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FILTRATION OF BROADLY GRADED SOILS BY WOVEN GEOTEXTILES
FILTRATION DES SOLS A GRANULOMETRIE ETALEE PAR LES GEOTEXTILES TISSES
FILTRIERUNG VON BÖDEN MIT UNGLEICHFÖRMIGER KORNVERTEILUNG MITTELS GEWEBEN

When applied to uniform soils, current filter criteria are reliable and unequivocal. However ambiguity remains regarding broadly graded soils, especially when they show a gap in their grain size distribution. Under these conditions, their characterization by an upper bound diameter D_{85} is no more warranted.

This paper presents the results of filter tests performed on artificially blended soils made of glass ballotini of sizes ranging between 0.1 and 14.5 mm. Three different soils with a coefficient of uniformity varying from 7 to 17 and a coefficient of curvature between 0.3 and 8, were constituted. The soil was placed in a 200 mm diameter permeameter to a height of 200 mm, on top of a square mesh. The opening size of the sieves used, decreased from 6 to 0.8 mm. The samples were subjected to a constant downward gradient coupled with vibrations. Periodic flowrate measurements, piezometer readings, as well as grain size distribution curves by layers, were used as parameters to infer the extent of the development of self-filtration by the bridging network within the soil mass adjacent to the mesh. The length of migration of particles according to their diameter, was deducted from the change in porosity and the measurements of local hydraulic gradients.

L'application des critères de filtre usuels à des sols uniformes est considérée généralement comme fiable. Avec les sols à granulométrie étalée et discontinue cependant, l'utilisation du diamètre D_{85} qui sert à les caractériser en filtration, peut ne pas être significative.

Cet article fait état des résultats d'essais de filtre effectués sur des mélanges artificiels de sols constitués de billes de verre dont le diamètre varie entre 0.1 et 14.5 mm. On a ainsi préparé trois mélanges différents avec des coefficients d'uniformité (Cu) variant entre 7 et 17 et des coefficients de courbure (Cc) entre 0.3 et 8. Les échantillons ont été mis en place dans un perméamètre de 200 mm de diamètre et 200 mm de hauteur dont la base était constituée d'un grillage carré et dont l'ouverture pouvait varier de 0.8 à 6mm. Les échantillons ont été soumis à l'action combinée d'un écoulement vers le bas et de vibrations. La propagation du phénomène d'autofiltration telle qu'elle a pu se manifester par le pontage des plus grosses particules au voisinage du filtre, a eté évaluée à l'aide de mesures périodiques des débits, des hauteurs piézométriques locales de même que par les courbes granulométriques des différentes zones. La migration des grains a été déduite à partir des variations spatiales de porosité et de gradients hydrauliques.

INTRODUCTION

The use of geotextiles as substitutes for mineral agregates in filters and drains is gaining wider acceptance amongst engineers and their selection criteria have recently been discussed in the literature by Hoare (4), Lawson (6), Giroud (2), Heerten and Wittman (3), Schober and Teindl (7). The filtration mechanism has been related to the two functions of the geotextile: to carry out water efficiently it must be more permeable than the protected soil and at the same time it must prevent these soil particles from being washed through. Since geotextiles are generally more pervious than the protected soils, selection criteria are based on geometrical considerations. Some percent of base soil particles must be larger than some percent of geotextile opening size. Most criteria are empirical since they were derived from filter testing: a characteristic base soil size (Dn) is usually compared to a characteristic geotextile opening (On) by means of a piping ratio (B) defined as

$$B = \frac{On}{Dn}$$

The maximum allowable ratio is mainly related to the geotextile structure and to the coefficient of uniformity of the soil. When comparing the various available criteria for $On = O_{95}$ and $D_n = D_{85}$, one can see considerable discrepancy amongst the different authors: for uniform soils (Cu ≈ 1) B varies between 1 and 3 whereas for non-uniform soils (Cu ≈ 20), B varies between 0.1 and 5. This scatter may indeed be attributed to two different factors:

1 - *The definition of the characteristic opening size (On) of the geotextile:* The most widely used parameter is the equivalent opening size (E.O.S.) (1). It is obtained from dry sieving given amounts of uniform size particles. The E.O.S. is defined as the particle size of which 5% of the fraction passed through the geotextile after a specified period of time. This method has been found to suffer serious drawbacks as regards reproductibility, because of the effect of electrostatic forces on small particles.

2 - <u>*The characterization of a soil by its upper boundary size D_{85}*</u>: When uniform soils (Cu ≈ 1) are involved, the choice of a representative diameter does not make any difficulty since $D_{85} \approx D_{50}$, ≈ D_{15}. With non-uniform soils however, the D_{85} size generally used in filter criteria, can be irrelevant because in spite of the fact that it may represent 15% of the <u>total mass</u>, it can be in some cases less than 1% of the <u>total number</u> of particles and thereby be completely uninfluential in the filtration process.

OCCURENCE OF SELF-FILTRATION

Some authors (2, 7) have considered the effect of broad distributions in grain size curves of base particles and they have proposed to reduce the allowable piping ratio in relation to the coefficient of uniformity. Assumption has been made that the coarsest and the finest particles have a negligible influence on the stability of the soil structure for soils graded linearly on a semi-log plot, excluding thereby gap-graded and internally unstable soils.

When describing the mechanism of filtration in fabric filters, Hoare (4) and Lawson (6) illustrated the bridging network of larger particles that is created near the soil fabric interface and which is consecutive to the washing of some particles finer than the opening size. The geotextile is thus believed to act as a catalyst and the time necessary for this mechanism to occur can be anything up to four or five months following geotextile installation. This process is the result of the self filtration induced within the soil mass and its extent is illustrated on fig. 1.

Figure 1 a) shows schematically the redistribution of particles that is to take place near the filter interface by the action of the viscous drag of water. Grain size curves would grow finer with increasing distance L from the filter as shown in part b). Finally part c) presents an hypothetical distribution of particles taller than the filtration opening O_f: at a distance L = Lc, the original size distribution of the base soil is found unaltered whereas at the interface it is assumed that every particle smaller than O_f has been taken away. For this equilibrium to take place, a certain amount of particles would have to be washed away. This quantity (ΔH) can be expressed, for a unit cross section, as a proportion of the original length of the zone on which self filtration was developed (L_c). It is the area of the cross-hatched surface of fig. 1c).

FILTER TESTS

In order to assess this self filtration process, model tests have been undertaken on three different broadly graded soils artificially made from mixes of spherical glass ballotini of 13 different sizes to result in the grain size curves given on fig. 2). The first soil (M-42) was straight line graded whereas M-8 can be classified as internally unstable i.e. its fine portion is susceptible of migration within its own mass according to Kenney et al. (5) M-6 is a gap-graded sand lacking medium size particles. These three base soils were filter- tested in the apparatus shown on fig. 3. It is a constant head permeameter that allows a standard 210 mm sieve to be attached at its lower end, to act as a filter. Different opening sizes were available. Five piezometers were installed laterally at different levels so that local permeabilities could be estimated. As shown on table I soil specimen were put in the cell at relatively low densities ($5 < I_D < 32\%$) and they were submitted to a dowward flow gradient ranging between 2.5 and 6.5. To avoid soil arching at the interface, vibrations were given to the permeameter by means of a rubber hammer. Regular measurements of flowrate, piezometric heads and sample height were made during the 2.5 hours tests. Upon completion, the sample was separated in 6 layers bounded at 0, 2, 5, 10, 13 cm from the bottom and at the top of the sample and named layer 1, 2, 3, ... Grain size analyses were made on each of these slices so that it was possible to estimate the migration of particles.

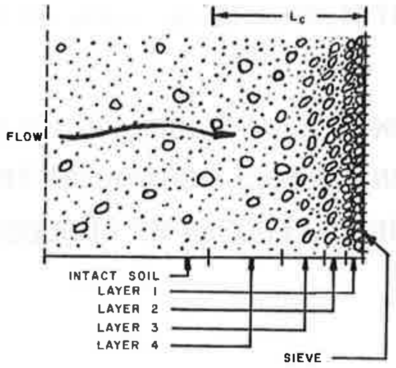

Fig. 1a) Redistribution of particles near filter

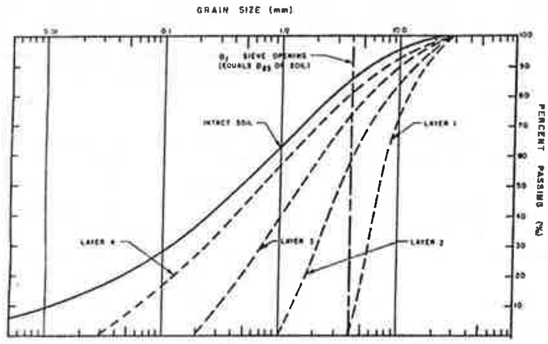

Fig. 1b) Grain size curves

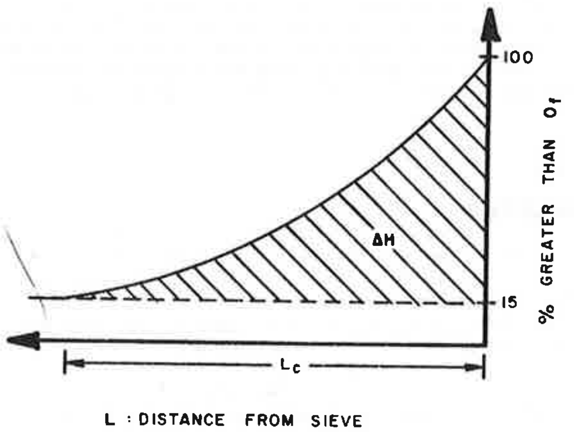

Fig. 1c) Redistribution of particules

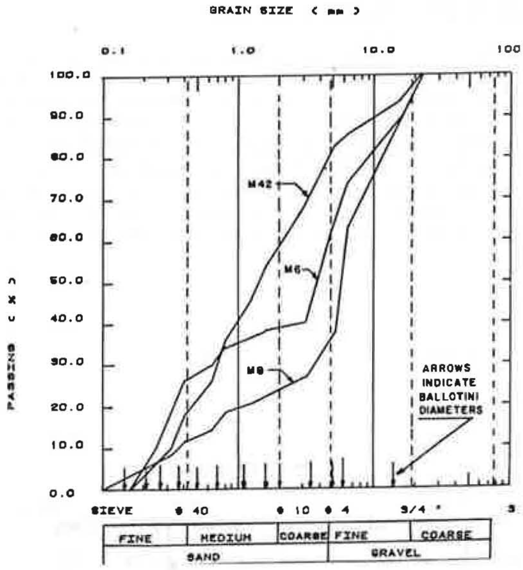

Fig. 2 Grain size curves of tested soils

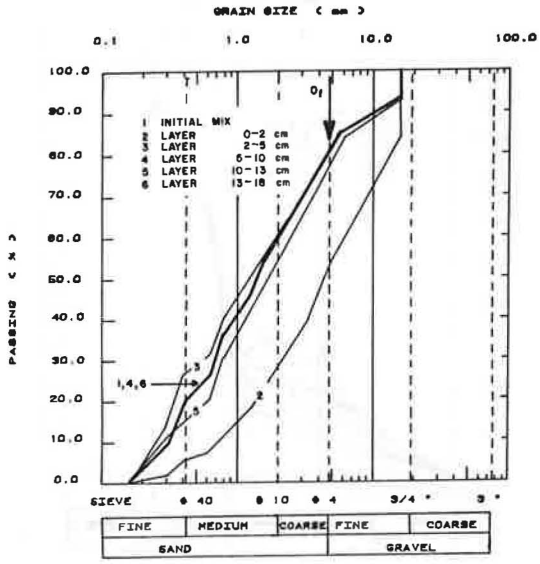

Fig. 4 M42-T4 test

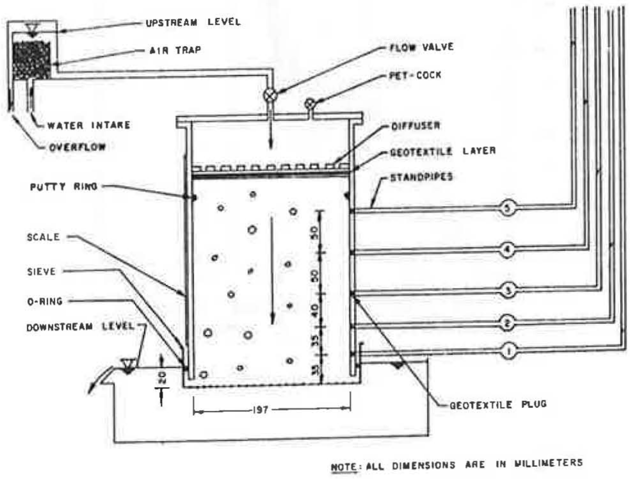

Fig. 3 Apparatus for filter testing

ANALYSIS OF SOIL MIGRATIONS

The results of the filter tests have been analysed according to the three different soil types:

A) Straight line graded soil M-42

In this case the opening size of the filter (O_f) corresponded to the D_{85}. The layer #1 still contained more than 50% of particles smaller than O_f, (fig. 4) whereas the other layers had their grain size distribution very similar to the original ones. The local permeabilities of fig. 9 show that k_1 was substantially greater as a consequence of the wash out of the fine whereas in the other layers, it remained practically the same. It is to be noted from table I that the layer 1 corresponding to the self- filtration zone, lost nearly 30% of its particles ($\Delta H/L_o$)

b) Internally unstable soil (M-8)

The results shown in fig. 5 and 6 illustrate very well the migration of fine base particle within the soil mass. When T5 is used (it corresponds to the D_{30} of the soil and being at the sharp bend in the curve, it could be taken O_f as the minimum diameter of the coarse skeleton), the filter fails to retain a significant portion of the fine particles. In fact, at the end of the test every layer contained less than 30% of the original fraction of particles smaller than O_f. These results are confirmed by the local permeabilities of fig. 10 that show a general increase with time in each layer.

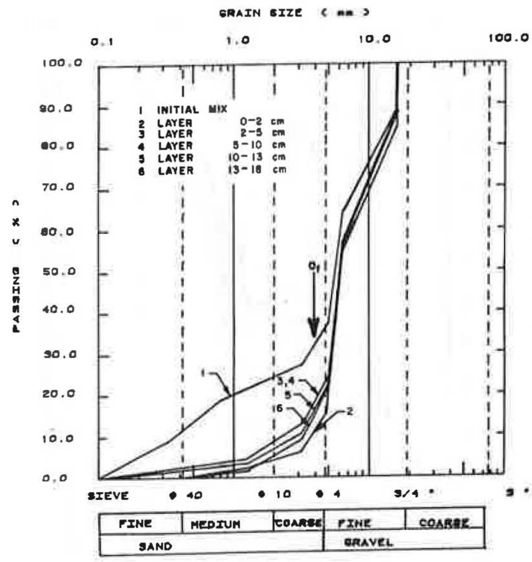

Fig. 5 M8-T5 test

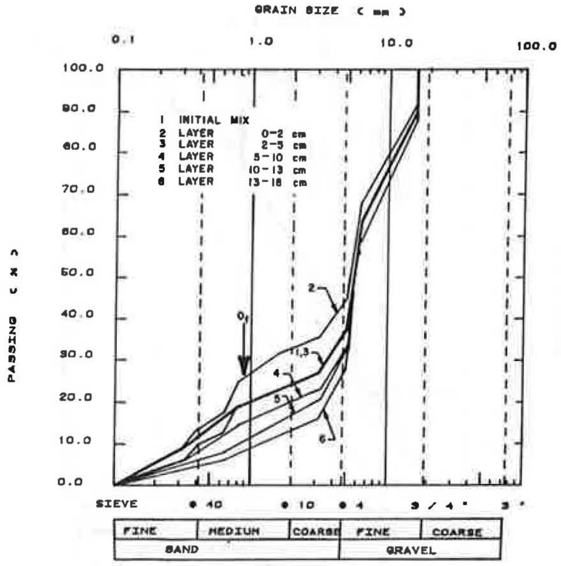

Fig. 6 M8-T20 test

When the smaller openings of T 20 are used, more base particles are stopped at the bottom layer #1. In fact fig. 6 shows that at the end of the test, this layer contains more fine particles than the original mix; these fines come from upper layers that appear to be coarser at this time. On fig. 11, the values of k_2, k_3 and k_4 are seen to vary with time in such a way that they are at the closure of the tests, one order of magnitude greater than k_1, this last value slightly decreased throughout the test, as a result of particle entrapment in layer 1. The ratio ($\Delta H/L_o$) has no meaning in the case of an unstable soil because the whole sample is subject to particle migration. The low $\Delta H/L_o$ ratios measured for M8 would at most indicate that the loss of fine particles did not damage the skeleton of the soil.

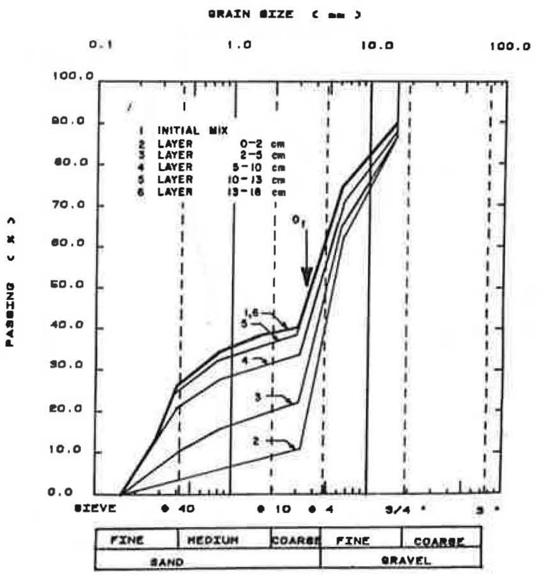

Fig. 7 M6-T6 test

c) Gap-graded soil (M-6)

The results of the tests made on the gap graded M-6 soil bears some similarity with the previous soil (M-8): the coarse skeleton is to a less extent uncapable of filtrating its own finer particles. The grain size curves of fig. 7 and 8 show that it took respectively 10 cm and 5 cm for the self-filter to develop. Fig. 12 and 13 show that k_1, is significantly larger than for the other layers, indicating that substantial fine washout occurred in this zone even with the smaller T 20 opening.

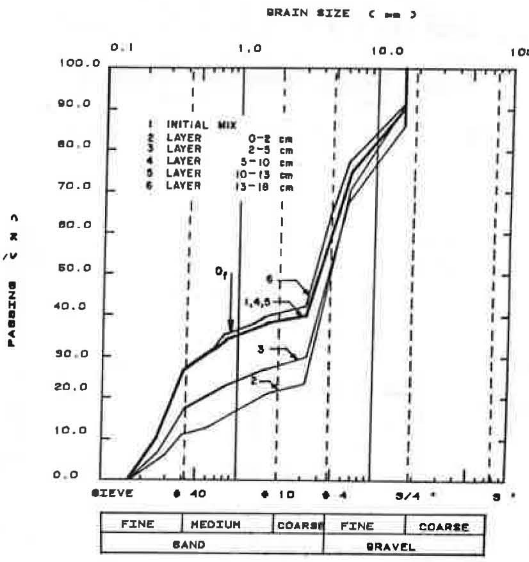

Fig. 8 M6-T20

Table 1 - Test conditions and results

	M42-T4	M8-T5	M8-T20	M6-T6	M6-T20
O_f (mm)	4.76	4.00	0.84	3.36	0.84
ρ initial (Mg/m^3)	1.84	1.97	1.97	1.86	1.89
I_D initial (%)	13	28	28	5	19
I_D final (%)	13	< 0	74	72	92
t_s (min)	70	80	20	--	--
L_c (cm)	2	>18	>18	10	5
$\Delta H/L_o$ (%)	29	<5	< 1	9	15

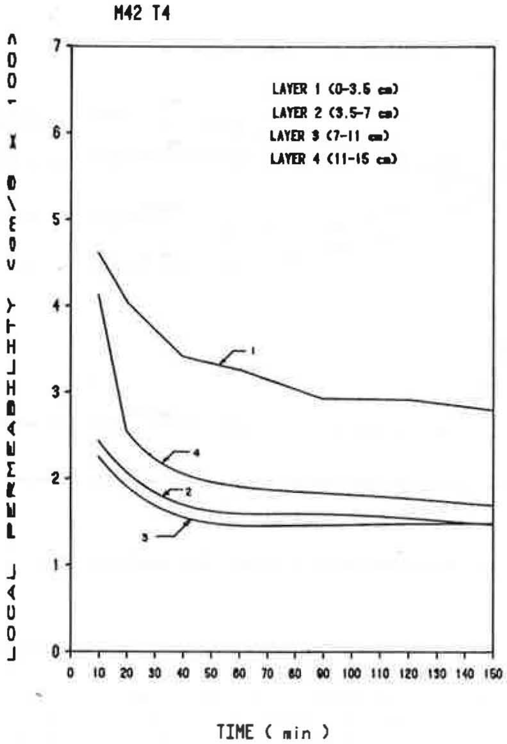

Fig. 9 Permeability for test M42-T4

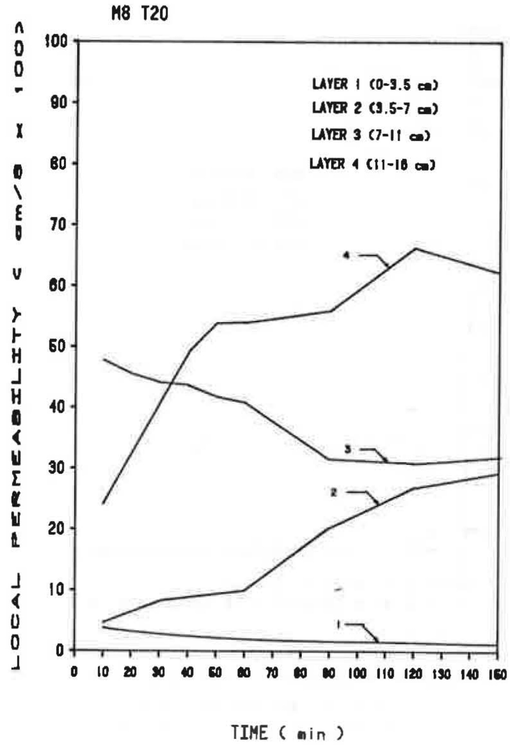

Fig. 11 Permeability for test M8-T20

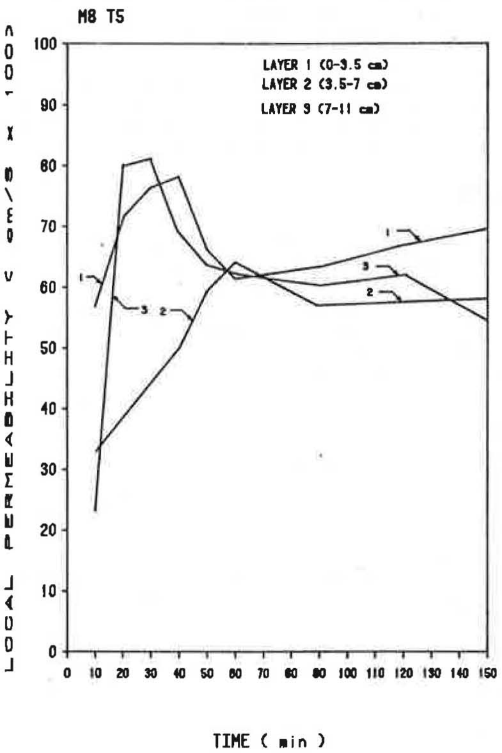

Fig. 10 Permeability for test M8-T5

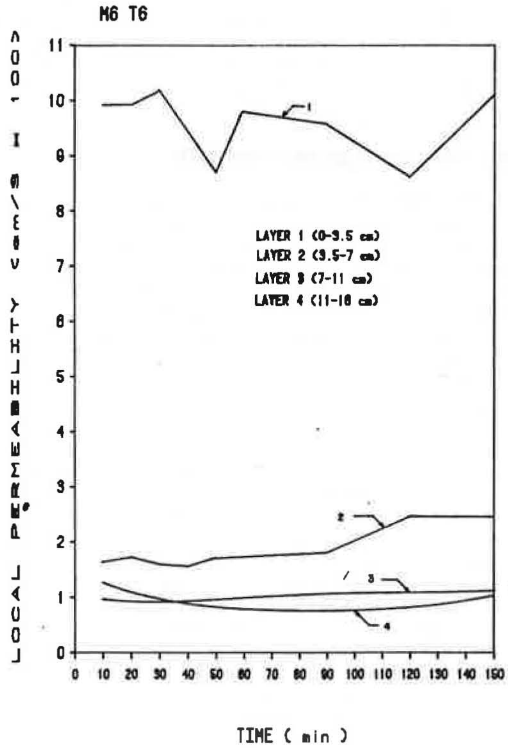

Fig. 12 Permeability for test M6-T6

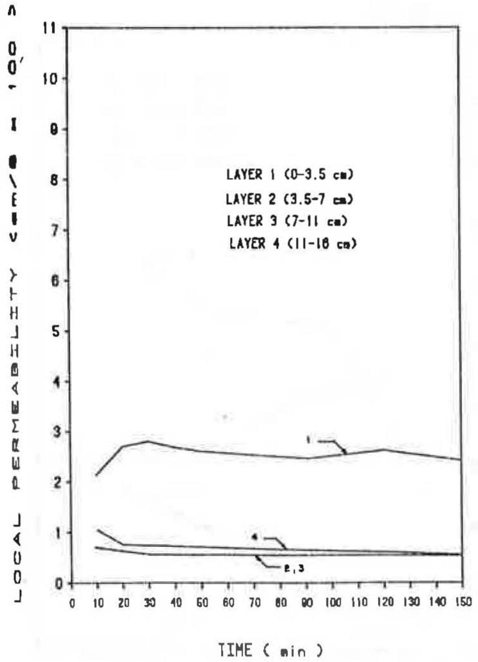

Fig. 13 Permeability for test M6-T20

The whole programme results are summarized on fig. 14 which presents the percent of base particles coarser than the opening size throughout the sample at the end of the test. One can see the different behaviour of the soils: For the self-filtrating M-42, the original size distribution is found less than 5 cm away from the filter. For the unstable M-8, the grain size distribution is altered throughout the specimen in both cases. Finally the gap graded soil M6 has a self filtrating zone that is less than 10 cm with the 3.36 mm opening (T-6) whereas it is 5 cm with the 0.84 mm. T-20 sieve. Beyond this distance, the grain size has been unaltered by the downward flow.

SUMMARY AND CONCLUDING REMARKS

A filter testing programme on artificial blended soils has been undertaken to assess the self filtration that is to take place near a square mesh filter analogous to woven geotextiles. In order to eliminate unquantifiable variables as surface cohesion and asperities, spherical glass ballotini were used and mixed in different proportions to modelize three different kinds of broadly graded soils: a straight line graded, an internally unstable and a gap-graded soil. The extent of self filtration (or absence of self-filtration) was assessed first by comparing grain size curves made before and after flow at different levels away from the soil filter interface and secondly, by evaluating the permeability changes with time at each of these levels, from piezometric measurements.

The test results have shown that a square mesh of definite opening size can act as a catalyst to the filtration of broadly graded soil provided that this soil is self-filtering. For the self-filtration to develop however, it is shown that a minimum washout of fines from the zone adjacent to the filter, is necessary. Limited test results on a straight line graded soil have shown that this zone was less than 2 cm thick but it has lost more than 30% of its particles when the opening size of the filter O_f was equal to the D_{85} of the soil. This amount would be substantially reduced, had a smaller opening been used.

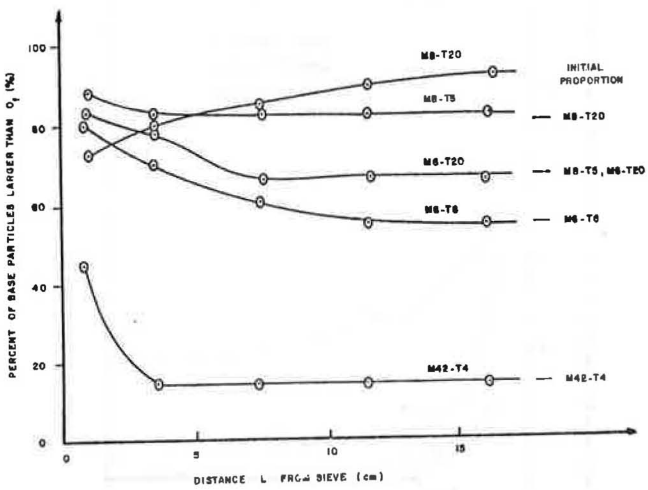

Fig. 14 Distribution of particles smaller than O_f

The results have also indicated that internally unstable and gap graded soils can be filtered if the opening size O_f is properly chosen. Tests made on both soils with two opening sizes have lead to a better understanding of the interparticle behaviour of a soil mass submitted to a flow. In the first case, the finer portion of the soil has been displaced within the coarse skeleton towards the bottom of the sample and depending on the opening size, it was either washed out or retained. This behaviour has been confirmed by local permeability that is very sensitive to the fine content in the various zones.

Finally the gap-graded soil has shown that its finer portion can be self-filtering because although the process has taken more volume to develop, a stable conbination has finally been encountered.

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