Interpretation of Gradient Ratio Test Results

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ABSTRACT: The gradient ratio test is used to assess soil-geotextile compatibility in filtration/drainage applications. Modifications to the test permeameter and sample preparation technique are reported which provide for good repeatability of results. Data are reported for three soils and non-woven geotextiles. A unified interpretation of the water head distribution, gradient ratio and permeability is presented which contributes to a better understanding of those factors governing design criteria proposed for interpretation of the gradient ratio test.

1 INTRODUCTION

The gradient ratio test (ASTM, 1990), is used to assess the compatibility between the pore size openings of a geotextile and retained soil particles in filtration and/or drainage applications. A rigid wall permeameter accommodates a cylindrical soil sample and geotextile test specimen, Fig. 1. The sample has a diameter, and length, of approximately 100 mm. Water is passed through the system by applying various total differential heads: two constant head devices (CHD) are used to maintain constant inflow and outflow water levels. Measurements of hydraulic head are taken at several locations on the apparatus, and used to establish the variation of hydraulic gradient through the soil sample and across the geotextile specimen. Flow rates through the system are determined, and used to calculate the permeability of the soil and the soil-geotextile composition system.

Some modifications were made to the gradient ratio permeameter used in this study to better monitor the behaviour of the soil-geotextile sample. An energy dissipator is mounted below the inlet, Fig. 1. Experience has shown that it prevents the top surface of the soil being disturbed when flow rates are high. Ports 3,5 and 7 are used to determine the gradient ratio in accordance with ASTM D5101-90. Ports 2, 4 and 6 are additional ones located 89.5, 50.8 and 8.0 mm respectively above the geotextile to better define the variation of hydraulic head in the sample.

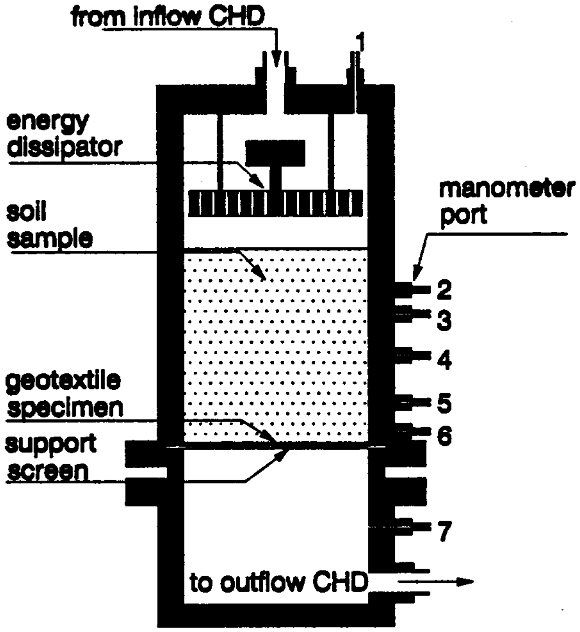

Figure 1 Gradient ratio test permeameter (not to scale).

The gradient ratio (GR) is defined as the ratio of hydraulic gradient in the soil-geotextile composite (i_{sg}) to that in the soil (i_s), and in accordance with ASTM (1990):

$$GR_{ASTM} = \frac{i_{57}}{i_{35}} = \frac{l_{35}}{l_{57}} \frac{h_{57}}{h_{35}} \qquad (1)$$

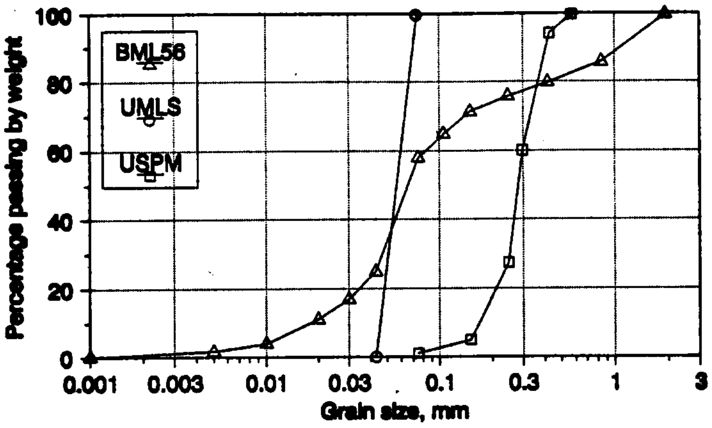

Figure 2 Particle size distribution curves.

where h_{35} and h_{57} are the differential water heads between ports 3 and 5, and 5 and 7 respectively; l_{35} and l_{57} are the sample lengths between ports 3 and 5, and 5 and 7, respectively; i_{35} and i_{57} are the hydraulic gradients between ports 3 and 5, and 5 and 7, respectively.

Test observations indicate the water head distribution between ports 2 and 6 tends to be linear (Fannin et al, 1994b), and suggest that port 6, which is much closer to the geotextile, provides an enhanced index of composite i_{sg}. Hence a modified gradient ratio is defined as:

$$GR_{mod} = \frac{i_{67}}{i_{35}} = \frac{l_{35}}{l_{67}} \frac{h_{67}}{h_{35}} \tag{2}$$

When the GR_{ASTM} is 4, the GR_{mod} is 7.4 (Shi, 1993).

2 TEST METHODOLOGY AND MATERIALS

A water pluviation technique is used with uniformly graded soils to create homogeneous, saturated samples (Vaid and Negussey, 1988). For well-graded sands, a slurry deposition technique is adopted (Kuerbis and Vaid, 1988). Complete details of the sample preparation technique to a targeted density, which varies from that of ASTM D5101-90, are reported by Fannin et al (1994a). Testing has followed the ASTM D5101-90 method which specifies a test be run at various system hydraulic gradients (i_{17} in the range 1 to 10, with each gradient imposed for a period of 24 hours or longer. Measurements are taken of flow rate, temperature and water level with time.

Test results are reported for three soils, for which grain size distribution curves are given in Fig. 2, and three nonwoven geotextiles, for which some material properties are reported in Table 1.

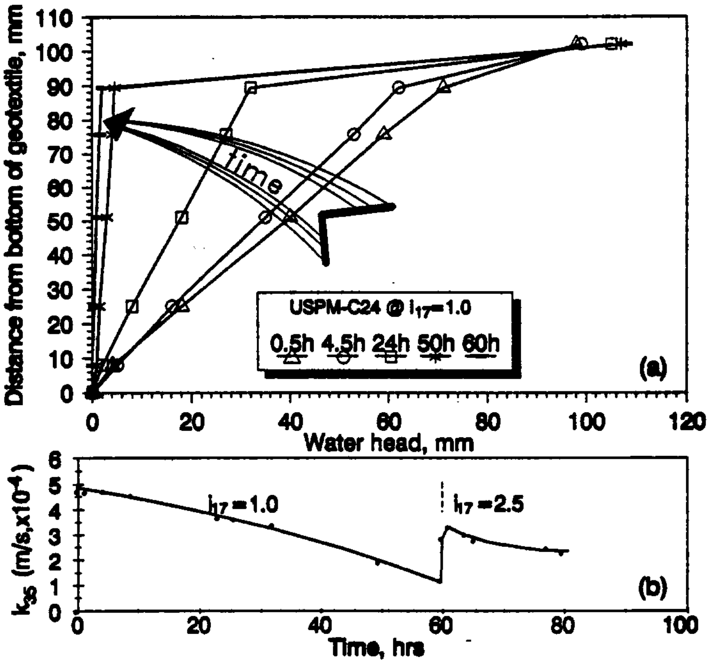

Figure 3 Water head distribution and soil permeability variation with time (de-aired water)

Table 1. Properties of geotextiles

Geotextile code	C24	1120	TS550
Opening size (µm)	75[1]	100[2]	150[2]
Thickness (µm)	2.2	1.9	1.6
Mass per unit area (g/m^2)	170	211	199
Grab strength (N), MD/XD	N/A	851/875	677/720
Elongation (%), MD/XD	N/A	79/84	53/102

[1] AOS; [2] FOS

MD: machine direction
XD: cross-machine direction

3 GENERAL OBSERVATIONS

Preliminary tests were performed to commission the apparatus and evaluate the test preparation and procedures. The distribution of water head and its variation with time for soil USPM and geotextile C24, are illustrated in Fig. 3a for an initial system gradient $i_{17} = 1.0$. De-aired water was recirculated during testing. A marked head loss, that increases with time, occurs near the top of the soil sample. The permeability of the soil decreases, from an initial value of k_{35} (soil permeability between ports 3 and 5, which represents the permeability of the soil) of 4.8×10^{-4} to 1.2×10^{-4} m/s, see Fig. 3b. Visual inspection of soil a the top of the sample revealed a thin layer of fine particles on the surface and the presence of slimes.

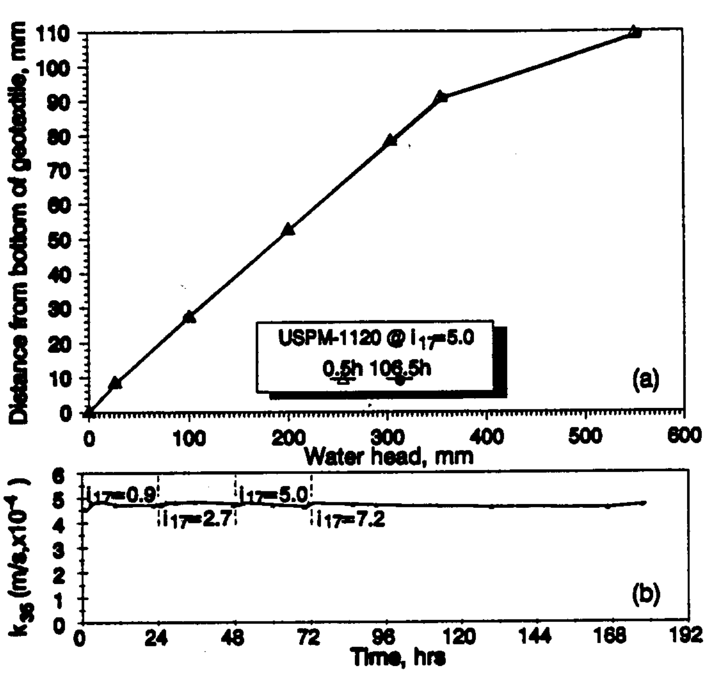

Figure 4 Water head distribution and soil permeability variation with time (de-aired water & 0.5% bleach).

The thin layer caused physical blinding of the soil sample, and therefore a remarkable head loss in this zone. The growth of slimes, which is attributed to biological activity, caused a decrease of soil permeability k_{35} with time.

Tests were also performed on a sample of USPM, prepared to the same relative density, using de-aired circulating water to which 0.5% concentration by volume of a commercial liquid bleach was added in an attempt to inhibit biological growth. Results for geotextile 1120, Fig. 4a, show the distribution of water head in the sample at a system gradient $i_{17} = 5.0$, and its variation with time. A marked head loss develops near the top of the sample during permeation, which again is attributed to physical blinding. However, it does not change with time. Furthermore, the soil permeability k_{35} is independent of time and gradient (see Fig. 4b), which is evidence that the bleach successfully inhibited biological growth in the sample; a liquid algaecide is now used in preference.

Physical blinding of the top of soil sample does not occur in coarse soils, but may be a problem for fine grained soils, in which case it is removed by siphoning (Fannin et al, 1994b).

4 TYPICAL SOIL-GEOTEXTILE RESPONSES

Tests have been performed on many combinations of soil and geotextile, in order to characterize the filtration response and better interpret results of the gradient ratio test with respect to clogging criteria. The distribution of water head in two selected tests is shown in Fig. 5. For silt UMLS and geotextile 1120, the distribution between ports 2 and 6, which is constant with time, and linear, is attributed to the homogeneity of the sample. The hydraulic gradient between ports 6 and 7 (the soil-geotextile composite) is less than that in the soil above, and suggests the permeability in this layer is greater than the soil itself. Gradient ratio values provide a quantitative measure of soil-geotextile compatibility. Since little variation of gradient ratio was observed with time, the value after an elapsed time of 24 hours at each system gradient is believed to represent a steady state flow condition. For a system gradient i_{17} of 1.1, 2.5 and 8.5, the modified gradient ratio values are 0.5, 0.7, 0.9 and 0.9, respectively. They are all less than one, and indicate the hydraulic gradient in the soil-geotextile composite is less than that of the soil.

In contrast, the distribution of water head for soil BML56 indicates the hydraulic gradient in the soil-geotextile composite between ports 6 and 7 is slightly greater than that in the soil above, see Fig. 5, and suggests the permeability in this layer is somewhat less than the soil itself. The modified gradient ratio values after an elapsed time of 24 hours at each system gradient are 1.2, 1.2, 1.4 and 1.3; they are essentially independent of system hydraulic gradient. A value greater than one implies a moderate restriction of flow adjacent to the geotextile.

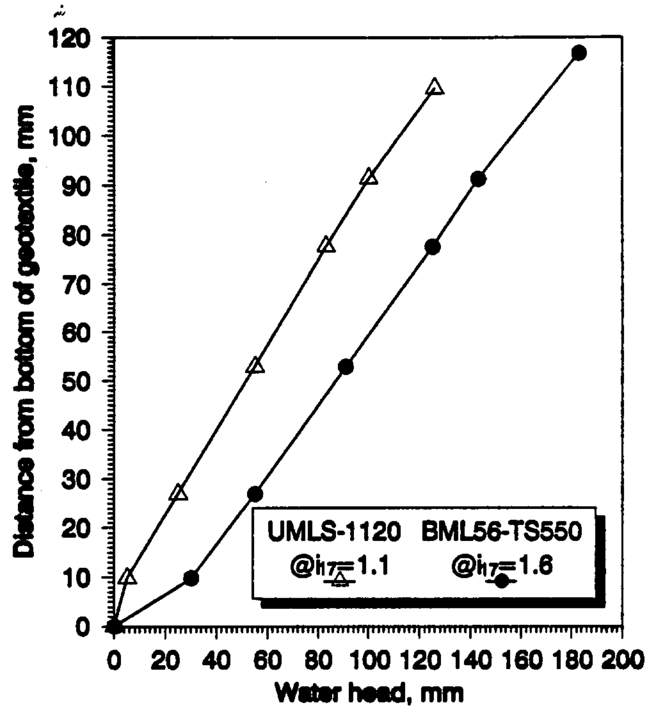

Figure 5 Characteristic soil-geotextile response (uniform and broadly graded soils)

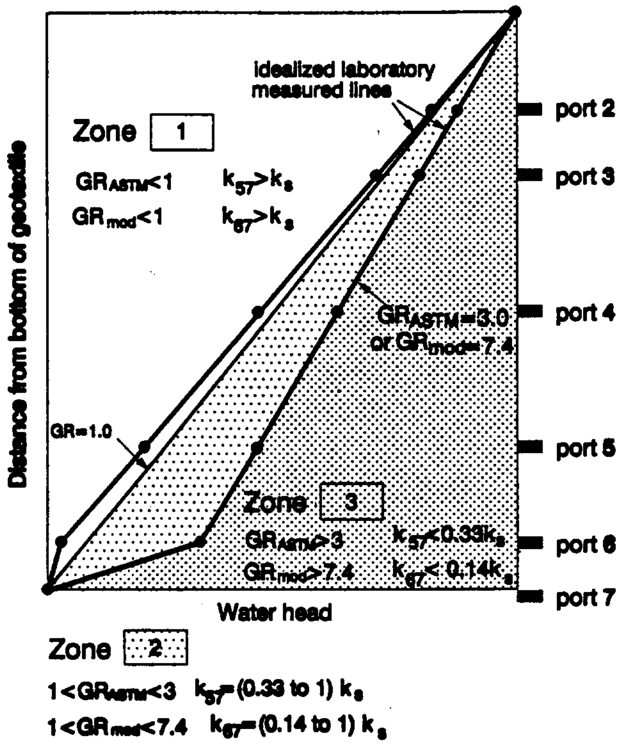

Figure 6 Unified interpretation of the test results.

5 UNIFIED INTERPRETATION

The type of soil and any interaction it has with the geotextile govern the hydraulic gradient through the soil and soil-geotextile composite, and therefore the value of gradient ratio. Assuming no top blinding of the soil sample, the distribution of water head is either linear or bilinear: the relationship is illustrated schematically in Fig. 6.

The permeability of the soil (k_s) and soil-geotextile composite (k_{sg}) are related by flow continuity:

$$k_s\, i_s = k_{sg}\, i_{sg} \tag{3}$$

which yields

$$GR = \frac{i_{sg}}{i_s} = \frac{k_s}{k_{sg}} \tag{4}$$

Three zones are defined in Fig. 6. The first bounds a water head distribution for which the gradient ratio is less than one and the permeability of the soil-geotextile composite exceeds that of the soil; the second bounds a distribution for which the gradient ratio is greater than one, but $GR_{ASTM}<3$ and $GR_{mod}<7.4$, and the permeability of the soil-geotextile composite is less than that of the soil; the third zone is defined by a $GR_{ASTM}>3$. The criterion of $GR_{ASTM}<3$ has been proposed for clogging, but its application is limited by few test data. A $1<GR_{ASTM}<3$ is associated with a permeability in the soil geotextile composite which is less than that of the soil; although this is counter to most filtration design criteria, the composite zone is so thin, there appears to be no significant influence on the system behaviour.

6 CONCLUDING REMARKS

Gradient ratio tests have been performed on nonwoven geotextiles and soils exhibiting a range of gradations. The following conclusions may be drawn regarding the interpretation of gradient ratio test data:

(1) The additional ports 2, 4 and 6 on the permeameter enable the water head distribution to the better defined. Consequently, a modified gradient ratio is established which is a better indicator of energy losses in the soil-geotextile composite layer.

(2) Biological growth, which led to clogging of the sample during testing, was eliminated by treatment of the water with commercial liquid algaecide.

(3) The relative permeability of soil-geotextile composite to the soil itself, which is important to filtration design, is easily obtained from the gradient ratio recognizing the principle of flow continuity.

(4) A unified interpretation of the gradient ratio test reveals an apparent inconsistency in design, which allows for a thin 25 mm soil-geotextile composite layer in the filter zone with a permeability k_{57} as low as 33% of the retained soil. The inconsistency is recognized, but does not have serious implications for performance.

7 REFERENCES

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