

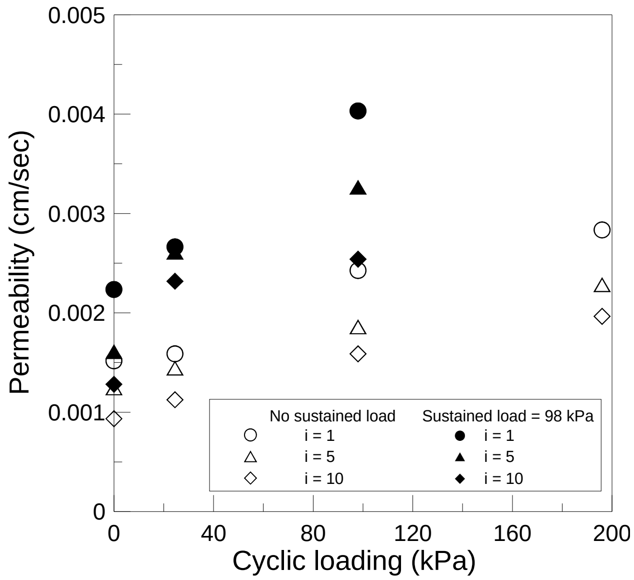


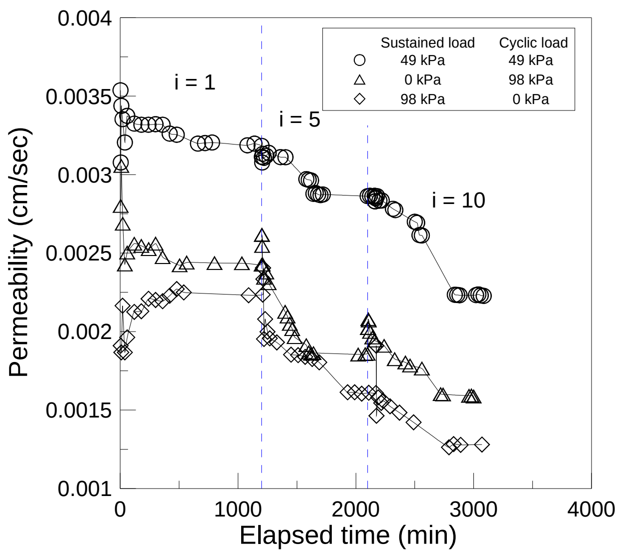
Figure 7. Relation between the averaged permeability and cyclic load (free sustained load and sustained load = 98 kPa)

Systems subjected to identical total load of various types

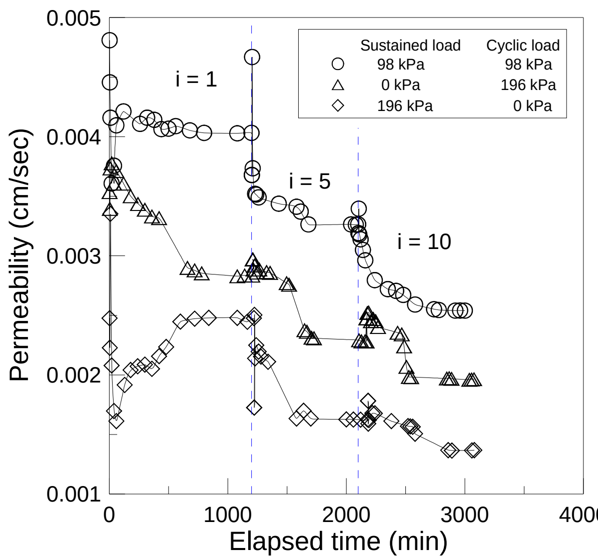
To study the influence of load type on the averaged permeability, identical total loads of various types were applied to the soil-geotextile composites. Three types of loads were applied to the composite prior to the filtration test, a sustained load only, a cyclic load only, and half the value of the sustained and half the value of the cyclic load were applied to the composite, designated as load Type 1, Type 2 and Type 3. To enhance the load combination, tests were conducted on a composite subjected to 49 kPa of cyclic and sustained loads and added into the test series. The variations in averaged permeability value with elapsed time for composites subjected to total loads of 98 and 196 kPa are depicted in Fig. 8. The results for composites tested under both total loads revealed that the composite subjected to the Type 3 load produced the highest averaged permeability value, while the Type 1 load produced the smallest value.

Soil loss, soil settlement and void ratio

The normal load application causes a reduction in the soil-geotextile composite thickness. The degree of soil compactness increases with the increase in total load (please see Table 1). The soil particle mass washed through the geotextile layer was collected, dried and weighted after filtration test completion. The soil loss mass ranged between 0.76 and 3.08 g for all tests, and there was no consistent relation found between the soil loss mass and load magnitude (please see Table 1). The soil particle mass above and remained in the geotextile, and the thickness of the soil-geotextile composite was used to evaluate the final void ratio for all tests. The results are tabulated in Table 1. The relationship between the void ratio and total pressure is depicted in Fig. 9. The results reveal that the void ratio of the composite decreased linearly with the increase in total load. The void ratio varied from 0.52 to 0.63.



(a) Total load = 98 kPa



(b) Total load = 196 kPa

Figure 8. Variations of the averaged permeability with elapsed time for systems subjected to different loading types

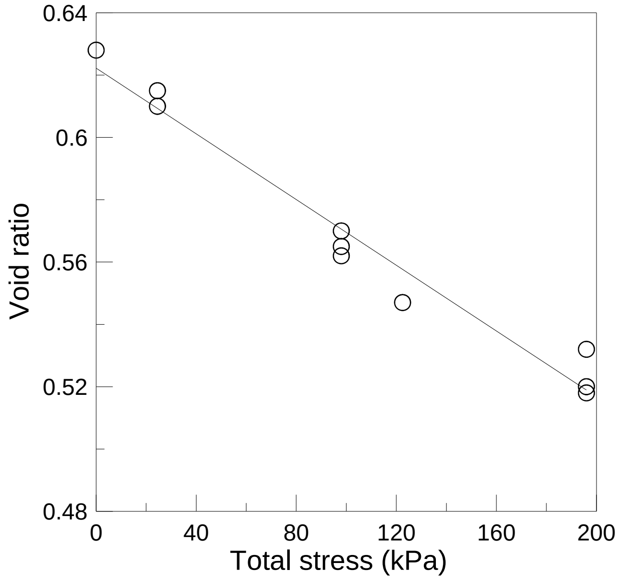


Figure 9. The relationship between soil void ratio and total load

The Kozeny-Carman equation (Kozeny 1927; Carman 1938, 1956) has been introduced into empirical relationships in estimating the hydraulic conductivity of sandy soils (Carrier 2003; Chapuis 2004). This estimation gives fairly good results when laminar flow conditions exist. The relationships suggest that

$$k \propto \frac{e^3}{1+e} \tag{1}$$

For the pure soil, the coefficient of permeability bears a linear relation to $e^3/(1+e)$. The averaged permeability value of the composite shows contradictory results to those for pure soils. The averaged permeability value increases with the increase in total load, which is coinstantaneous with the decrease in void ratio (Fig. 9). The literature on the cyclic load effect on the filtration behavior of soil-geotextile composites reports that cyclic load is one of the reasons for the increase in soil contamination (soil mass passing through a unit geotextile area) due to pumping action (Snaith and Bell 1978; Hoare 1982; Saxena and Hsu 1986). The change in the geotextile pore size distribution due to in-plane strain is another factor reported in the literature which may change the soil-geotextile system filtration characteristics (Fourie and Kuchena 1995; Fourie and Addis 1997, 1999; Wu et al. 2008).

In this study, different load types were introduced to distinguish the effect between the in-plane strain and cyclic load on the permeability change. Firstly, results from soil-geotextile composite subjected to sustained loads ranging from 0 to 196 kPa can be used to study the pore size enlargement effect. The averaged permeability value increases with the increase in sustained load although the void ratio is decreased. These results can be ascribed to the in-plane strain of the geotextile. The increase in geotextile strain results in an increase in permeability for the soil-geotextile layer and offsets the permeability decrease in the soil layer due to soil particles compactness.

Secondly, the soil-geotextile composite free of sustained load and subjected to cyclic loads ranging between 24.5 to 196 kPa exhibited both the pumping and pore size enlargement effects. The increase in cyclic load increased the averaged permeability value of the composite. Except for the composite subjected to 24.5 kPa load, composites subjected to cyclic loads have greater permeability than those subjected to sustained loads of the same amount. The increase in the averaged permeability may be attributed to the combination of in-plane strain and pumping action in the cyclic load.

CONCLUDING REMARKS

This paper studied the influence of load type on the filtration characteristics of a non-woven geotextile. Apparatus was designed and built to conduct filtration testing for soil-geotextile systems under various types of applied loads. The three types of loads were applied; sustained load only, cyclic load only, and cyclic load acting on a composite subjected to a sustained load. The load was applied to the composite prior to the filtration test. The frequency of the cyclic load was 0.1 Hz and 5000 cycles of repeated load was applied. The experimental results show: (1) By averaging the permeability values for the soil-geotextile layer (the combined 2.5-cm soil length and geotextile thickness) and the soil alone layer (2.5 cm) from the GR test, the averaged values for low, medium and high hydraulic gradients are close to those obtained from the load test apparatus conducted on the 5-cm thick soil and geotextile composite. This result indicates that the load test apparatus produced a result comparable to the GR test result for the unloaded soil-geotextile system. (2) For the soil-geotextile composite subjected to sustained loads of 24.5, 98 and 196 kPa, the composite subjected to greater sustained load resulted in a higher averaged permeability value. However, the increase trend subsides at high sustained load, especially for systems tested at high hydraulic gradients. (3) A series of cyclic load tests were conducted on soil-geotextile composites free of sustained loads and subjected to 98 kPa sustained loads. For composites subjected to specific sustained loads and hydraulic gradient, the averaged permeability value increased with the increase in cyclic load. For composites subjected to identical cyclic loads, the composites tested under the 98 kPa sustained load produced greater averaged permeability values than those tested free of sustained load. (4) Total loads of 98 and 196 kPa in different types were applied to the composites. For the composites subjected to the same amount of total load, the composite acted by half the value of the sustained and cyclic loads and produced the largest seepage flow. Composites acted on by the full value of the sustained load produced the least amount of seepage flow. (5) Different amounts of soil particles were washed through the geotextile, however, no consistent relation between soil loss mass and magnitude of load could be found. (6) The void ratio of the composite decreased linearly with the increase in total load, but the averaged permeability value of the composite increased with the increase in total load, which is coinstantaneous with the decrease in void ratio. This contradicts the pure soil characteristics attributed to the combination of geotextile in-plane strain and cyclic load pumping action.

Acknowledgements: The authors would like to thank the National Science Council of the Republic of China for financially supporting this research under Contract no. NSC96-2221-E-032-039-MY3.

Corresponding author: Prof Cho-Sen Wu, Dept. of Civil Engr. Tamkang University, Tamsui, Tamsui, Taipei, 25137, Taiwan. Tel: 886 2 26222796. Email: cswu@mail.tku.edu.tw.

REFERENCES

Bell, A.L., McCullough, L.M. & Snaith, M.S. 1982. An experimental investigation of sub-base protection using geotextiles. Proceedings of the 2nd International Conference on Geotextiles, Las Vegas, 1, 435-440.

Carman, P.C. 1938. The determination of the specific surface of powders. J. Soc. Chem. Ind. Trans., 57, 225

Carman, P.C. 1956. Flow of gases through porous media. Butterworths Scientific Publications, London.

Carrier III, W.D. 2003. Goodby, Hazen; Hello, Kozen-Carman. Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 129 (11), 1054-1056.

Chapuis, R.P. 2004. Predicting the saturated hydraulic conductivity of sand and gravel using effective diameter and void ratio. Canadian Geotechnical Journal, 41 (5), 787-795.

Floss, R., Laier, H. & Brau, G. 1990. Dynamic loading of geotextile/soil systems. Proceedings of the 4th International Conference on Geotextiles, Geomembranes and Related Products, Hague, Netherlands 1990, 1, 183-188.

Fourie, A.B. & Addis, P.C. 1997. The effect of in-plane tensile loads on the retention characteristics of geotextiles. Geotechnical Testing Journal, GTJODJ, 20 (2), 211-217.

Fourie, A.B. & Addis, P.C. 1999. Changes in filtration opening size of woven geotextiles subjected to tensile loads. Geotextiles and Geomembranes, 17 (5-6), 331-340.

Fourie, A.B. & Kuchena, S.M. 1995. The influence of tensile stresses on the filtration characteristics of geotextiles. Geosynthetics International, 2 (2), 455-471.

Hoare, D.J. 1982. A laboratory study into pumping clay through geotextiles under dynamic loading. Proceedings of the 2nd International Conference on Geotextiles, Las Vegas, 1, 423-428.

Kozeny, J. 1927. Ueber kapillare Leitung des Wassers im Boden. Wien. Akad. Wiss., 136(2a), 271.

Lafleur, J., Rollin, A.L. & Mlynarek, J. 1990. Clogging of geotextiles under pumping loads. Proceedings of the 4th International Conference on Geotextiles, Geomembranes and Related Products, Hague, Netherlands, 1, 189-192.

Lafleur, J., Assi, M. & Mlynarek, J. 1996. Behavior of nonwoven geotextiles under pumping loads. Recent Developments in Geotextile Filters and Prefabriced Drainage Geocomposites, ASTM, STP 1281, Bhatia & Suits (Eds.), American Society for Testing and Materials, 211-221.

McMorrow, J. 1990. Filtering action of non-woven geotextiles under dynamic loading. Proceedings of the 4th International Conference on Geotextiles, Geomembranes and Related Products, Hague, Netherlands, 1, 233-238.

Narejo, D.B. & Koerner, R.M. 1992. A dynamic filtration test for geotextile filters. Geotextiles and Geomembranes 11, 395-400.

Saxena, S.K. & Hsu, T.S. 1986. Permeability of geotextile-included railroad bed under repeated load. Geotextiles and Geomembranes, 4, pp. 31-51.

Snaith, M.S. & Bell, A.L. 1978. The filtration behavior of construction fabrics under conditions of dynamic loadings. Geotechnique 28, 466-468.

Wu, C.S., Hong, Y.S. & Wang, R.H. 2008. The influence of uniaxial tensile strain on the pore size and filtration characteristics of geotextiles. Geotextiles and Geomembranes. (in press).

Wu, C.S., Hong, Y.S., Yan, Y.W. & Chang, B.S. 2006. Soil-nonwoven geotextile filtration behavior under contact with drainage materials. Geotextiles and Geomembranes, 24 (1), 1-10.