Development of a New Filtration Testing Apparatus Involving Mechanical Stresses

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ABSTRACT: Filtration testing is typically conducted using ASTM D5101. However, this procedure, developed in the mid 80's, presents numerous limitations as it is only possible to simulate steady state flows under constant hydraulic heads, and there is no mechanical stresses applied on the soil/geotextile system. The actual filtration applications for which the field conditions correspond to, can be reproduced in an ASTM D5101 test, however, are limited to a fraction of many drainage applications (agricultural drainage or foundations drainage). In fact, many geotextile filter applications, including separation in roadways or hydraulic applications, will involve reversing flows or mechanical stresses, and even some dynamic stresses as the case of shore protection or traffic. A new apparatus was developed to reproduce at the laboratory scale the conditions experienced by a soil-geotextile system in such applications. This apparatus has the capacity to apply mechanical stress on the soil/geotextile structure, as well as to apply reversing flows. Measurements and application of the stress are controlled by a computer, which is also used to collect flow rates and piezometric levels within the soil. The mass of soil passing through the geotextile can also be collected during the test, without influencing the piezometric readings. This paper presents details of the apparatus as well as results of a few tests conducted per ASTM D5101 as well as per this updated procedure. It is shown that mechanical and hydraulic stresses are important factors to be considered while designing geotextile filters.

1 INTRODUCTION

In presence of some soils such as non-cohesive, fine-grained soils, designing geotextile for filtration may require to conduct a filtration test as per ASTM D5101, as stated by Mlynarek (1999) or AASHTO M288. However, even in the case such a test were conducted, there are some situations where the filtration test will demonstrate that the soil / geotextile system is compatible, but where the actual field experience may be different. This is believed to be related to the fact that ASTM D5101 considers solely the hydraulic gradient as a variable influencing the filtration behavior, but neglects other factors such as cyclic flows and/or steady or cyclic mechanical stress.

In the field, soil-geotextile systems are always exposed to different constraints presented by the hydraulic and mechanical environment. Consequently, the ASTM D5101, which simulates only a constant hydraulic head, is not believed to allow for proper characterization of several field conditions. Moreover, if mechanical and/or hydraulic stresses are found to adversely influence the compatibility of a soil / geotextile system with respect to filtration, this test could be considered to be non-conservative, thus inappropriate for design in its standard form for many field conditions.

2 SCOPE OF STUDY

This study focuses on the influence of mechanical stresses on the soil-geotextile compatibility, applied to the cases when the ASTM D5101 presents good soil-geotextile compatibility, but mechanical conditions encountered in the field lead to a decrease in the geotextile retention capacity or clogging effects.

This paper illustrates this discrepancy between standard laboratory testing and results obtained in the field and therefore, the inadequacy of the traditional testing regimes to date.

Other studies were conducted by the University of British Columbia (Srikongsri, 2007) to observe the behavior of soil geotextile systems under cyclic flows.

3 FILTRATION TEST DEVICE

The new Gradient Ratio testing apparatus developed by SAGEOS was designed to allow for the analysis of the compatibility of soil-geotextile systems under static or dynamic mechanical stresses. It includes a permeameter, an axial loading system and a soil collector (Fig. 1).

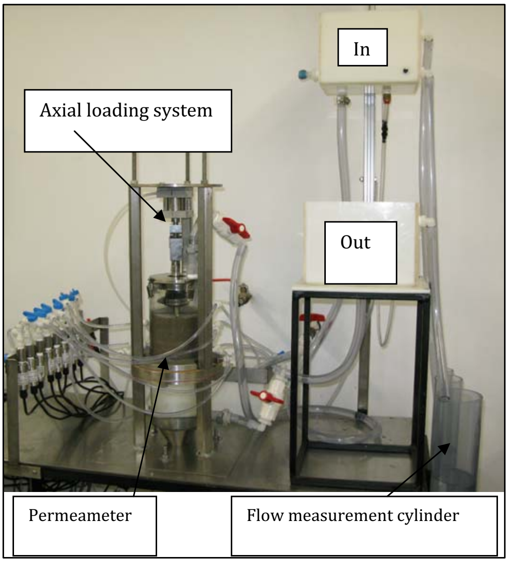

Figure 1. GR test device.

3.1 *Permeameter*

The permeameter is a rigid, transparent cylinder. Soil is placed above the geotextile in the cylinder and water flows vertically through the system under a range of hydraulic heads. One pressure transducer is located under the geotextile, six are located 6 mm, 25 mm and 75 mm above the geotextile (ports 2 to 7), and one above the soil.

Flow rate is determined by volumetric measurements, and recorded at the same frequency than the piezometric levels.

3.2 *Axial loading system*

A load up to 200 kPa is applied on the soil by means of a piston pressing on a mesh wire placed above the soil.

3.3 *Soil collector*

The particles of soil that pass through the geotextile are collected in a pipe system connected to the permeameter. A system of three ball valves allows for collecting the soil during the test, without influencing the water pressure at any location in the test area (Fig. 2).

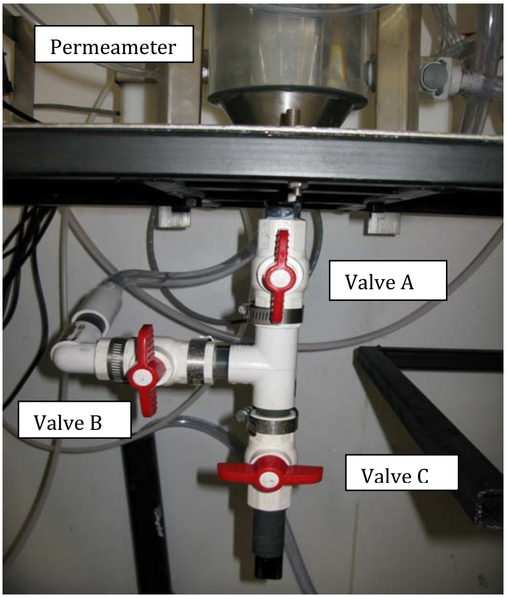

Figure 2. Soil collector.

4 TEST MATERIALS

4.1 *Soil*

For this study, a cohesionless soil was selected because of its critical nature. It is a silty soil, for which piping phenomena was observed in the field, whereas Gradient Ratio test results would not present any undesirable behavior.

A grain size analysis was conducted to determine the particles distribution, which is presented in Fig. 3.

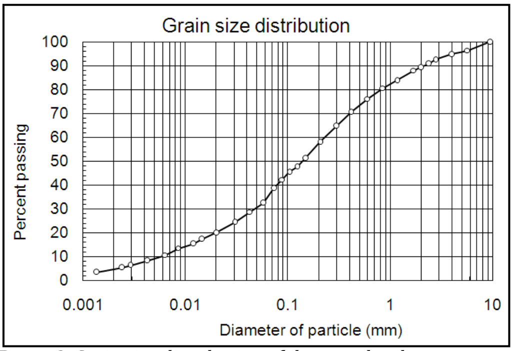

Figure 3. Grain size distribution of the tested soil.

4.2 *Geotextile*

The geotextile used in this study is a needle-punched, nonwoven with staple fiber and made of polypropylene, with a Filtration Opening Size (FOS, as measured per CAN-CGSB 148.1 n°10) of 146 µm.

4.3 *Soil-geotextile compatibility*

According to the design tool developed by Mlynarek (1999), the FOS of the geotextile should be between 150 µm and 850 µm For unidirectional flows, and between 150 and 300 µm for bidirectional flow / non-severe hydraulic conditions, or 100 to 130 µm for severe hydraulic conditions (i.e. wave attack).

Because the soil falls into a problematic category, AASHTO M288 would recommend a filtration test to confirm the applicability of any candidate geotextile.

5 TEST METHODOLOGY

5.1 *Test procedure*

The test conducted consists of a 24 h period of filtration testing without application of any normal load, followed by a 24 h period of cyclic mechanical stress.

In both cases, the hydraulic gradient was set to 5. The normal stress used was 10 kPa and the wave period 10 seconds.

5.2 *Definition of the 'Gradient ratio'*

The gradient ratio is defined by the ratio of the hydraulic gradient at the soil-geotextile interface (i_{sg}) and the hydraulic gradient of the soil itself (i_s). These values are calculated basing on the piezometric measurements taken at 0, 25 and 75mm as per ASTM D5101:

$$GR = i_{sg}/i_s = i_{31}/i_{43}$$

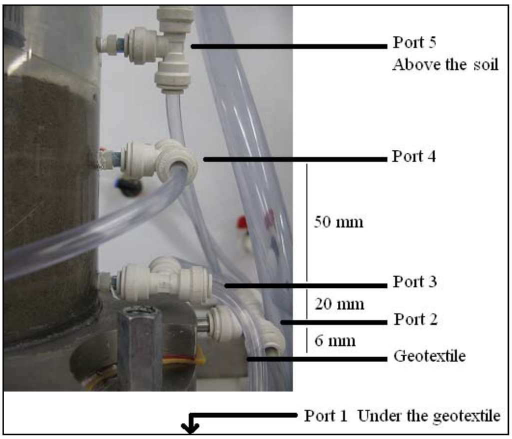

Figure 4. Gradient Ratio definition.

6 RESULTS AND DISCUSSION

6.1 *Pressure stability*

The new gradient ratio device enables observation of the water head in the soil as a function of the applied compressive stress. Fig. 5 presents the observed pressure measurements for an applied cyclic compressive stress with a period of ten seconds.

It can be observed that if the piezometric levels are relatively stable above and below the system exposed to cyclic mechanical stresses, the pore pressure in the soils is significantly influenced by the mechanical stress induced on the soil matrix.

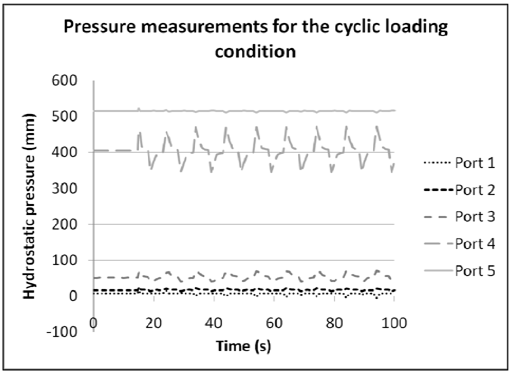

Figure 5. Observation of the water head (hydrostatic pressure) in the soil when a cyclic normal load is applied.

6.2 *Gradient Ratio*

The two sequences of testing lead to different behavior with respect to Gradient Ratio. Fig. 6 shows that when tested without normal load, the Gradient Ratio is stable and lower than 1.0, which indicates a good behavior according to the appendix of ASTM D5101. However, when a cyclic compression stress is applied to the system, the Gradient Ratio shifts from 0.5 to about 0.1 (Figure 7).

6.3 *Retention capacity*

During the first period of testing, that is without any mechanical stress induced on the soil, no soil particles were observed passing through the geotextile or were detected in the collector system. The water stayed clear throughout the first 24h period.

A few seconds after the cyclic mechanic stress was applied, particles were observed to pass through the geotextile. Over the 24h period, 396 g/m^2 of soil particles were collected.

6.4 *Synthesis*

The observations presented above confirms that when a soil-geotextile system is subjected to a cyclic mechanical stress, the soil particles that were once stable, may become instable and potentially lead to a piping phenomena.

This behavior, although it represents well the observations made in the field for this particular soil, could not be detected using ASTM D5101, which does not allow for application of mechanical stress.

7 CONCLUSION

This paper illustrates the limitations of a classic Gradient Ratio device at predicting the soil-geotextile compatibility when the system is subjected to mechanical stresses. Moreover, the observations obtained from ASTM D5101 were found to be non-conservative, although this test is recommended to assess the compatibility of soil / geotextile systems by several agencies or authors, such as Mlynarek (1999) or AASHTO M288.

Consequently, it is recommended to implement ASTM D5101 to include modeling of mechanical stress in the test procedure, to assess the filtration compatibility of a given soil / geotextile system under given field conditions. In this process, the work previously conducted by UBC shall also be considered and modeling of field specific hydraulic conditions shall also be included.

8 ACKNOWLEDGEMENT

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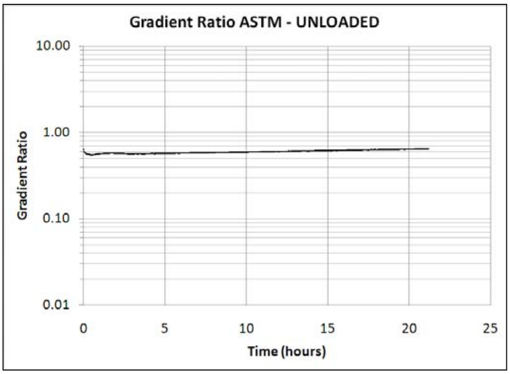

Figure 6. Gradient Ratio obtained using ASTM D5101 procedure, without mechanical stress.

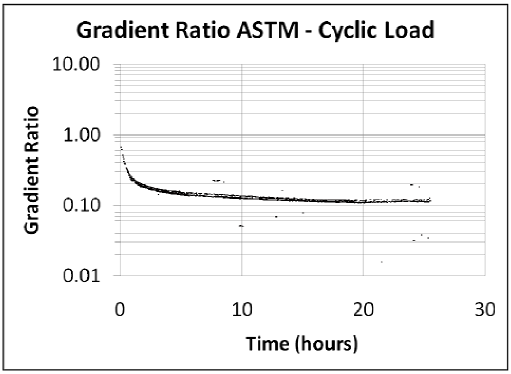

Figure 7. Gradient Ratio obtained for cyclic mechanical stress.

REFERENCES

Mlynarek, J. 1999a. “Designing Geotextile Filters Part 1: Soil Filtration”; CGS 1999;

Mlynarek, J. 1999b. “Designing Geotextile Filters Part 2: Leachate Filtration”, CGS 1999;

Austin, D., Mlynarek, J., Blond, E. 1997. Expanded anti-clogging criteria for woven filtration geotextiles. *Geosynthetics 97*. Vol. 2 pp. 1123-1144.

ASTM D5101 - 01(2006) Standard Test Method for Measuring the Soil-Geotextile System Clogging Potential by the Gradient Ratio, ASTM Volume 04.13.

Srikongsri, A., Fannin, E.J., 2007: “Retention Capacity of Geotextile Filters in Cyclic Flow”, Proceedings of Geosynthetics’2007, Salt Lake City