A modified gradient ratio test for the filtration performance of geotextiles

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ABSTRACT: For filtration applications, geotextiles should have opening size small enough to retain particles of the adjacent base soil and voids large enough to let drained water pass through geotextile without restriction. Candidate geotextiles are selected for most applications according to index tests : the filtration opening size of the geotextile is compared to the indicative grain size of the base soil and this retention ratio must be smaller than one. For applications with silty and broadly graded soils however, the ASTM D5101 Gradient Ratio test is often reported for the evaluation of the soil/filter compatibility. The primary function of a filter is to retain base particles. In broadly graded soils with $C_u > 8$, filtration involves the washout of a certain amount of particles before bridging can result in a stable combination. Filtration tests on broadly graded cohesionless soils have highlighted the existence of a self-filtration zone near the interface. The washout of a certain amount of base particles finer than the opening size of the filter was observed and it is a function mainly of the retention ratio and of the shape and extent of the gradation curve of the base. Stable combinations were encountered with a threshold value of 2500 g/m^2 of washed out particles above which continuous piping developed. It is proposed that the compatibility testing procedure is modified to include the measurement of the amount of particles passing through the geotextile and collected at the bottom of the permeameter.

Keywords: filtration, retention, hydraulic gradients, piped particles.

1 INTRODUCTION

The range of application of geotextiles in filtration and drainage is very broad and they are used in many civil engineering works where they are put in contact with base soils having the most important variability. Particles gradation and hydraulic conductivity cover at least six orders of magnitude in range: from 10^3 to 10^{-3} mm and from 10^{-10} to 10^{-3} m/s, respectively. Most of the filter criteria including the foremost classical Terzaghi criterion however, have been developed and proposed from results of tests involving uniform soils. Depending on the geological conditions, filtration can involve broadly graded soils containing appreciable amounts of erodible silt size cohesionless particles. A broadly graded soil is defined as a soil with a coefficient of uniformity $C_u > 8$ and a coefficient of curvature C_c between 1 and 3. The interaction between such a base soil and the filter is rather complex since the latter cannot retain all the particles of the former. It is forcibly admitted that some washout takes place before equilibrium is attained.

2 FILTRATION OF BROADLY GRADED SOILS

In his paper, Lafleur (1999) has evaluated the rearrangement of particles of broadly graded cohesionless soils near the filter interface from a program of compatibility tests with piezometric measurements in an apparatus similar to that of the ASTM standard D-5101. Each soil was tested by increasing the opening size of the filter until marked piping developed. Three mechanisms were observed as a function of the retention ratio R_R defined as

$$R_R = \frac{\text{filter opening size } O_F}{\text{indicative base size } D_I} \quad (1)$$

where the filter opening size is obtained by the standardized FOS-value. As regards the indicative base size, broadly graded soils were classified according to the shape of their gradation curve: concave upward, rectilinear and gap-graded, as shown on Fig. 1. Also given by the arrows are the corresponding indicative base size for which the equilibrium was attained after the washout of an amount of particles that will be discussed in the following section. They are respectively D_{30}, D_{50} and D_G, values incidentally smaller than the usual value of D_{85} originally quoted in most of the retention criteria. In its latest edition, the Canadian Foundation Engineering Manual (CGS, 2006) has incorporated this prescription for the selection of filters for cohesionless soils with Cu > 8.

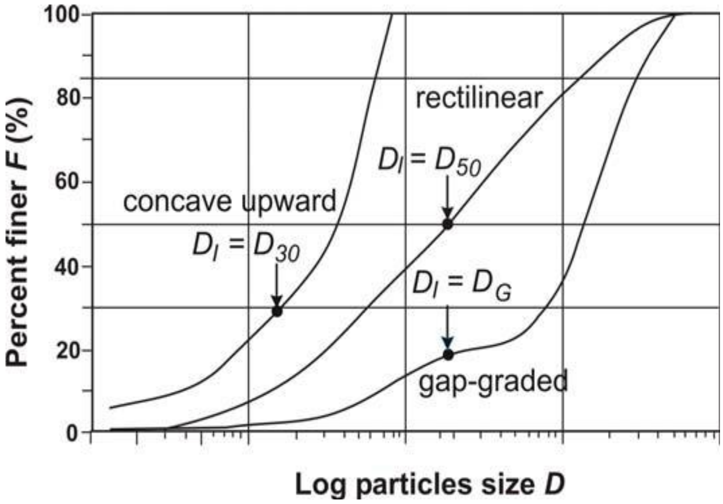

Figure 1: Classification of gradation curves for broadly graded soils.

The Fig. 2 represents schematically and graphically the pore structure changes with the filtration of broadly graded soils. On the left, the changes in gradations involved in this process are represented schematically on the adjoining sketches. The third column represents the local hydraulic conductivity k (in full) compared to the average permeability of the base $\bar{k}_B$ (dotted) after a certain time as a function of the distance from the interface and finally the right graphs give the variation in the system hydraulic conductivity $\bar{k}_B$ compared to k_F of the filter, as a function of time for each mechanism. They are represented from top to bottom by order of decreasing values of R_R. When R_R is much larger than unity, **piping** occurs, the finer base particles are continuously washed out through the filter, increasing thereby $\overline{k_B}$ that trends ultimately toward k_F with time. With R_R near unity, equilibrium is gradually promoted by **bridging**: the larger particles near the geotextile filter the medium size particles that on their turn filtrate the smaller ones at a certain distance from the interface in the self-filtration zone as called by Lafleur et al. (1989), resulting in a small increase in local *k*-values. The left hand graphs on this line show that at this distance the gradation curves remain unchanged upon flow of water. This limited washout resulted in a slight increase in $\overline{k_B}$ but with time the system conductivity reaches a constant value corresponding to equilibrium.

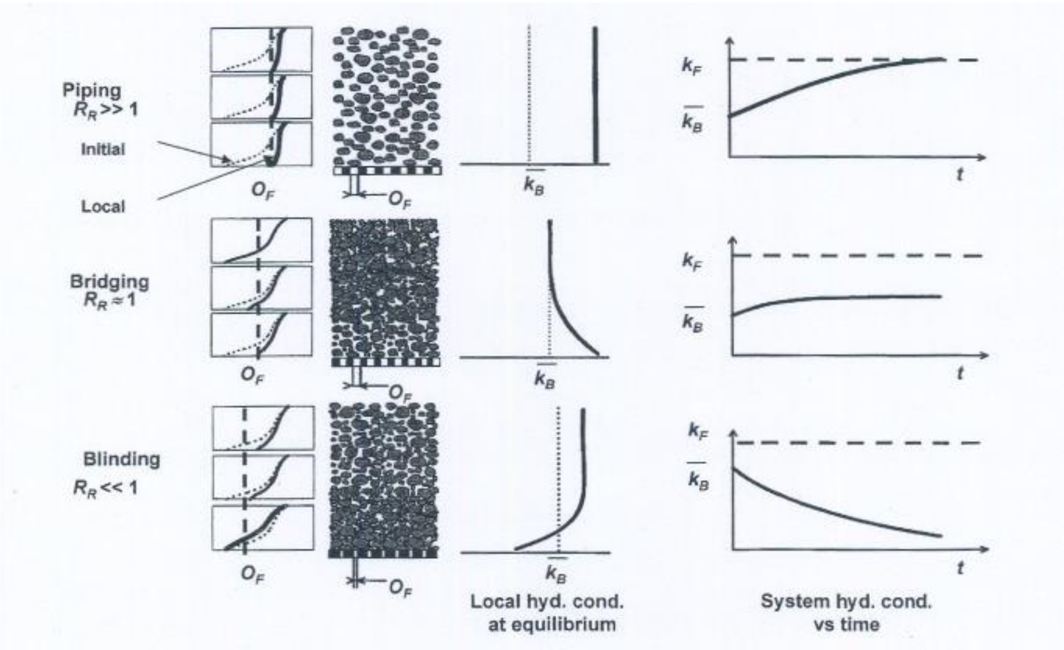

Figure 2: Pore structure changes during the filtration of broadly graded soils.

The bottom graphs shows the mechanism involved when internally unstable or suffosive soils are filtered and the filter is too tight i.e. a R_R-value much lower than unity. **Blinding** sometimes called caking or improperly, clogging, results from the interception at the filter interface of finer freely moving base particles through its coarser skeleton. This blocking causes a marked decrease in local *k*-values in this zone as shown on the center right figure. The other consequence of this, is a constant decrease in $\overline{k_B}$ leading to a deficient drainage of the base soil.

The above has demonstrated that the filtration of broadly graded soils is accompanied by an inner rearrangement of finer particles near the interface. If this movement is continuous, the whole mass is eroded and voids will appear in the soil to be retained. If blinding of internally unstable soils occurs at the base/filter interface, free drainage is impaired.

3 AMOUNT OF WASHED OUT PARTICLES

The amount of washout has been recognized as an important factor in the interpretation of compatibility tests. In the keynote paper by Heibaum et al. (2006), the results of a screen test program with the three types of gradations of Fig. 1 were presented. The reconstituted soils were submitted to a downward gradient of 10 in the permeameter and filtered at their base by square mesh conventional 200-mm sieves with varying opening sizes. Lateral piezometer recorded local hydraulic gradients. The Fig. 3 presents in the shaded area the mass of washout per unit area M_P as a function of the retention ratio R_R. Results obtained by Fannin et al. (1994), Mlynarek and Lombard (1997) and Lafleur et al. (2002) show the same trend: M_P increases with R_R. Continuous piping occurs and the combinations are unstable beyond a threshold value of 2500 g/m^2 for M_P when R_R is near to or larger than unity. For the uniform soils (FVS-U and ML), the break at $R_R = 1$ is obvious and involved minimal washout before. These lower M_P-values for FVS-WG and ML-POA>10 were attributed to the smaller Percent Opening Sizes (POA < 10%) of the woven geotextiles compared to those of the screen tests (>> 10%).

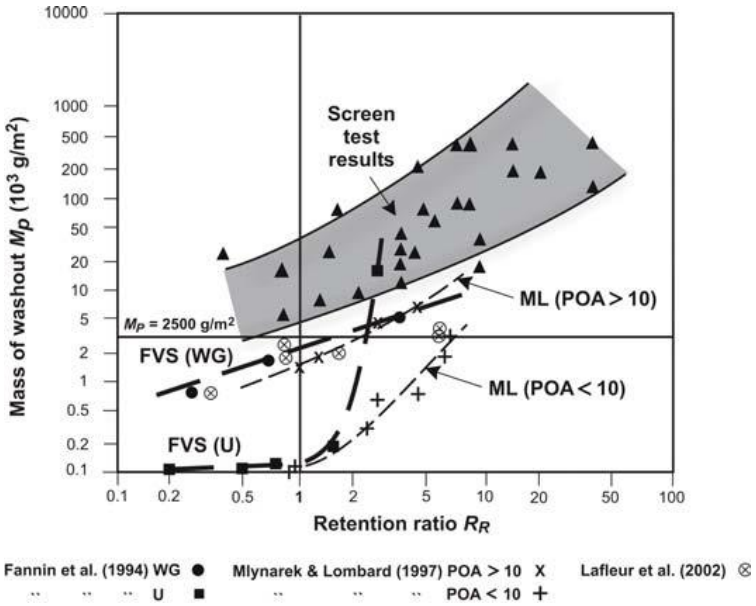

Figure 3: Mass of washout M_P versus Retention Ratio R_R.

4 USE OF THE GRADIENT RATIO TEST

The results of Fig. 3 have highlighted the influence of the coefficient of uniformity on the filtrability of broadly graded soils. The increase in M_P with R_R is gradual and the results show high dispersion. A threshold value of 2500 g/m^2 represents the limit between stable and unstable tested combinations. This limit may change however, with gradation properties of different soils and types of geotextiles. This would suggest modifications to the existing Gradient Ratio test. Further to evaluate the rearrangement of base particles near the interface, a measurement of particles passing through the filter M_P would appear to be an important complement.

In his discussion of the Gradient Ratio test procedure, Fannin (2015) clearly demonstrated on his graph of head losses through a soil/filter combination, that a GR-value larger than 3 is an indication of excessive clogging, GR being defined as:

$$GR = \frac{i_{SF}}{i_S} \tag{2}$$

where i_{SF} is the hydraulic gradient in the lower 25 mm near the interface and i_S the gradient in the base between 25 and 75 mm from the interface. This reasonning could be deduced also from the bottom distribution of local hydraulic conductivity for blinding on Fig. 2, k being lower near the interface than above would result in higher local gradients.

It is proposed that further to the measurement of *GR* with time, the apparatus shown on Fig. 4 would allow the collection of washout at the end of the test. This value of M_P combined with the evolution with time of *GR* would give a better assessment of the base/filter compatibility since it evaluates both the retention capability of the filter and the rearrangement of base particles near the interface to prevent undesirable piping or blinding.

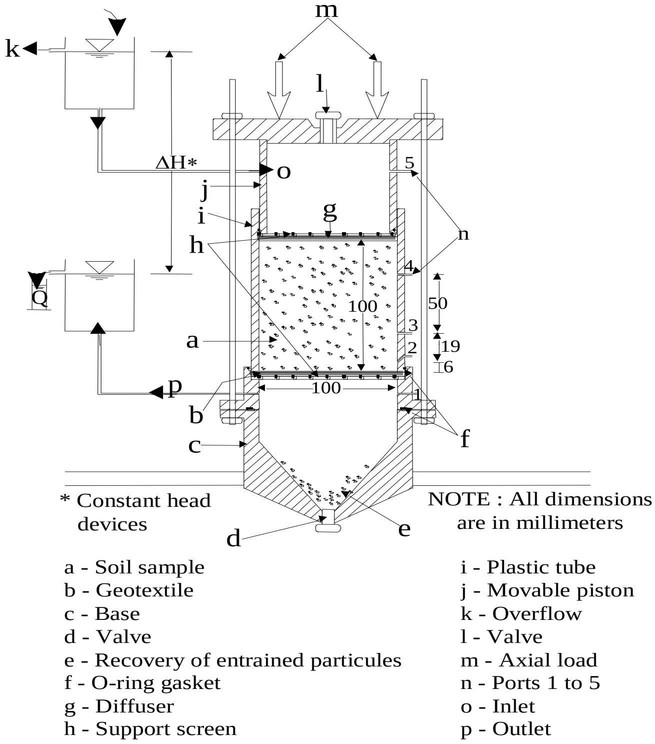

Figure 4 : Proposed downward flow filtrameter for gradient ratio test.

5 DISCUSSION AND CONCLUSION

Although the existing Gradient Ratio test procedure gives indications of the rearrangement of the base particles near the filter interface, it does not yield the complete portrait of the compatibility between a filter and a base soil, especially when they are broadly graded and cohesionless, a situation which occurs more than often in nature. Some passage of particles is unavoidable and if it exceeds a threshold value observed to be 2500 g/m^2, continuous piping is to be encountered.

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