Evaluation of the retention of slurry sediments using geotubes

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ABSTRACT: Woven geotextiles are often used in containment and filtration applications to filter, retain, and dewater fine sediments. For most engineering applications, geotextiles must be designed to prevent the migration of fines while at the same time be permeable enough to allow water to pass, without clogging. Retention criteria are often based on the hydraulic properties of the geotextile, in particular its characteristic opening size. Although woven geotextiles are commonly used in many civil and environmental applications, limited work has been done to characterize their hydraulic properties and relate them to their retention behaviour. This paper presents the results of a systematic evaluation of the hydraulic properties of four different woven geotextiles commonly used in dewatering and filtration applications. The characteristic pore openings of the woven geotextiles are evaluated using dry sieving (AOS), hydrodynamic sieving (FOS), and scanning electron microscopy (SEM). The results of these evaluations are used to evaluate the retention performance of the woven geotextiles. Two types of tests, pressure filtration and cyclic hydrodynamic sieving, are performed to evaluate the soil retention/passing of slurry sediments.

1. INTRODUCTION

Similar to the behaviour of natural soil filters, geotextile filters primarily aim to pass water and retain soil particles. Geotextile filters, under certain circumstances, are subjected to clogging, blocking, or blinding, which can lead to failure. The selection of a suitable geotextile filter to fulfil the filtration requirements under different flow conditions is of critical importance. In many civil and environmental applications, geotextile filters are subjected to unidirectional flow, bidirectional flow, and cyclic flow. For example, steady-state unidirectional flow occurs in embankments, bidirectional flow could represent riprap over dam slopes, and cyclic flow is similar to wave or tide action.

Filtration criteria for steady-state flow have been studied extensively by many researchers (Giroud 1982; Carroll 1983; Christopher and Holtz 1985; Bhatia et al. 1990; et al.) Existing geotextile retention criteria use size ratios in the form of O_x/d_x, where O_x refers to a characteristic pore opening size of a geotextile and d_x refers to a characteristic particle size of soil. Furthermore, Giroud's (1988) retention criterion used the coefficient of uniformity of the soil (C_u) in addition to the O_x/d_x ratios. Many of these and other criteria were developed for soil/geotextile systems in which soil is in good contact with geotextiles under unidirectional and bidirectional flow conditions.

Several recent studies (e.g. Holtz et al. 1997; Hawley 2001; Schiereck 2003; and Srikongsri and Fannin 2009) have evaluated the retention capacity of woven and nonwoven geotextile filters under cyclic flow conditions. In these studies, the O_{95}/d_{85} ratio is used to assess the retention performance of the geotextiles. Srikongsri and Fannin (2009) noted that a significant soil mass loss occurred at values of $AOS/d_{85} > 2.5$ for woven geotextiles, where AOS is the O_{95} of the geotextile obtained by dry sieving. They further noted that the coefficient of uniformity and the shape of the grain size curve may also influence filtration compatibility.

Kutay and Aydilek (2004) used some of the existing retention criteria to assess the compatibility of woven geotextiles with dredged and fly ash slurry sediments. They found that existing retention criteria (Giroud 1982; Christopher and Holtz 1985; and Carroll 1983) predicted that geotextiles would fail in retaining dredged slurry sediments; however, filter press and hanging bag test results indicated that most geotextiles successfully retained sediments. Kutay and Aydilek (2004) advocated for the development of retention criterion for such applications. On the other hand, a recent study by Satyamurthy (2008) showed that for dredged sediment slurries, an average soil passing or soil retention is related to AOS/d_{85}, where O_{95} was measured using dry sieving. It was found that when AOS/d_{85} <2, the average soil mass loss was less than 2%.

Therefore, in contrast to unidirectional and cyclic flow seepage in filter applications, there is a longstanding body of knowledge on the use of geotextiles that is based on considerable laboratory and field studies. However, regarding issues of unidirectional or cyclic flow with soil sediments, our current knowledge is very limited. In addition, few recent studies give contrasting conclusions. Retention capability of woven geotextiles under such conditions is of critical importance, particularly for dewatering applications using geotextile tubes.

In this study, four woven geotextiles were evaluated. The characteristic opening sizes of the geotextiles were measured using dry sieving, hydrodynamic sieving, and scanning electron microscopy (SEM). Performance tests were conducted to evaluate the effect of characteristic opening size on soil retention and soil loss. The performance tests include pressure filtration tests (PFT) and bidirectional hydrodynamic filtration tests. Performance tests were conducted on slurries consisting of silty sand.

2. TEST MATERIALS

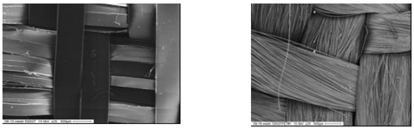
2.1 Geotextiles

Four woven geotextiles were used in this study. The geotextiles have different weave patterns and were divided into two groups based on their opening sizes. Three woven geotextiles (W1, W3, and W4) were made of polypropylene (PP) and geotextile W2 was made of polyester (PET). The permittivity of the geotextiles ranges from 0.28 s^{-1} to 0.51 s^{-1} and the AOS ranges from 0.15 mm to 0.425 mm (see Table 1). Scanning electron photomicrographs of the geotextiles are shown on Figure 1.

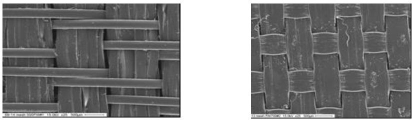
Table 1: Physical and Hydraulic Properties of the Woven Geotextiles given by the Manufacturer

Geotextile	Structure-Polymer Type	Mass/UnitArea (g/m^2)	Thickness (mm)	Permittivity (s^{-1})	AOS (mm)
W1	SF – PP	585	1.04	0.37	0.425
W2	MU–PET	813	0.98	0.38	0.15
W3	SF – PP	271	0.89	0.51	0.30
W4	MF – PP	210	0.40	0.28	0.18

PP: polypropylene; PET: polyester; SF: Slit Film; MF: Monofilament; MU: Multifilament



W1 (Slit Film) W2 (Multifilament)



W3 (Fibrillated Monofilament) W4 (Monofilament)

Figure 1: Scanning Electron Photomicrographs of the Geotextiles (magnified 25x)

2.2 Glass Beads

Glass beads were used for the dry and hydrodynamic sieving tests. The beads ranged in diameter from 2 mm to less than 0.03 mm (#10 to < #400 US standard mesh). The glass beads were purchased from Potters Industries Inc., Brownwood, Texas.

2.3 Soil

Soil samples were extracted from the soil washing process at a local gravel pit in Tully, New York. "Tully Silt" is classified as a silty sand (SM), as per ASTM D2487. The fine fraction of Tully Silt has a liquid limit (LL) of 23.6, plastic limit (PL) of 21.2, and plasticity index (PI) of 2.4. The particle size distribution of the Tully Silt is shown on Figure 2.

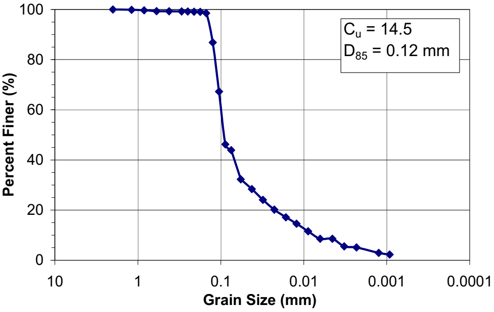


Figure 2: Particle Size Distribution of Tully Silt

3. TEST METHODS

3.1 Dry Sieving Test

Dry sieving tests were conducted in accordance with ASTM D4751 to obtain the AOS of the geotextiles. Five specimens of each geotextile were tested. Results were found to be reproducible for the geotextiles tested.

3.2 Hydrodynamic Sieving Test

The hydrodynamic sieving test is recommended by Canadian standard CAN/CGSB 148.10 94 as an indirect method to estimate the characteristic opening sizes of geotextiles. An 87.5 g glass bead mixture, with a coefficient of uniformity greater than 4, was placed on top of the geotextiles. The testing cylinders were then immersed in water for 1000 cycles. The glass beads that passed into the water-filled buckets were then dried and sieved. The particle size distribution of the dried glass beads allowed for the determination of O_{95} or filtration opening size (FOS) of the geotextile. Further details on this method can be found in Bhatia and Smith (1996).

3.3 Scanning Electronic Microscopy (SEM)

In SEM, small geotextile specimens (approximately 1 cm by 1 cm) were mounted on sampling platforms and magnified. The pore sizes of the geotextiles were measured from the magnified images of the geotextiles. A random group of pores (ten pores from each geotextile) was measured from each geotextile specimen and an average value was taken to represent the geotextile.

3.4 Pressure Filtration Test (PFT)

For PFTs, a 7.2-cm diameter geotextile specimen was secured in the test setup, as shown on Figure 3. A 33% solids content slurry of Tully Silt was poured into the testing apparatus. The top cap was secured and a pressure of 34.5 KPa was applied. Volume and time readings were taken frequently for the first 10 to 15 minutes and additional readings were taken at 5 to 15 minute intervals thereafter. Upon completion of the test, the filter cake height, filter cake moisture content, percent solids retained, flow rate, and percent solids passing were evaluated. For each geotextile, three tests were performed. Results were found to be reproducible for the geotextiles tested.

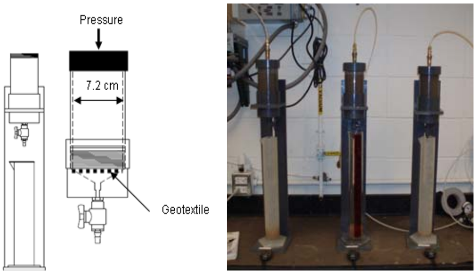


Figure 3: Pressure Filtration Test Set-Up

3.5 Bidirectional Hydrodynamic Filtration Test

Bidirectional hydrodynamic filtration tests were conducted using the same test setup as used for the hydrodynamic sieving tests. Cylinders with a flange at the bottom held the tested geotextiles, which were immersed in water in a bidirectional motion. The diameter of the geotextile specimens were 14 cm. A schematic diagram of the test set up is shown in Figure 4.

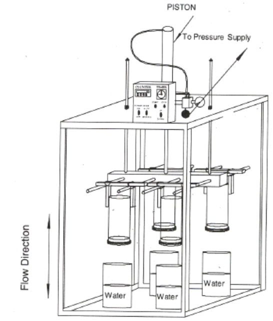


Figure 4: Hydrodynamic Filtration Test Set-Up

In this test, 450 g of Tully Silt was mixed with water to form a slurry. The slurry was poured on the top of the geotextiles that were secured to the bottom of the cylinders. The height of the slurry was approximately 5 cm above the geotextile. The cylinders were then immersed in buckets of water such that in each cycle the water rose in the cylinders up to 10 cm. This water height was selected based on requirements for the hydrodynamic sieving test (CAN/CGSB 148.10 94). Tests were performed for 100 cycles. Cycle durations of 180 seconds/cycle were used in accordance with Chen et al. (2008), where the specimens were subjected to wave periods of 600, 300, 150, and 75 seconds/cycle. After 100 cycles, the geotextiles with the remaining slurry on top (filter cake) were allowed to drain completely. The filter cakes on the geotextiles were then dried in an oven for 24 hours. The geotextiles were air dried. The masses of the dried geotextiles and dried filter cakes were recorded. The masses of the sediments passing through the geotextiles were also measured. For each geotextile, four specimens were tested.

4. RESULTS AND DISCUSSION

A comparison of characteristic opening size (O_{95}) results obtained by the different test methods (dry sieving, hydrodynamic sieving, and SEM) are presented in Table 2. As shown, the dry sieving results obtained in this study were similar to the dry sieving results provided by the manufacturer, with the exception of geotextile W1. The dry sieving results were consistently higher in comparison to the other methods used (hydrodynamic sieving, SEM). The filtration opening size (FOS) of the tested geotextiles was typically 80% of the apparent opening size (AOS). This is in agreement with observations by Bhatia and Smith (1996). SEM results showed a greater degree of scatter, primarily due to difficulties in measuring the smallest dimensions of the pores observed through imaging. It was also observed that the hydrodynamic sieving results had less scatter as compared to the dry sieving results.

Table 2: Geotextile Opening Size Results

O_{95} (mm)		W1			W2		
		Max.	Min.	Ave.	Max.	Min.	Ave.
Dry Sieving	Syracuse University	0.27	0.21	0.26	0.18	0.14	0.17
	Manufacturer	NA	NA	0.425	NA	NA	0.15
Hydrodynamic Sieving		0.18	0.15	0.17	0.15	0.13	0.14
SEM		0.31	0.25	0.29	0.13	0.09	0.10

O_{95} (mm)		W3			W4		
		Max.	Min.	Ave.	Max.	Min.	Ave.
Dry Sieving	Syracuse University	0.28	0.22	0.26	0.15	0.13	0.15
	Manufacturer	NA	NA	0.30	NA	NA	0.18
Hydrodynamic Sieving		0.23	0.20	0.22	0.17	0.12	0.14
SEM		0.27	0.24	0.25	0.09	0.06	0.07

Pressure filtration tests (PFTs) allowed for the evaluation of geotextile filter behaviour under the effect of 34.5 KPa constant pressure, representative of typical pressures found at the base of geotextile tubes upon filling. The test results shown on Figure 8 are for Tully Silt slurry with a solids concentration of 33%. The volume of filtrate versus time for the geotextiles tested is shown on Figure 5. The test results showed that the geotextiles tested exhibited similar dewatering behaviour. The percent piping for the geotextiles tested was less than 0.5%. This high retention capacity of the geotextiles can be attributed to the well-graded nature of the Tully Silt, which quickly forms a stable filter cake on top of the geotextiles.

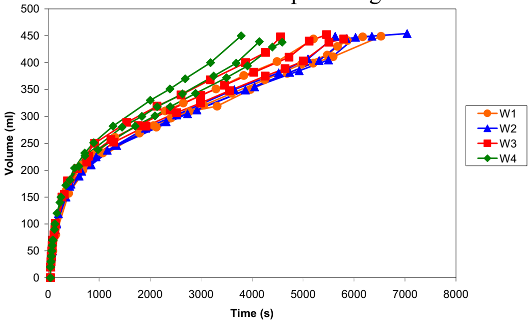


Figure 5: Volume of Filtrate versus Time

The amount of sediment loss was measured for each geotextile and average values are plotted with respect to average AOS (dry sieving) and FOS (hydrodynamic sieving) values for each geotextile on Figure 6. Sediment loss through the geotextiles provides a very useful means to characterize soil-geotextile compatibility.

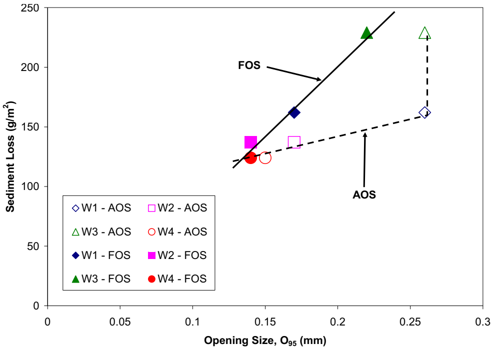


Figure 6: Average Opening Size (O_{95}) Versus Sediment Loss in Pressure Filtration Test

Geotextiles W1 and W3 have similar AOS values; however, behaved differently in terms of the amount of sediment loss. Furthermore, it was observed that geotextiles W2 and W4, whose AOS values were similar, had approximately the same amount of sediment loss.

From Figure 6, it can be noticed that geotextiles W2 and W4 lost similar amounts of sediment. W1 has a smaller FOS value than W3, and therefore the piping was smaller. These results lead to the conclusion that increasing values of FOS would result in greater sediment losses, which is not true for AOS.

The filtration behaviour of the four woven geotextiles under bidirectional flow directions shows the effect of cyclic motion. In Figure 7, sediment losses at 100 cycles are plotted with respect to AOS and FOS values of the geotextiles.

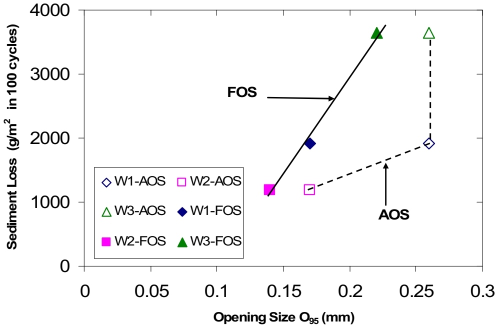


Figure 7: Average Opening Size (O_{95}) Versus Sediment Loss in Hydrodynamic Bidirectional Flow Tests

Geotextile W4 has similar AOS and FOS values as compared to geotextile W2; however sediment results were very different. The three tested specimens of geotextile W4 took more than four times the amount of time to drain slurry as needed for geotextile W2. Additionally, it was found that geotextile W4 did not drain completely even after longer times. It is believed that geotextile W4 exhibited partial clogging or blinding. In general, hydrodynamic sieving results (FOS) are easier to relate to retention behaviour for the other three geotextiles as compared to AOS.

Numerous researchers have used the AOS/d_{85} filter ratio to evaluate the retention capability of woven and nonwoven geotextiles under different flow conditions. Much of the work in this area is limited to regular soils rather than dredged slurry sediments and fly ash. Recently, several studies have been carried out by Kutay and Aydilek (2004), Muthukumaran and Illamparuthi (2006), Liao and Bhatia (2008), and Satyamurthy and Bhatia (2009a,b) assessing retention capabilities of dredged sediment slurries with different solid contents. These studies have been aimed to evaluate geotextile filter performance for geotextile tube dewatering applications. In such applications, dewatering as well as sediment retention or piping are important. If one phenomenon is dominant, efficiency of the geotextile is greatly affected. The balance between retention of sediment with maximum expulsion of water without much loss of sediment is necessary.

Existing piping criteria that have been developed for geotextile filter applications when the geotextile retains soil on the upstream side are not applicable for slurry filtration applications since the fundamental phenomena and associated mechanisms are different. Aydilek and Edil (2002) and Aydilek (2006) suggested an allowable sediment loss limit as 1800 g/m^2, based on their study of wastewater treatment sludge. A recent study by Satyamurthy (2008) with fine silt slurry suggested that a sediment loss limit of 1500 g/m^2 can be used for the relative comparative performance of different geotextiles. Moreover, Satyamurthy and Bhatia (2009b) found that piping amount is a function of slurry concentration and volume and found a weak correlation between sediment loss and AOS of the geotextile. They related sediment loss to AOS/d_{85} values to evaluate the compatibility of the geotextiles.

In Figure 8, data from both the pressure filtration tests and the hydrodynamic bidirectional flow tests for the geotextiles tested are plotted in terms of sediment loss versus AOS/d_{85}. Selected geotextiles have a ratio of AOS/d_{85} in the range of 1.3 to 2.3, and amounts of sediment loss were in the range of 100 to 3500 g/m^2. Small amounts of sediment loss indicate that the geotextiles tested showed great retention capabilities, although greater AOS/d_{85} ratios resulted in higher sediment loss. It is important to note that the bidirectional hydrodynamic sieving test resulted in significantly higher sediment losses in comparison to the pressure filtration test. Only geotextile W3 which has the largest opening size amongst the selected geotextiles showed sediment losses of about 3500g/m^2, which is higher than the other geotextiles tested, where the sediment losses were less than or very close to 1800g/m^2, which is the acceptable piping limit according to Aydilek and Edil (2004).

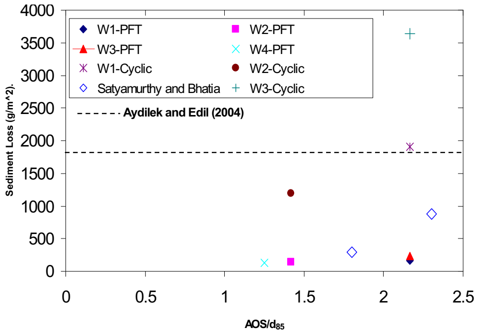


Figure 8: AOS/d_{85} versus Sediment Loss

5. CONCLUSION

Characteristic pore openings of four woven geotextiles using dry sieving, hydrodynamic sieving, and scanning electron microscopy were measured. The filtration behaviour of these geotextiles and Tully Silt slurry were evaluated using pressure filtration tests and bidirectional hydrodynamic filtration tests. The compatibility of Tully Silt slurry was assessed using measured AOS and FOS of the geotextiles. The following conclusions can be drawn:

1. Both dry and hydrodynamic sieving tests yielded reproducible results for the four woven geotextiles selected for the study. In general, O_{95} results measured by hydrodynamic sieving were smaller than dry sieving values.
2. The amount of sediment loss, in both the pressure filtration tests and in the bidirectional hydrodynamic filtration tests, related well to FOS values of the geotextiles.
3. Greater FOS values resulted in higher sediment loss in both types of tests.

4. Woven geotextiles exhibited blinding/clogging in the bidirectional hydrodynamic filtration tests.
5. Although the relationship between FOS and AOS and sediment loss was similar for both tests, the amount of piping was significantly higher for the bidirectional hydrodynamic filtration test than for the pressure filtration test.

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