A Study of Some Key Factors on Geotextile Hydraulic Property Measurement

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ABSTRACT: The commonly accepted test methods of assessing geotextile hydraulic properties, both in isolation and in soil, are briefly reviewed. A test system with 3 different diameters (44, 93 and 193 mm), 2 types of pressure reading port (extended, non-extended) and comprising six sets of apparatus has been designed and constructed. Details of an experimental study of some key factors of geotextile hydraulic property measurement in isolation and in soil are discussed. It is shown that the preferred size of tube diameter for measuring the hydraulic property of geotextile in isolation (permittivity) is between 44 mm and 93 mm, and about 93 mm in soil/geotextile system. There is also an indication that the quality of the test water is important to the test results obtained. Finally, it is shown that the combined method of long-term flow rate, in conjunction with hydraulic gradient analysis along the soil column, can provide a more reliable prediction of the clogging potential for the tested geotextile/soil system.

1 INTRODUCTION

It is well known that when a geotextile is used in filtration applications as a filter, failure may result from piping of fine-grained particles through the geotextile or from clogging of the geotextile. Many workers have studied this phenomenon and a number of design criteria and several mechanisms of soil/geotextile interaction have been proposed (Koerner, 1990; Lawson, 1986; Pang, 1989). Laboratory simulation of soil/geotextile filter systems, which model the formation of the filter layer next to the geotextile, are considered to be able to more accurately predict the field performance of the soil/geotextile filtration system.

Examination of the literature reveals that the primary laboratory methods used to evaluate the filter behaviour usually refer to permittivity, gradient ratio (GR), and long-term flow rate tests. However, each of these methods has its own characteristics and advantages. The permittivity test is an unconfined flow test through an isolated geotextile layer and has been used extensively to index geotextiles. However, it can't be used to evaluate the soil/geotextile filter performance. ASTM (ASTM, 1985) and the Standards Association of Australia (AS, 1990) have proposed standard test methods for evaluating the permittivity of geotextiles in isolation. However, the test results based on different standards are not quite comparable because of the different test conditions and apparatus used (eg. in ASTM D4491-85, the permittivity test of geotextiles is under different constant heads with a minimum tube diameter of 25 mm; while in AS 3706.9-1990, the test is under different constant flow rates with a minimum tube diameter of 50.5 mm). Gradient ratio test methods and long-term flow rate test methods could be used to assess the geotextile/soil filter clogging problem. In this type of field simulation test, the application of a cylinder-tube permeameter (diameter from 85 mm to 300 mm) under constant-head pressure (hydraulic gradient from 1 to 10) has been adopted by many workers (Greenway, 1986; Haliburton, 1982; Lawson, 1982 and 1986). However, in most of the soil/geotextile permeameter systems, the test results are not quite comparable because of the lack of a commonly accepted standard, test method, test procedure or test apparatus.

In this work, attention is focused on using the cylinder-tube permeameter system to analyse the permittivity of geotextiles in isolation and the piping and clogging phenomena in simulated soil/geotextile systems based on several key factors.

2 EXPERIMENTAL

2.1 Sample preparation and apparatus

Geotextiles: The geotextiles used in the tests were spun-bonded needle-punched polyester non-woven fabrics. Table 1 shows the basic physical properties of all geotextile samples. It should be realised that the thickness of geotextiles, especially of the type used in this work, is dependent upon the lateral pressure applied. For example, the thickness of S1 measured by using KES-FB compression tester (AWTOMEC, 1987) is 1.552 mm under the pressure of 22 gf/cm^2 and 1.46 mm with 37.5 gf/cm^2 respectively. Its EOS of $O_{95,d}$ and $O_{90,d}$ are 0.212 mm and 0.202 mm respectively (measured according to AS 3706.7 - 1990).

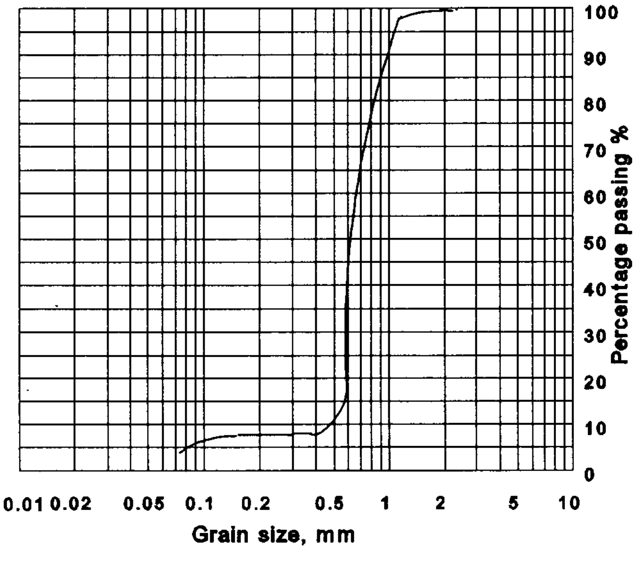
Table 1 Physical properties of test samples

Sample	Mass per unit area (g/m^2)	Thickness* (mm)
S1	141.59	1.56
S2	323.84	3.02
S3	503.72	3.55

*measured under the pressure of 20.4 gf/cm^2

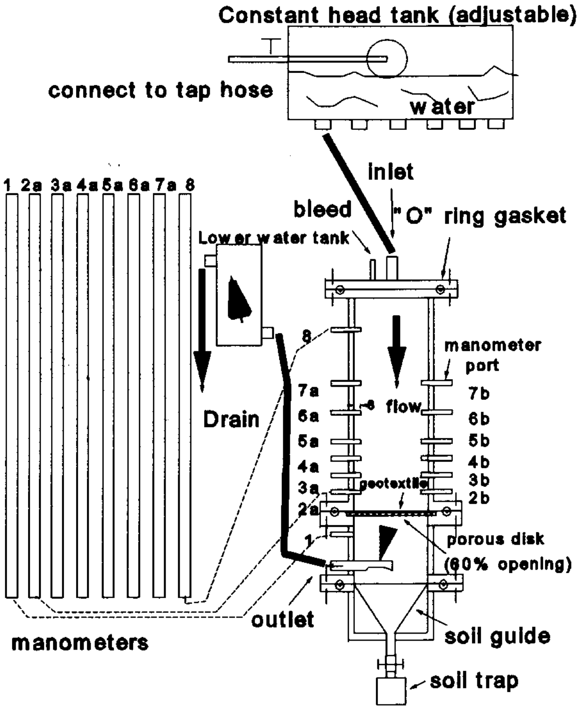
Soil: Different sizes of silica sand were mixed, and the sand structure was designed as a gap graded cohesionless medium in order to provide a high potential for internal soil migration. Particle size distribution of the mixed silica sands was measured according to AS 1289.C6.1-1981 and graphically shown in Figure 1.

Fig.1 Particle size distribution of mixed silica sand



Apparatus: Fig 2 shows a schematic diagram of the extended manometer port test apparatus system. Three nominal diameters of cylindrical tube were used: 50 mm, 100 mm and 200 mm. Two types of manometer port, along the edge of the testing tube and extended inside the testing tube (Fig. 2), were also utilised in order to investigate the soil specimen edge effect (if any) on pressure head readings. The water was introduced from the upper tank through the top of the permeameter, passed through the outlet tube at the side of middle section of the apparatus, and drained through the lower water tank. A geotextile fabric was clamped between upper and middle sections and supported by a porous disk.

Fig. 2 Schematic diagram of testing system



Both in-isolation tests and soil/geotextile filtration tests can be operated in this test system. Further details regarding the apparatus design and construction are given elsewhere (Li, 1992).

2.2 Geotextile permittivity test in isolation

This test was carried out primarily to examine the effect of the apparatus tube dimensions on the permittivity test result, i.e. the cross-sectional area of apparatus tube (viz test size of specimen) might affect the permittivity result. In principle, one may expect that the larger the area of test specimen, the less variable and thus more reliable would be the test results to represent the geotextile. Needle-punched non-woven geotextiles S2 and S3 were used to examine the effect on permittivity of the three different sizes of permeameter, viz 44 mm, 93 mm, and 193 mm inner diameter. The tests were conducted following the procedure in AS 3706.9 - 1990.

2.3 Geotextile/soil filtration performance test

Geotextile/soil filtration tests were also carried out to examine the effect of the size of the apparatus tube, soil column height, system hydraulic gradient, and the hydraulic pressure reading port type on the system flow rate, permeability and Gradient Ratio.

The six tube set-up (see Fig. 2) covered two of the system variables being investigated, i.e. size of geotextile sample and the position and type of manometer inlet port. In order to assess the influence of soil column height, two long-term runs were undertaken using different soil heights. Within these two runs, 3 levels of system hydraulic gradient were imposed, as described in Table 2.

Table 2 System hydraulic gradient applied on long term test runs

Tube No.	1	2	3	4	5	6
Sample size (mm)	44	44	93	93	193	193
Port type*	A	B	B	A	B	A
Test 1 (250mm)	3.6	3.6	1.2	1.2	1.2	1.2
Test 2 (150mm)	1.0	1.0	1.0	1.0	1.0	1.0

* A: extended; B: non-extended

The particular mixed silica sand (Fig. 1) and geotextile S1 used in these long term tests provide a high potential for internal soil migration (Haliburton, 1982) and soil clogging of the geotextile filter (Lawson, 1986).

In Test 1, the soil height was set at 250 mm uncompacted. In Test 2, the soil height was 150 mm. As can be seen in Table 2, 3 different levels of system hydraulic gradient of 3.6, 1.2 and 1.0 were applied during the two tests, adjusted by varying the position of the lower water tanks and upper water tank.

For both test runs, a heat-bonded non-woven bag was attached to the water inlet to the upper tank, to assist in water filtration and, perhaps more importantly, to reduce disturbance to the water level from the incoming supply. In Test 2, filters made from S1 were attached to the outlets of the upper tank for units 1, 2, 3, 4 and 5. Unit 6 remained as for Test 1.

3 TEST RESULTS AND DISCUSSION

3.1 Geotextile permittivity test in isolation

Fig. 3 shows the test results for S2 and S3 using the three different sizes of apparatus. It indicates that there are some differences of the permittivity results measured between different diameter tubes used. Statistical significant tests were used to exam these difference as shown in Table 3. No statistically significant difference was found between the permittivity values obtained with the 2 larger tubes for both geotextile specimens. However, statistically significant differences were observed between the permittivity values obtained with the 44 mm diameter tube as compared to the two larger ones.

Fig.3 Effect of tube diameter on permittivity test results

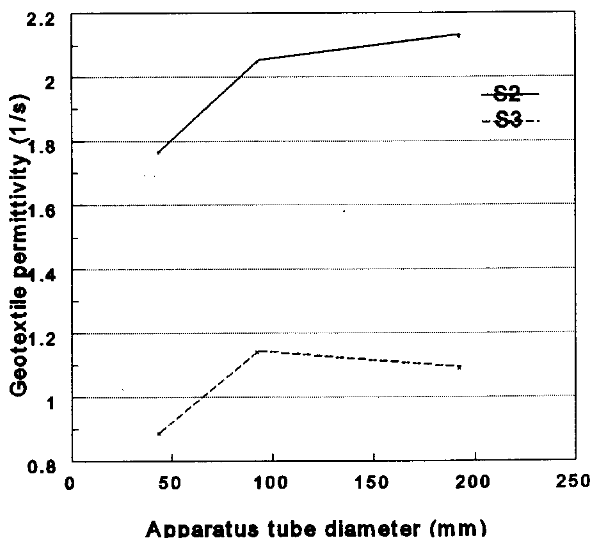


Table 3 T - statistic analysis of Fig. 3

Apparatus	Fabric	A - B	A - C	B - C
A,B,C	S2	3.8639*	8.6655*	1.0853
A,B,C	S3	6.6403*	4.3511*	1.8320

A, B, C refers to tube diameter of 44, 93 and 193 mm, respectively; T-value of least significant difference in 95% and 99% confidence is 2.306 and 3.355 respectively; * indicates the significant difference between two means is greater than 1% level.

The reason for this phenomenon is the edge effect of the clamping force. The void spaces of specimens along the clamping edge region are usually reduced because of the reduction of thickness due to the clamping force. When the size of cross sectional area of the apparatus tube is smaller, this edge effect will become obvious and dominant. However, when the size of cross sectional area is larger, this effect decreases in importance and can be ignored when the affected edge area is small in comparison to the total cross sectional area. The test results as shown above suggest that the size of 93 mm inner diameter tube is large enough to ignore this edge effect.

The Australian Standard "Determination of Permittivity" (AS 3906.9 - 1990) recommends that the minimum area of the specimen when fixed in the testing tube should not be less than 2000 mm^2. Further, this standard requires that the approach velocity should be controlled between 0 m/s and 0.035 m/s, with at least two of these approach velocities being below 0.01 m/s and another between 0.01 m/s and 0.035 m/s. However, according to Darcy's law, (Vennard, 1982)

$$R = (V*D)/\phi$$

where: R is Reynold number; D is diameter of cylindrical tube; ϕ is kinematic viscosity of water at 20°C [1.003 * 10-6 (m^2/s)].

When $R \leq 2100$, laminar flow exists in smooth circular pipes. Therefore, for D = 44 mm, 93 mm, 193 mm, the corresponding critical approach velocities are $V_{44} = 0.048$ m/s, $V_{93} = 0.023$ m/s and $V_{193} = 0.011$ m/s respectively.

This obviously indicates that the larger is the diameter of the permeameter tube, the smaller is the critical value of approach velocity. As to the recommended critical value of 0.035 m/s approach velocity, this does not seem to be valid when using a larger diameter testing tube. Therefore, it appears to be necessary for an upper limit of the test tube diameter to be suggested in the standard. In the case of a critical approach velocity of 0.035 m/s in a smooth tube (Reynold number 2100), the corresponding critical diameter limit is 60.2 mm.

3.2 Geotextile/soil filtration performance test

Fig 4 and Fig 5 show the family of system permeability curves with logarithmic time of the different test permeameters. Fig. 6 and Fig. 7 present the curves of gradient ratio (GR) versus log time in Test 1 and Test 2, respectively. The similar trend of curves 1 and 2, 3 and 4, 5 and 6 indicates that GR is controlled by the tube diameter. Fig. 8 and Fig. 9 show the relationship of hydraulic gradient at various locations along the soil column against log time in permeameter 3 in Test 1 and Test 2 respectively.

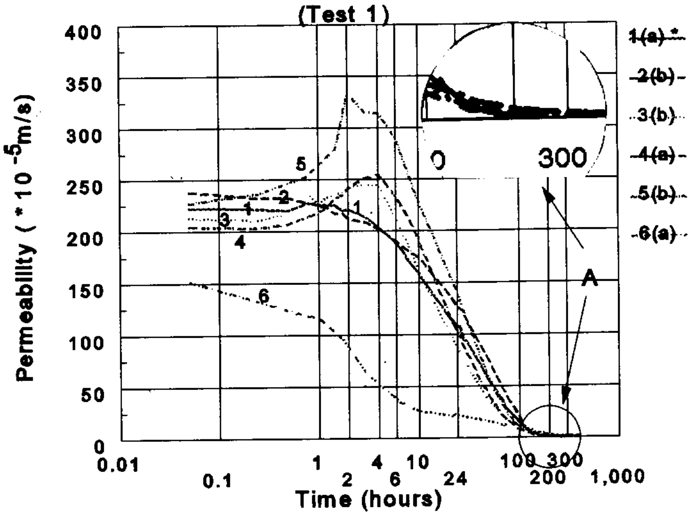
The initial GR values of Test 2 (Fig. 7) suggest that the small size permeameters tended to give higher GR values. Table 4 shows that smaller size permeameters give much higher GR values at 24 hours.

Table 4 Gradient ratio value measured at 24 hours for Test 2

Tube	1(A)	2(B)	3(B)	4(A)	5(B)	6(A)
GR	19.49	10.12	1.8	1.8	0.79	0.9

Fig. 4 System permeability VS time

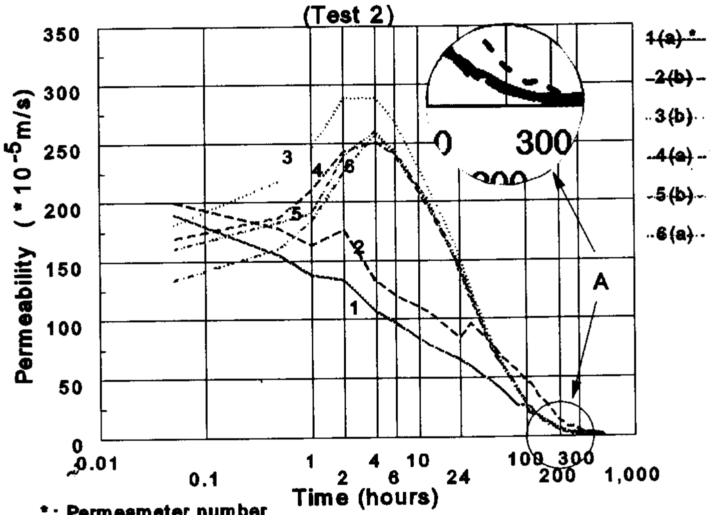
(Test 1)



*: Permeameter number
a: extended manometer port
b: non-extended manometer port

Fig. 5 System permeability VS time

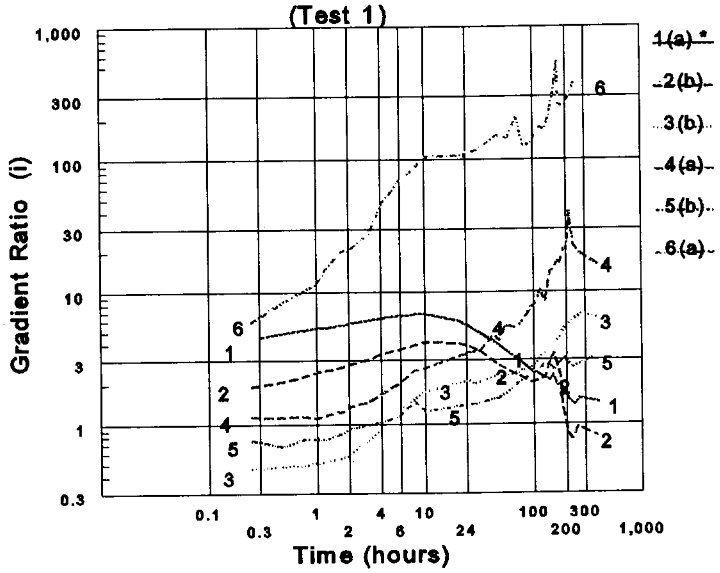
(Test 2)



*: Permeameter number
a: extended manometer port
b: non-extended manometer port

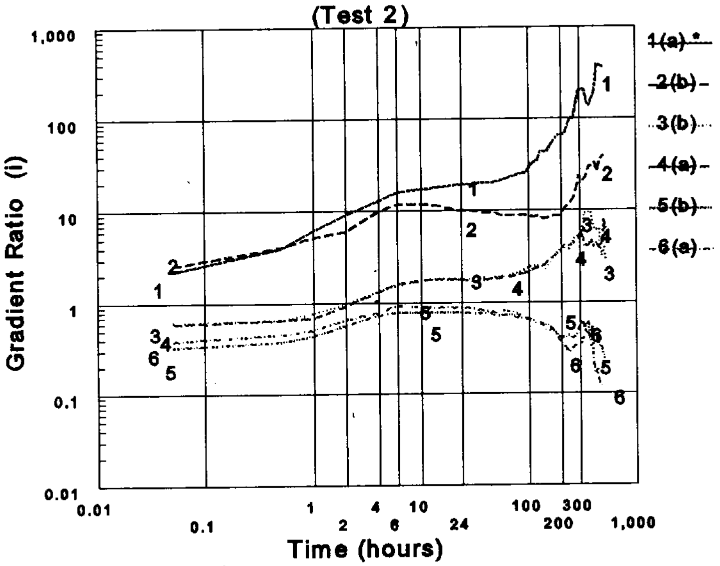
Fig. 6 Gradient ratio VS time

(Test 1)



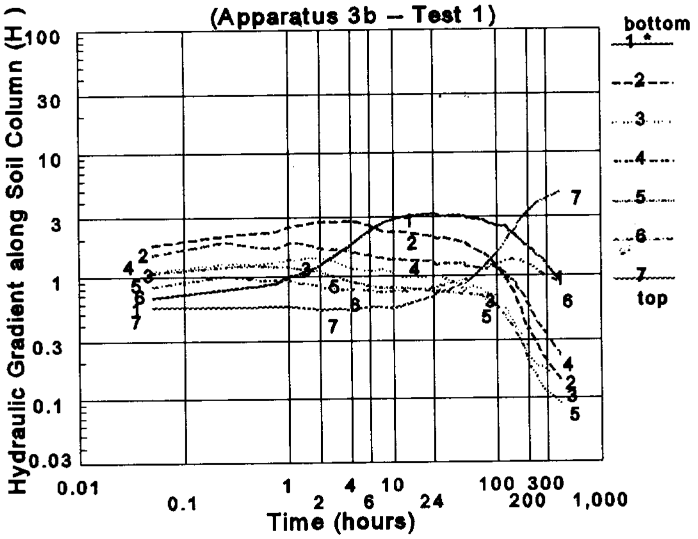
*: Permeameter number

Fig. 7 Gradient ratio VS time (Test 2)



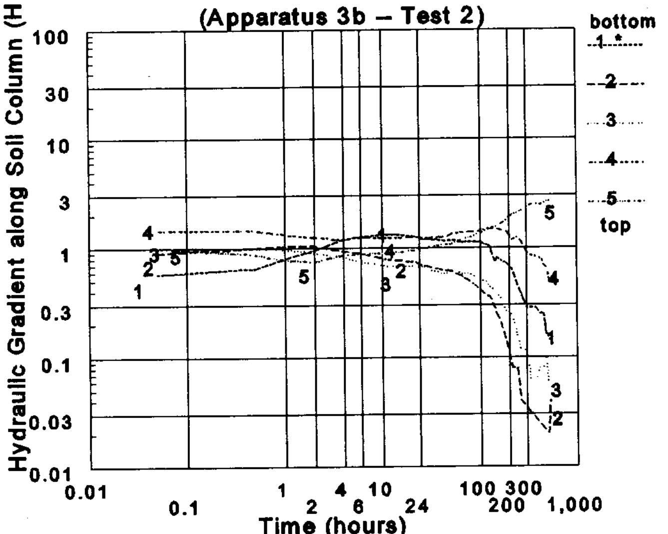
*: Permeameter number

Fig. 8 Hydraulic gradient VS time (Apparatus 3b – Test 1)



*: Soil layer number

Fig. 9 Hydraulic gradient VS time (Apparatus 3b – Test 2)



*: Soil layer number

According to the U.S. Army Corps of Engineers, GR = 3 (after 24 hours) is used as the critical value to evaluate the clogging potential of designed soil/geotextile systems (Haliburton, 1982). Thus, soil/geotextile systems 1 and 2 would be failed, while systems 3, 4, 5 and 6 would be passed. It seems that a contradicting prediction of the same soil/geotextile system may be made if the size of testing instrument is different from 100 mm in inner diameter, which the U.S. Army Corps of Engineer suggested.

Fig. 4 and Fig. 5 also show that no matter how diverse the initial system permeability curves were, all the curves from different size permeameters came close together at the final range. From Figs 8 and 9, the hydraulic gradients imposed on the top layer sand in all systems increase with time. This suggests that the top layer may control the long-term hydraulic performance. One interesting point arising here is that the size of permeameter seems not to affect the long term flow rate test, especially if more field conditions affect the simulation process, such as field water, etc.

Again from Fig 4 and 5, it can also be observed that the higher the soil column height, the shorter the transition period, although the impurities of the supply water could be an influencing factor on this transition period. Higher flow rates were initially established through higher system hydraulic gradients imposed on the higher column, and thus a higher rate of impurity input occurred with the higher column.

Differences could be observed between A-type (extended) and B-type (non-extended) ports for most permeameters. From Fig. 6 and 7, B-type port tends to give lower GR values because of the edge effects. Pressure values collected from A-type reading ports are generally considered to be closer to field conditions because of reduced effects of edge geometry.

It can be observed from Figures 4, 5, 8 and 9 that higher system hydraulic gradient contributed to higher initial system permeability and higher local hydraulic gradient imposed in different layers. However, it cannot be observed that it has any effect on the length of transition period and the system permeability at the end of the transition period.

The reasons for the gradual increase of hydraulic gradient on the top layer soil in all soil/geotextile systems both in Test 1 and Test 2 (Fig 8 and Fig 9) is the clogging of the top layer due to the sedimentation of impurities from the water supply (Li, 1992).

4 CONCLUDING REMARKS

In the geotextile permittivity test, it is shown that there should be a minimum size of apparatus tube between 44 mm and 93 mm, in which the edge effect could be ignored. AS 3706.9 - 1990 would be valid only when the diameter of apparatus tube was less than 60.2 mm. This tube diameter should be assessed for the clamped edge effect.

The soil/geotextile simulation test for short-term GR clogging potential prediction is related to many factors. The size of testing permeameter affects the GR value in that a larger size produces a smaller GR value while a smaller size gives a larger GR value. Medium size (93 mm) tends to get consistent results. A non-extended pressure reading port tends to yield a lower GR value because of the geometry edge effect.

Water impurity does not affect short-term GR tests, but it does affect the long-term flow rate test. The failure of a soil/geotextile system may come from the clogging of the geotextile or the clogging of the top soil layer in the field situation, depending on the size of soil particles and the impurities of the water supply. The Gradient Ratio may only be used to predict the failure of geotextile, but it can't be used to predict the failure of the whole soil/geotextile system. Long-term flow rate tests can predict the failure of the soil/geotextile system, but can't explain the reasons for that failure. The combined long term flow rate test and hydraulic gradient analysis could more accurately predict the compatibility of soil/geotextile system with field water introduced.

The different system hydraulic gradients ($i = 1\text{-}3.6$) used in the experiments did not affect the long-term flow rate test.

In some of the soil/geotextile tests, an initial increase of flow rate in uncompacted soil was observed. This was due to the initial internal soil migration and soil piping out of the system from the soil/geotextile interface. The great reduction of flow rate after the initial stage was due to partial clogging in the soil/geotextile interface. The flow rate after the transition period was totally controlled by the top (contaminated) layer rather than interaction between the soil and geotextile.

In the study of the effect of tube diameter on GR, higher GR values were recorded with the small size tube (i.e. 44 mm) compared to the larger ones. The results can't be used to predict the clogging behaviour of the soil/geotextile system, unless predetermined GR's are known for particular tube sizes. This suggests that the recommended GR value is valid only when the test apparatus and condition are the same as that used in establishing the GR recommendations.

For hydraulic pressure head readings, the extended manometer port usually gives higher values of pressure head reading, being set in a position which eliminates the pressure drop associated with the relatively high flow rate at the wall of the tube (i.e. edge effect).

The relationship between the soil column height and the transition time period still needs to be further investigated because the impurities of the water supply were also involved in this effect. In determining the system transition period, Gradient Ratio fluctuation and stabilisation of flow rate are clear indications of the end of the transition period.

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