The Load Type Influence on the Filtration Behavior of Soil-Nonwoven Geotextile Composite

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Abstract

The load type influence on the filtration behavior of soil-nonwoven geotextile composite has been studied through a series of tests using an experimental apparatus designed specifically for the laboratory tests. In these tests, 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. One of the three load types, namely sustained load, pulsatory load, and compound load of pulsatory and sustained load, was applied to the composite prior to the filtration test. Water was allowed to flow through the composite from the soil into a drainage layer at various hydraulic gradients. The permeability value was extracted by using Darcy’s law to characterize the filtration performance of the entire soil-geotextile composite.

The test results revealed that the void ratio decreased with the increase of total load. Composite exhibited a normal relationship between the permeability and the normal load applied; the permeability increased with an increase in the total load. Different load types could produce different results in the permeability for the soil-geotextile composites under study.

Key Words: Sustained Load, Pulsatory Load, Non-Woven Geotextile, Permeability, Soil Composite, Filtration

1. 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 a filter or separator when subjected to earth pressure and dynamic or impact loads caused by highway vehicles, railroad trains or landing aircraft. The success of these applications relies on the retention and permeability capabilities of the geotextiles, as well as the prevention of undue clogging when geotextiles are subjected to in-plane stress/strain and dynamic load. In practice, the in-plane strain may change the geotextile pore size while fine particles may be pumped out by the dynamic load action. Thus, the existing filter criteria for a soil-geotextile system, that are established based on the pore size and permeability of plain geotextile and the clogging potential of soil-geotextile system evaluated by assuming no load, cyclic or static, was applied, may not be warranted.

Some earlier studies considered the migration of “fines” that passed into and through the fabric under dynamic loads [1–3]. Laboratory tests were conducted to study the change in permeability and clogging of soil-geotextile system while subjected to dynamic load [4–8]. The effect of tensile strain on the filtration characteristics of geotextiles was studied [9–12]. The study examined the changes on filtration opening size and the permeability of geotextile while the geotextile subjected to
different in-plane tensile load, biaxial or uniaxial. Permeability test results using nonwoven and woven geotextiles showed a relatively small increase in tensile stress could result in a dramatic decrease in flow rate [10]. Tensile stress of less than 3% of the ultimate tensile strength of geotextile could induce a decrease in flow rate up to 80% as compared with the unstressed specimens [9]. Fourie and Addis [11] reported that a biaxial load has the opposite influence on the opening size of thick and thin woven geotextiles. Wu et al. [12] illustrated previously from experimental tests conducted on two woven and two nonwoven geotextiles that the pore size and the mean flow rate through plain geotextiles both increased with increase in tensile strain. In this study, different load types were introduced onto a soil-geotextile composite to investigate and distinguish the effect between the in-plane strain and the pulsatory load on the permeability change.

2. Experimental Program

2.1 Test Apparatus
The apparatus consists of a pneumatic loading device and a permeameter chamber. Two 100-mm internal diameter and 125-mm outer diameter acrylic tube sections and a clamped specimen mounted between two tube sections constitute the permeameter chamber. A clamp made of two steel rings with an internal diameter of 100 mm is employed to secure the geotextile specimen. The chamber is arranged by allowing the clamped geotextile specimen to be inserted between a 5-cm soil layer and a layer of steel beads. Steel beads were placed beneath (down stream) the geotextile specimen to serve as a drainage layer and to support the composite.

The lower acrylic section 35 mm in height seats on a steel base. This section houses stainless steel beads to support the test geotextile and to drain seepage water. A perforated plate fitted within a steel tube, adjustable along the vertical direction, is placed beneath the steel beads to support the geotextile and the soil above. The adjustable perforated plate, regulated by screwing the plate against the steel tube wall, ensures that the steel beads are level with the geotextile specimen. The upper acrylic section, 95 mm in height, contains the test soil and a porous steel plate placed on the top of soil to disperse the applied load. A top platen is mounted on top of the acrylic section, leaving holes for water inlets, a vent valve and a loading piston to intrude into the permeameter chamber. The schematic diagram and picture of experimental apparatus are both presented in Figure 1.

A layer of steel beads, 15.85 mm in diameter, is placed beneath a geotextile sheet to provide support. The steel beads are arranged in a specific pattern such that the opening area for the water flow maintains at the same value for each test. Thus the contact area between the geotextile and the drainage layer will not be a variable for the seepage flow [13].

2.2 Experimental Procedure
The test set-up assembly started with inserting the lower acrylic tube section into the base rim. A steel tube with an adjustable perforated plate was then placed inside the lower acrylic tube. Steel beads were placed on the perforated plate and adjusted to be level with the geotextile specimen. The top acrylic tube was installed and mounted on the clamped geotextile specimen between the two tube sections. Five-centimetre thick of soil was then filled into the top acrylic section on top of the geotextile specimen layer by layer. The density of soil layer was checked by each one-centimetre increment of the soil layer. Finally, a perforated plate was placed on top of the soil layers and the entire assembly secured by using three steel rods. The entire chamber setup was moved underneath the pneumatic loading device. A dial gauge was attached to the chamber setup to measure the vertical displacement of soil-geotextile composite.

Prior to a filtration test, different type of normal load could be applied to the soil-geotextile composite via the loading piston. There are three types of loads acting on the composite, namely sustained load, pulsatory load and compound load of pulsatory and sustained load. The frequency of the pulsatory load was 0.1 Hz with 5000 cycles of repeated load applied. Following the completion of normal loading, water was allowed to flow through the composite under test using hydraulic gradients of 1, 5 and 10. These three hydraulic gradients were designated as low, medium and high hydraulic gradients, respectively.

The water flow 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 the tests in this study, the elapsed times were about 1200, 900 and 900 minutes for hydraulic gradients of 1, 5 and 10, respectively. The flow rates at various elapsed times were measured and the corresponding permeability values, using Darcy’s law for the entire composite length (5-cm soil and geotextile thickness), were calculated. Soil particles remaining in the chamber were collected, dried and weighted after the completion of filtration test to determine the weight of soil particles washed through the geotextile specimen. A total of 10 tests were carried out to study the effect of load type on the filtration characteristics of soil-geotextile composite.

A series of wet sieving tests were also conducted with clamped geotextile samples to characterize the pore size distribution using the apparatus described in Wu et al. [12]. Gradient ratio test (GR test) was also performed on similar soil-geotextile composite with a thicker soil layer (10-cm) and free of the normal load.

2.3 Materials Used

The soil used had a specific gravity of \( G_s = 2.60 \), mean diameter \( d_{50} = 0.19 \) mm, maximum unit weight \( \gamma_{\text{max}} = 18.05 \) kN/m\(^3\), minimum unit weight \( \gamma_{\text{min}} = 13.15 \) kN/m\(^3\), with the particle size distribution curve shown in Figure 2. The soil specimen filled in the permeameter was controlled to a unit weight \( \gamma = 15.70 \) kN/m\(^3\).

A chemical bonded non-woven geotextile made of polypropylene was employed in this study. The mass per unit area of the test geotextile is 210 g/m\(^2\). The pore size distribution of the test geotextile is presented in Figure 2. The apparent opening size (AOS) for the geotextile determined from the distribution curve is 0.112 mm.

3. Experimental Results

The load conditions and test results for the composites are tabulated in Table 1.
3.1 Permeability of the Pure Soil and Soil-Geotextile Layers Using GR test Apparatus

The test soil permeability was evaluated using a gradient ratio test apparatus. Figure 3 depicts the GR test results, the GR value and the permeability value of the soil alone and the soil-geotextile layers are presented. The permeability value of soil alone under different hydraulic gradients (i = 1, 5 and 10) ranges between 0.0014 cm/sec and 0.0015 cm/sec. These results reveal that the test soil permeability has a stable value and is not significantly affected by the hydraulic gradient.

The permeability value of the soil-geotextile layer decreases from 0.0011 cm/sec for the low hydraulic gradient (i = 1) to 0.0005 cm/sec for the high hydraulic gradient (i = 10). This indicates that clogging or blinding might have occurred in the soil-geotextile layer when the system was subjected to a higher hydraulic gradient. Figure 3 showed a decrease in permeability value for soil-geotextile layer can result in an increase in the GR value.

3.2 Permeability of the Unloaded Soil-Geotextile Composite Using the Load Test Apparatus

The combination of 5-cm soil layer and a geotextile sheet is treated as a soil-geotextile composite unit. The permeability value, using Darcy’s law for the entire length (5-cm soil and the geotextile thickness), is adopted to represent the filtration characteristics of the entire com-

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**Table 1. Filtration test results for the loaded soil-geotextile composites**

| Sustained load (kPa) | Pulsatory load (kPa) | Soil settlement (mm) | Soil loss (g) | Void ratio | Averaged permeability $(10^{-3} \text{ cm/sec})$
<table>
<thead>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>i = 5</td>
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<td>0.00</td>
<td>2.92</td>
<td>0.628</td>
<td>1.518</td>
</tr>
<tr>
<td>0</td>
<td>24.5</td>
<td>0.38</td>
<td>0.76</td>
<td>0.615</td>
<td>1.588</td>
</tr>
<tr>
<td>0</td>
<td>98</td>
<td>1.73</td>
<td>2.10</td>
<td>0.585</td>
<td>2.426</td>
</tr>
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<td>0</td>
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<td>3.43</td>
<td>3.62</td>
<td>0.540</td>
<td>2.835</td>
</tr>
<tr>
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<td>0.28</td>
<td>1.26</td>
<td>0.619</td>
<td>1.805</td>
</tr>
<tr>
<td>98</td>
<td>0</td>
<td>1.94</td>
<td>3.08</td>
<td>0.580</td>
<td>2.235</td>
</tr>
<tr>
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<td>2.92</td>
<td>0.554</td>
<td>2.468</td>
</tr>
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<td>49</td>
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<td>2.57</td>
<td>0.577</td>
<td>3.189</td>
</tr>
<tr>
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<td>2.48</td>
<td>2.68</td>
<td>0.564</td>
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</tr>
<tr>
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<td>98</td>
<td>3.36</td>
<td>2.61</td>
<td>0.540</td>
<td>4.032</td>
</tr>
</tbody>
</table>

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

**Figure 3.** GR value and permeability of soil and soil-geotextile layers.
posite. The variation of permeability with elapse time for a soil-geotextile composite measured by using the load test apparatus is also plotted in Figure 3. It shows that permeability value decreases with the elapsed time and reaches a stable value for each different hydraulic gradient. The stable permeability values are 0.0015 cm/sec, 0.0012 cm/sec, and 0.0009 cm/sec, respectively for low, medium and high hydraulic gradient. This result reveals that clogging or blinding at the soil-geotextile interface that is consistent with the finding obtained from the GR test.

By averaging the permeability values for the soil-geotextile layer (the combined of 2.5-cm soil length and the geotextile thickness) and the soil alone layer (2.5 cm soil length) from the GR test, the averaged values are 0.00133 cm/sec, 0.00103 cm/sec, and 0.00095 cm/sec for low, medium and high hydraulic gradient respectively. These values are close to those permeability results obtained by using the load test apparatus for the 5-cm thick soil and geotextile.

3.3 Permeability for the Soil-Geotextile Composites Subjected to Various Sustained Loads

Variations in the permeability value against elapsed time for the soil-geotextile composites subjected to sustained load of 24.5 kPa, 98 kPa and 196 kPa are presented in Figure 4. The result for the same soil-geotextile composite free of load is used as the reference. While water flows through the composites with a 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 varies depending on the magnitude of the sustained load.

For the composite subjected to high normal load (98 kPa 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 (24.5 kPa) or free of normal load, the value continued to decrease with elapsed time and reached a stable value. The filtration behaviour for a composite subjected to low sustained load is similar to that of the soil-geotextile layer in the GR test free of a normal load.

For all sustained load tests, the permeability value decreases with the increase in hydraulic gradient. At a specific hydraulic gradient, the permeability value of soil-geotextile composite increases with the increase in sustained load. Variations in the permeability value with sustained load for the composites subjected to various hydraulic gradients are presented in Figure 5. A composite subjected to a greater sustained load produces a higher permeability value. However, this increase trend subsides at high sustained load, especially for a composite subjected to a high hydraulic gradient.

3.4 Permeability for the Soil-Geotextile Composites Subjected to Various Pulsatory Loads

Two series of pulsatory load tests were conducted to

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**Figure 4.** Variation of the permeability with elapsed time for composite subjected to various sustained loads.

**Figure 5.** Relation between the permeability and sustained load.
study the influence of pulsatory load on the soil-geotextile composite. A series of 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.

Pulsatory loads of 24.5 kPa, 98 kPa and 196 kPa were applied to composites free of sustained load. Pulsatory loads of 24.5 kPa and 98 kPa were applied to composites subjected to 98 kPa sustained load. The variations in permeability value with elapsed time for composites under all types of load combinations are shown in Figure 6. All test results indicates that a greater hydraulic gradient produces a smaller permeability value. For a composite subjected to a specific sustained load and hydraulic gradient, the permeability value increases with the increase of pulsatory load. The relationship between the permeability and the pulsatory load is presented in Figure 7. Note that for composites subjected to identical pulsatory loads, the composites tested under 98 kPa sustained load exhibited higher permeability values than those tested free of sustained load.

### 3.5 Permeability for the Soil-Geotextile Composites Subjected to Identical Total Load of Various Types

To study the influence of load type on the permeability, identical total loads of various types were applied to the soil-geotextile composites. Prior to the filtration test different type of normal load was applied to the composite via the loading piston. Three types of loads, a sustained load, a pulsatory load, and compound load of pulsatory and sustained load were applied onto the composite, designated as load Type 1, Type 2 and Type 3. To expand the load combinations, tests were also conducted on a composite subjected to 49 kPa of pulsatory and sustained loads and added into the test series. The variation in permeability values with elapsed time for composites subjected to total loads of 98 kPa and 196 kPa are depicted in Figure 8. The results reveal that the composite subjected to the Type 3 load produces the highest permeability value, while the Type 1 load produces the lowest value.

### 3.6 Soil Loss, Geotextile Displacement and Soil Void Ratio

A normal load causes a thickness reduction in the soil layer and a downward displacement in the clamped geotextile specimen. This results in a denser soil specimen. To evaluate the compactness of the soil layer under normal load application, the composite settlement and the geotextile downward displacement should both be measured. Because the present apparatus is incapable of measuring the downward displacement in a clamped geotextile specimen, the geotextile downward displacement corresponding to different normal load should be...
calibrated separately for dried composite. Two cycles
(loaded-unloaded) of a normal load up to 440 kPa were
applied onto the top of dry soil-geotextile composite for
calibration. The displacements at the centre of geotextile
specimen corresponding to normal loads were measured
with the results shown in Figure 9. The downward dis-
placement increases with an increase in normal stress,
however, no significant rebound was found when the
composite specimen was unloaded. Reloading the com-
posite also produced a negligible displacement response.

The soil mass loss of composites ranges between
0.76 g and 3.62 g for all tests. No consistent relationship
was found between the soil mass loss and the load mag-
nitude (please see Table 1). The soil particle mass re-
mained in the chamber and the soil-geotextile composite
thickness were used to evaluate the final soil void ratio.
The final composite thickness was obtained by adding
geotextile downward displacement to, and subtracting
soil settlement at top from the initial thickness. Because
the geotextile specimen deforms unevenly when sub-
jected to normal loads, it deforms mainly in the blank
area between the steel beads. For simplicity, half of the
measured geotextile’s downward displacement from the
calibration test is used as the value for the averaged
geotextile downward displacement. The final void ratios
for different composites are presented in Table 1. For all
load types applied to the composite, the soil void ratio
varies from 0.540 to 0.628. The relation between the soil
void ratio and the total load is depicted in Figure 10. The
experimental results show that the degree of soil comp-
pactness increases with the increase of total load; the
load type exhibits no significant effect on the void ratio
(please see Table 1). Figure 10 indicates that the soil void
ratio in a composite decreases with the increase of total
load. A sharper reduction on soil void ratio occurs for
composites subjected to low total loads.

4. Discussion

The Kozeny-Carman equation [14–16] has been in-
corporated into an empirical relationship to estimate the
hydraulic conductivity of sandy soils [17,18]. This esti-
mation gives fairly good results for predicting the lam-
nar flow seeping through soil. The relationship suggests
that

\[ k \propto \frac{e^3}{1+e} \]  

For pure soil, the coefficient of permeability bears a
linear relation to \( e^3/(1 + e) \). Here \( e \) is soil void ratio. The
permeability value of the composite obtained from the
load test contradicts that of pure soil estimated by using
Eq. (1). For the composite subjected to sustained load,
the permeability value of the composite is increased
while the load increased, which is coincident with the
decrease in soil void ratio (Figure 10). Because the geo-
textile sagging between steel beads produces in-plane
strain [19], the pore size distribution of geotextile and
therefore the soil-geotextile system filtration characteristics were changed [9–12]. The literatures on the filtration behavior of soil-geotextile composite subjected to cyclic load reported that cyclic load could contribute to the increase of soil contamination (as soil mass passing through a unit geotextile area) due to the pumping action [2,4,20].

In this study, different load types have been experimented to distinguish the effect between an in-plane strain and a pulsatory load on geotextile composite specimens in terms of the permeability change. Firstly, results from a soil-geotextile composite subjected to sustained load ranging from 0 to 196 kPa can be used to study the pore size enlargement effect. While the void ratio decreases, the permeability value of the composite increases with an increase in sustained load. These results can be attributed to the in-plane strain of geotextile. The increase in geotextile strain results in an increase in permeability for the soil-geotextile layer. That can offset the permeability decrease in the soil layer due to increasing soil particles compactness.

Secondly, a soil-geotextile composite free of sustained load but subjected to a pulsatory load ranging between 24.5 kPa to 196 kPa exhibited both pumping and pore size enlargement effects. The increase in pulsatory load increased the permeability value of the composite.

Except for the composite subjected to 24.5 kPa load, all composites subjected to pulsatory load exhibited higher permeability than those subjected to sustained load of the same value. The increase in the permeability could be attributed to the combination of in-plane strain and pumping action induced by the pulsatory load. Thus, these results reveal that pumping does reduce the blocking or clogging potential of the soil-geotextile combination.

5. Concluding Remarks

This paper studied the effect of different load type on the filtration characteristics of chemical-bonded nonwoven geotextile-soil composite. An experimental apparatus was designed and built to conduct the filtration tests on soil-geotextile composites by applying various types of normal load on the composite under test. One of the three load types, namely sustained load, pulsatory load, and pulsatory load acting on with a sustained load, was applied to the composite prior to the filtration test. The frequency of the pulsatory load was 0.1 Hz and composites under test subjected to 5000 cycles of repeated load for the test.

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, this averaged value is close to the permeability value of 5-cm thick soil and geotextile composite obtained from a new load test apparatus reported in this paper. This result indicates that new load test apparatus could be used to generate comparable GR test result for an unloaded soil-geotextile system.

2. For the soil-geotextile composite subjected to sustained load alone, the permeability value increases with an increase in sustained load. However, the increase trend on permeability subsides at high sustained load, especially for the composites tested at high hydraulic gradients.

3. For the composites free of sustained load or subjected to 98 kPa sustained load, their permeability values increase with an increase on pulsatory load. For composites subjected to an identical pulsatory load, the composite tested with 98 kPa sustained load produces greater permeability value than that tested free of sustained load.

4. Different load type produces various permeability results for the soil-geotextile composites. For composites subjected to a certain magnitude of total load, compound load of pulsatory and sustained load (Type 3 load) produces the highest permeability values amongst the three load types. Composites acted on by the sustained load (Type 1 load) produces the lowest permeability values.

5. Different amount of soil particles could be washed through the geotextile, however, no consistent relation between soil loss mass and magnitude of load could be found.

6. For composites subjected to different load types, the degree of soil compactness increases with the increase in total load. As a consequence, the void ratio of soil in the composite decreases with the increase in total load. Test results in the present study show that permeability of the composite increases with the increase in total load, which contradicts the pure soil characteristics. Geotextile in-plane strain and pumping action can be used to illustrate this relation.

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References


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