BLINDING AND CLOGGING OF A NONWOVEN GEOTEXTILE

TATSUAKI NISHIGATA\textsuperscript{1)}, R. JONATHAN FANNIN\textsuperscript{1)} and YOGINDER P. VAID\textsuperscript{1)}

ABSTRACT

The filtration compatibility of soil-geotextile systems has been assessed experimentally in the laboratory with the gradient-ratio test. A nonwoven geotextile was used against a variety of model soils that were prepared from glass beads. They exhibited a range of fines content, in both gap-graded and broadly-graded size distributions. Filter blinding and clogging, if it happens, occurs within hours of initiating unidirectional flow. The zone of soil above the geotextile that is influenced is relatively thin. In gap-graded soils, the movement of fine particles appears to occur at a condition of $D_{55}/D_{15}>8$. A new dimensionless index is proposed to quantify the internal stability of gap-graded soils.

Key words: erosion, geotextile, sand, seepage, silt (IGC: E7/D4/H7)

INTRODUCTION

The use of geotextiles in filtration applications requires the selection of a fabric that retains the soil to be protected, without development of an unacceptably low permeability across the filter zone. Two concerns exist for soil retention. One is that of continued piping of fine particles through the geotextile after formation of a filter zone, which may lead to internal erosion. The other is that of entrapment of fine particles against and/or within the geotextile which may result in blinding and/or clogging of the fabric. The ASTM gradient-ratio test (D5101) was developed as a performance test for evaluation of soil-geotextile compatibility in such applications.

The gradient-ratio (GR) is defined by the ratio of hydraulic gradient in the soil-geotextile composite ($i_\phi$) to that in the soil ($i_s$), where, with reference to manometer port locations 3, 5 and 7 (see Fig. 1):

$$GR = \frac{i_\phi}{i_s} = \frac{i_7}{i_5}. \quad (1)$$

Ideal conditions would yield a uniform head loss through the soil sample, and a gradient ratio value of unity ($GR=1$). Entrapment of fine particles on or within the geotextile results in a zone of relatively lower permeability, and an increased head loss across the composite soil-geotextile filter zone. The value of gradient-ratio then exceeds unity ($GR>1$). The U.S. Army Corps of Engineers (1977) proposed a criterion $GR<3$ to avoid a potential for catastrophic clogging, that was supported by Haliburton and Wood (1982) from tests on silty sand samples with different silt contents. Design guidance for critical/severe conditions (Christopher and Holz, 1985; Canadian Geotechnical Society, 1992; Holz et al., 1997) has subsequently included that criterion, recognizing that it is based on limited testing.

The objective of the research described in this paper is...
to use observations of filtration behaviour to examine the influence of particle-size distribution on blinding and clogging, from gradient-ratio tests on a nonwoven geotextile. A series of broadly-graded and gap-graded model soils were examined, for conditions of unidirectional flow, against one needle-punched nonwoven geotextile. The variation of gradient-ratio with time, and observations of seepage-induced movement of fine particles, were used to seek further confirmation of recommended guidance for design practice.

TEST PROGRAM AND MATERIALS

Tests were performed on eight reconstituted, homogeneous, saturated model soils. The particle-size range matches that of a silty sand (see Table 1). Six samples had a fines content (<75 μm) of approximately 20%: one sample was broadly-graded (#0), and five were gap-graded (#1 to #5). Two samples had a higher fines content of approximately 30 and 40% (#1A and #1B): both were gap-graded. The model soils were prepared from blends of commercially-available round glass beads, and particle-size distribution curves are illustrated in Fig. 2.

One needle-punched nonwoven geotextile was used in testing, for which material properties are reported in Table 2. The characteristic opening size, O<sub>95</sub>, is established from a wet sieving test using glass beads (JSSMFE, 1994).

TEST EQUIPMENT

The rigid-wall permeameter accommodates a soil sample 102 mm in diameter and about 110 mm in length, L. Manometer ports that connect to glass tubes are located at seven elevations. Ports 3, 5 and 7 are used to determine the gradient ratio in accordance with ASTM D5101. Ports 2, 4 and 6 are additional ones that have been included to better define the distribution of water head through the soil, the latter port being 8.0 mm above the geotextile (Fannin et al., 1994). It is used to define a modified gradient-ratio that is a more sensitive index of soil-geotextile compatibility:

\[
GR_{mod} = \frac{i_{o1}}{i_{95}}.
\]  

The need for this better definition of head loss adjacent to the geotextile is well-recognized (Chang and Nieh, 1996; Austin et al., 1997). Unidirectional flow down through the soil and geotextile is controlled by a constant differential head, \( h_{17} \). An energy dissipater is mounted below the inlet, to prevent disturbance of the top surface of the soil sample in tests where the flow rate is high. The system hydraulic gradient, \( i_{17} \), is defined as:

\[
i_{17} = \frac{h_{17}}{L + t_g}
\]  

where \( t_g \) is the thickness of the geotextile specimen.

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<tr>
<th>Table 1. Properties of the model soil samples</th>
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<td>Sample No.</td>
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<tr>
<th>Table 2. Properties of the non-woven geotextile</th>
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<td>Mass/unit area</td>
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<td>Opening size, O&lt;sub&gt;95&lt;/sub&gt;</td>
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<tr>
<td>Tensile strength</td>
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<td>Grab strength</td>
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SAMPLE PREPARATION TECHNIQUE AND TEST PROCEDURE

In preparation for testing, the geotextile specimen was de-aired by boiling it in water. Homogeneous, saturated model soil samples were reconstituted in a loose condition using a slurry deposition method (after Kuercis and Vaid, 1988). Further details of the sample preparation technique are given by Fannin et al. (1994). De-aired water, treated with a liquid algicide to prevent biological growth, was recirculated during testing.

The test procedure requires measurements of water head $h$ (assuming water level in manometer 7 as datum) and flow rate $q$ be taken at an imposed hydraulic gradient $i_{17}$ across the soil sample and geotextile specimen. All tests were conducted at $i_{17}=5$, for a total of 11 to 14 days.

Upon completion of testing, the sample was drained and a thin-walled tube of 50 mm diameter then inserted to extract an undisturbed core. The core was cut into 5 mm sections that were sieved on a 0.075 mm mesh, to establish the distribution of fines content along the length of the sample.

TEST RESULTS AND ANALYSIS

Permeability

The system permeability $k_{17}$ is found to be nearly constant with elapsed time, and in the range 0.001 to 0.008 cm/s. Sample 1 yields the highest permeability. A good agreement is observed in a test that was repeated on the same gradation, termed Sample 1R (see Fig. 4a). Samples 3, 4 and 5 exhibit a decrease in system permeability (see Fig. 5a) that is consistent with the diminishing particle-size distribution of the soil matrix (see Fig. 2). Likewise, the decrease in permeability observed for Samples 1-A and 1-B (see Fig. 6a) is consistent with their increasing fines content (see Fig. 2). Samples 2 and 3, which have a similar particle-size distribution, have a similar value of $k_{17}$. The same observation applies to Samples 0 and 1-A.

Water Head Distribution

Ideally, a homogeneous sample will exhibit an initial gradient-ratio value $GR_{mod}=GR=1$. A lower value would imply a more permeable zone immediately upstream of the geotextile and, in contrast, a higher value would suggest a less permeable zone associated with entrapment of fines on or within the geotextile. For the condition $GR_{mod}=GR=1$, inspection of the modified gradient-ratio value (see Figs. 4b to 6b), determined over a relatively thin 8 mm zone above the geotextile, confirms it to be a more sensitive index than the gradient-ratio established for a thicker 25 mm zone determined in accordance with ASTM D5101 (see Figs. 4c to 6c). Sample 0 exhibits a constant $GR_{mod}=GR=1$ with time. In contrast, a rapid and very significant increase occurs in Sample 1, to a $GR_{mod}=6$. A rapid, but moderate change occurs in Sample 2, to a $GR_{mod}=2$. A value close to unity is observed for Samples 3, 4 and 5. Compared to Sample 1, a significant and moderate increase is observed for Samples 1-A and 1-B respectively.

A change in the value of gradient-ratio with time suggests a non-uniform distribution of water head is established during permeation of the sample. The variation of hydraulic gradient observed between manometer ports over time is shown for the tests that yielded a $GR_{mod}>2$, namely Samples 1, 2 and 1-A, in Figs. 7 to 9. A large hydraulic gradient exists between ports 6 and 7 ($i_{17}>10$), indicative of a marked head loss in this 8 mm thick zone. All other values of hydraulic gradient are less than the system hydraulic gradient $i_{17}=5$, implying the marked head loss is very localised within the sample. Sample 1-A responds in a similar manner, with the exception that $i_{17}>i_{17}>5$, which suggests the zone in which head loss occurs
(a) Variation of system permeability with time

(b) Variation of GR with time

(c) Variation of GR with time

Fig. 5. Test results (Samples 3 to 5)

Fig. 6. Test results (Samples 1 to 1-B)

Fig. 7. Variation of hydraulic gradient with time: Sample 1

is slightly thicker than that of the other two samples.

Fines Content
Examination of a core extracted from the sample after testing, and sieve analysis of discrete layers taken from it, established the variation of fines content along the length of the sample. For reference, the fines content of Sample 1 after testing is compared with that before testing, with the latter profile being established from a "dummy" sample (see Fig. 10a). The initial fines distribution is reasonably uniform, in the range 15 to 20%, and believed consistent with a homogeneous sample. A fines content greater than 25% adjacent to the geotextile, at the end of testing, is attributed to a migration of fines from the sample and entrapment by the fabric structure. The after-test profile
DISCUSSION

Particle Migration

Restrain of particle migration in a soil relies on the pore constrictions between the primary fabric of the soil being small enough to hold finer particles in place. Kenney and Lau (1985) report the gradation stability of a soil is governed by three factors: (i) particle-size and size distribution, (ii) porosity or relative density, and (iii) the severity of the disturbing forces. This current study examines filtration behaviour for different particle size distributions against a geotextile, at similar loose densities, and at the same hydraulic gradient \(i_{17}=5\). Taylor (1948) shows, from analysis of geometry, that a small sphere can move through the gap between three larger and equal spheres, arranged with the densest state of primary fabric, if the ratio of diameters exceeds 6.5 (see Fig. 11). Bertram (1940) demonstrates, from laboratory investigation of reconstituted tamped soils at hydraulic gradients in the range 6 to 20, that appreciable migration of one uniform soil into an adjacent uniform soil occurs when the particle-size ratio exceeds 10. For the spherical glass bead samples tested in this study, a plot of modified gradient-ratio against \(D_{50}/D_{15}\) reveals a marked change in behaviour at \(D_{50}/D_{15}=8\) (see Fig. 12). For reference, a uniform distribution of water head yields \(GR_{mod}=\frac{1}{10}\). A value of gradient-ratio greater than unity is indicative of particle migration within the sample leading to entrapment of most or all of those fines against the geotextile. Assuming \(D_{50}\) to characterise the primary fabric of the soil, or large spheres, and \(D_{15}\) the fine fraction, or small spheres, the behaviour appears very consistent with the theoretical analysis of Taylor (1948) and laboratory
observations of Bertram (1940).

Kenney and Lau (1985) present two graphical methods to assess the potential for grading instability, established from seepage tests under conditions of discharge rate and light vibration believed to be severe in comparison to engineering practice. The basis of each method is a mass fraction analysis, and associated boundary between the grain size characteristics of soils that exhibit stable and unstable gradings. Analysis of the materials used in this study indicates Samples 1, 2 and 1-A are unstable gradings, that Samples 3 and 1-B are borderline, and that Samples 0, 4 and 5 are stable gradings. The analysis is consistent with the relationship between $GR_{mod}$ and $(D_{95}-D_{50})/(D_{50}-D_{10})$ illustrated in Fig. 13. This non-dimensional ratio of particle size is proposed in order to quantify the potential for grading instability, for materials in which the gap, or size-deficiency, lies between $D_{50}$ and $D_{15}$.

Design Criteria for Clogging

Criteria for clogging address the opening size of a geotextile, and the nature of the soil against which it is placed. It is suggested that the porosity of nonwoven geotextiles exceed 50%, and the percent open area of woven geotextiles exceed 4%. For a broadly-graded soil (CU > 3), and less critical or severe conditions, Holtz et al. (1997) require the permeability of the geotextile exceed that of the soil and:

$$O_{95} \geq 3D_{15}.$$  

(4)

Where $O_{95}$ is the opening size of the geotextile for which 95% of the pores are smaller.

For critical or severe conditions it is recommended that a gradient-ratio test be performed, in sandy and silty soils, to assess directly the compatibility of soil and geotextile. It is also recommended for soils that have an unstable grading.

Three of the samples used in this study have an unstable grading and demonstrate a tendency toward clogging of the geotextile, taken arbitrarily as $GR_{mod} > 2$ (see Fig. 13). The remaining five samples have a stable grading.

The range of $D_{15}$ for the tested samples is relatively small, lying between 0.035 and 0.043 mm (see Table 1). The value of $O_{95}$ opening size for the geotextile is 0.070 mm (see Table 2). Consequently, eight tests exhibit a $O_{95}/D_{15}$ ratio of approximately 2, and none satisfy the criterion of Eq. (4). The results indicate that clogging will likely occur when $O_{95}$ is less than 3 $D_{15}$, and the soil has an unstable grading. However, they imply the criterion is conservative for soils that are internally stable.

CONCLUSIONS

Gradient-ratio tests were performed on model soils and a needle-punched nonwoven geotextile. The model soils, prepared from glass beads, exhibited the particle-size range of a silty sand and included gap-graded size distributions. The gradation curves yielded stable and unstable gradings. The silt-size content varied between 20 and 40%. The geotextile was selected for its relatively small pore-size openings. The following conclusions are drawn on the phenomenon of blinding and clogging due to seepage flow:

(1) The onset of blinding and clogging occurs very rapidly, and is evident within hours of initiating flow. The action is attributed to movement of fine particles within the sample that are entrapped on and within the surface of the geotextile.

(2) Post-test observations, of fines content along the sample length, show the zone above the surface of the geotextile that is influenced by blinding and clogging to be relatively thin. It has a thickness less than 10 mm.

(3) The modified gradient-ratio value, based on a port located 8 mm above the surface of the geotextile, is confirmed to be a more sensitive index of soil-geotextile compatibility.

(4) The movement of fine particles in moderately dense, gap-graded samples, appears to initiate at a condition of
$D_{so}/D_{15}>8$. This ratio compares well with the theoretical analysis of two unequal sized spheres proposed by Taylor (1948).

(5) A dimensionless index $(D_{90}-D_{50})/(D_{so}-D_{15})$ is proposed to quantify the potential for grading instability in materials with a size-deficiency, or gap, between $D_{50}$ and $D_{15}$.

(6) For the combination of materials used in testing, two conditions were found necessary for blinding and clogging to occur. First, the soil must be internally unstable. The mass fraction analysis technique of Kenney and Lau (1985) is a suitable predictor. Second, the geotextile must have pore-size openings that are sufficiently small compared with the size of the migrating particles. The criterion of Holtz et al. (1997) is confirmed as appropriate in this case.

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**REFERENCES**


