Second International Conference on Geotextiles,
Las Vegas, U.S.A.

GIROUD, J. P.
Woodward-Clyde Consultants, Chicago, Illinois, U.S.A.

Filter Criteria for Geotextiles
Critères de filtre pour les géotextiles

Classical criteria used in soil mechanics for granular filters such as sand were established as a result of a combination of laboratory findings and theoretical considerations. In the recent past, considerable efforts have been devoted to experimental studies of geotextile filters. As an attempt at complementing experimental findings, a theoretical analysis of the filtration mechanism related to geotextiles is presented in this paper. Although the considered mechanism is similar to the mechanism of filtration related to granular materials, the derived criteria for permeability and opening size of geotextile filters are different from the corresponding criteria related to granular filters. Also the analyis presented in this paper shows that simplistic criteria often used to select geotextile filters can be misleading. A design example shows that the use of the simplistic criteria, instead of the criteria proposed in this paper, would have caused a significant risk of piping in a dam where a geotextile filter has been used successfully.

Les critères classiques utilisés en mécanique des sols pour les filtres granulaires, en sable par exemple, ont été établis en combinant résultats expérimentaux et considérations théoriques. Ces dernières années, de nombreux travaux expérimentaux ont été consacrés aux filtres géotextiles. En complément à ces travaux expérimentaux, une étude théorique du mécanisme de filtration avec géotextile est présentée dans cet article. Bien que le mécanisme considéré soit analogue à celui relatif aux filtres granulaires, les critères obtenus pour la perméabilité du géotextile et pour la dimension de ses ouvertures sont différents des critères relatifs aux filtres granulaires. De plus, l'analyse présentée dans cet article montre que les critères simplistes souvent utilisés pour sélectionner les filtres géotextiles peuvent conduire à des erreurs. Un exemple montre qu'utiliser les critères simplistes au lieu de ceux proposés dans cet article aurait provoqué un important risque d'érosion interne dans un barrage où un filtre géotextile a été utilisé avec succès.

INTRODUCTION

It is difficult to simulate in a laboratory the longterm behavior of a filter in the field. To decrease the testing time, unrealistic values of some parameters (such as the gradient) are often selected, and results are misleading. When tests are properly carried out, facts concerning the mechanism of clogging can be learned but no simple results are obtained because many parameters are involved. Consequently, classical criteria for granular filters were established as a combination of laboratory findings and theoretical considerations, and justified, a posteriori, by years of successful field applications.

Similarly, there is little hope to establish practical filter criteria for geotextiles from laboratory tests only. It seems appropriate to use the combined approach (laboratory and theory) that proved successful for soils. Filter criteria for geotextiles, established using theoretical considerations, are presented in this paper.

This paper is user oriented. Design criteria and examples are presented first. Definitions, derivations and comments may be found in Appendices.

1. DISCUSSION OF THE MECHANISM OF FILTRATION

A filter must retain the soil and allow the water to pass through. These two requirements are contradictory when they are formulated too strictly. If it were required that all soil particles be retained, an impervious screen would be needed, in which case water would not flow through it. Conversely, if it were required that the flow of water be absolutely unimpeded by the filter, openings of the filter should be so large that practically no soil particles would be retained.

Consequently, the two requirements must not be formulated too strictly: the filter must only negligibly impede the flow of water and must also prevent destruction of the soil structure by erosion. A good filter has openings both large enough and small enough. It needs openings large enough to allow water to flow almost freely (this could result in the loss of some of the finest soil particles) but it should have openings small enough so that the particle skeleton, which gives the soil structure stability, is not disturbed as a result of the loss of some fine particles. To evaluate these two "reasonable requirements", a filtration theory must be developed. A complete theory would be difficult to formulate due to two reasons, the variety of phenomena involved (two phase flow and capillarity, chemical and electrical interactions between filter and particles, erosion, variation of the mechanical behavior of soil as a function of water content and pore water pressures, etc.) and the large amount of parameters: (i) geometrical conditions (shape of the soil mass, location of the fluid, flow direction which may vary) and mechanical conditions (gravity, stresses); and (ii) properties of materials such as the fluid (composition, density, viscosity), the soil particles (shape, dimension, distribution, density, chemical nature), the soil (density, mechanical properties such as friction and cohesion, permeability), the constituents of the filter (shape, dimensions, distribution, density and chemical nature of solid elements (grains or fibers) of filter, and void distribution of filter), the filter (continuity, permeability, mechanical properties such as compressibility).

At the present time we are far from having a complete theory dealing with the above phenomena and parameters. We use a simplified approach for granular filters as well as geotextiles, which consists of considering two criteria, established separately by neglecting some phenomena and parameters: the permeability criterion and the filtration criterion. Consequently, soil filtration with geotextiles is neither better, nor worse understood than soil filtration with granular filters. The proposed criteria for geotextiles are probably as valid as the classical criteria used for granular filters discussed hereafter.

2. CRITERIA FOR GRANULAR FILTERS

Criteria for granular filters can be found in every soil mechanics textbook. Original work was done by Terzaghi in 1922 (1) and was followed by considerable work done by many researchers and organizations. As a result, various expressions of the criteria can be found. A typical one is:

$$d_{15}\ (\text{filter}) > 4\ d_{15}\ (\text{soil}) \qquad (1)$$

$$d_{15}\ (\text{filter}) < 4\ d_{85}\ (\text{soil}) \qquad (2)$$

Eq. 1 is the permeability criterion and Eq. 2 is the retention criterion.

Comments related to Eq. 1. It is known that the hydraulic conductivity (coefficient of permeability) of a granular material with a uniform particle size distribution is proportional to the square of the diameter of its particles. When the particle size distribution is not uniform, it is classical to consider that the hydraulic conductivity is proportional to d_{10}^2 or d_{15}^2. Therefore, Eq. 1 implies that the permeability of the filter must be greater than 16 times (say approximately 10 times) the permeability of the soil in contact.

Comments related to Eq. 2. In a granular material made of identical spheres in the most compact state (hexagonal arrangement), the ratio between the diameter of the spheres and the diameter of the largest sphere likely to go through this granular material is: $3/(2-\sqrt{3}) = 6.5$. In a loose state (cubic arrangement), the ratio becomes $1/(\sqrt{2}-1) = 2.4$. An approximate average value is 4. The same ratio can be applied to d_{10} or d_{15} in the case of a granular filter with a non uniform particle size distribution. In other words, Eq. 2 means that large particles of soil (d_{85}) must be larger than the openings of the filter ($d_{15}/4$).

Summary. Classical criteria for granular filter mean that: (1) the hydraulic conductivity (coefficient of permeability) of the filter must be approximately 10 times larger than the hydraulic conductivity of the soil; and (2) large soil particles (d_{85}) should be larger than openings of the filter.

3. CRITERIA FOR GEOTEXTILE FILTERS

Permeability criterion. As shown in Appendix 2, the permeability criterion for geotextile filters is:

$$k\ (\text{geotextile}) > 0.1\ k\ (\text{soil}) \qquad (3)$$

The hydraulic conductivity k (coefficient of permeability) of a geotextile filter must be at least one tenth of the hydraulic conductivity of the soil in contact. This is different from Eq. 1 related to granular filters. Comments are made in Appendix 2.

Retention criterion. In Appendix 3, the retention criterion is established for the case when the soil in contact with the filter is cohesionless. This criterion, presented in Table 1 and Fig. 1, depends on the density of the soil (characterized by I_D) and on the slope of its grading curve (characterized by C'_u). The required opening size of the geotextile can be larger or smaller than the soil particles, depending on the values of I_D and C'_u. Comments are made in Appendix 3.

Limitations to the use of the proposed retention criterion are: (i) the criterion is conservative in the case of a clay with high cohesion (the same limitation exists with the classical criterion for granular filters); (ii) the criterion must not be used with unstable gap-graded soils (see Fig. 3, soil 1) because with such soils clogging of filters cannot be prevented; (iii) the criterion cannot be used when the soil structure is repeatedly destroyed by a turbulent flow of water that changes periodically in both direction and velocity (bank protections).

Table 1. Retention criterion (I_D and C'_u are defined in Appendix 1). The criterion is represented graphically in Fig. 1.

	Density index of the soil (Relative density)	Linear coefficient of uniformity of the soil	
		$1 < C'_u < 3$	$C'_u > 3$
loose soil	$I_D < 35\%$	$O_{95} < C'_u d_{50}$	$O_{95} < \frac{9}{C'_u} d_{50}$
medium dense soil	$35\% < I_D < 65\%$	$O_{95} < 1.5\ C'_u d_{50}$	$O_{95} < \frac{13.5}{C'_u} d_{50}$
dense soil	$I_D > 65\%$	$O_{95} < 2C'_u d_{50}$	$O_{95} < \frac{18}{C'_u} d_{50}$

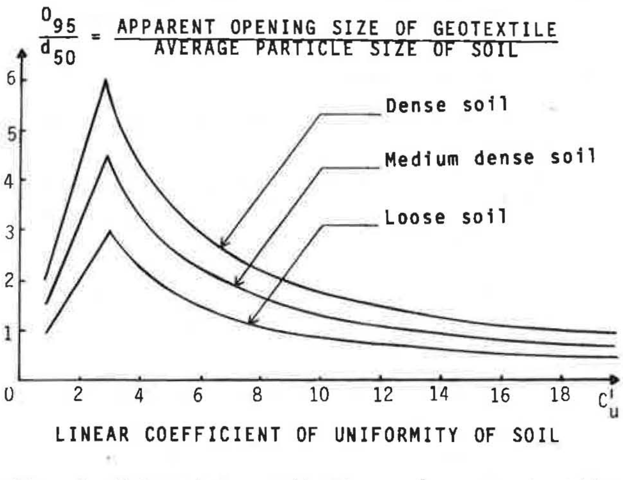


Fig. 1. Retention criterion for geotextile filter (see Table 1).

4. DESIGN EXAMPLE

The particle size distribution curve shown in Fig. 2 is related to Valcros Dam (2). At the time of the construction of this dam (1970), little was known about filter criteria for geotextiles. The only design consideration was to check that the opening size of the geotextile available on the site (then believed to be approximately 0.1 mm) was smaller than the d_{85} of the soil (7 mm, according to Fig. 2). For twelve years, Valcros Dam has performed well. Today it is an interesting exercise to verify this early design using the criteria presented above.

First, the retention criterion is considered. For d_{50} = 0.47 mm and C'_u = 49, according to Fig. 2, the required maximum opening size of the geotextile is determined using Table 1:

$$O_{95} < 18 \times 0.47/49 = 0.17 \text{ mm}$$

This requirement is satisfied by the geotextile used in Valcros Dam because its apparent opening size, O_{95}, lies between 0.13 and 0.17 mm according to various tests. It is noteworthy that the use of the simplistic criterion, $O_{95} < d_{85}$ = 7 mm, could have led to an important mistake (significant risk of piping).

The permeability criterion (Eq 3) is easily verified because the hydraulic conductivities are approximately 10^{-4} m/s for the geotextile and 10^{-7} m/s for the soil.

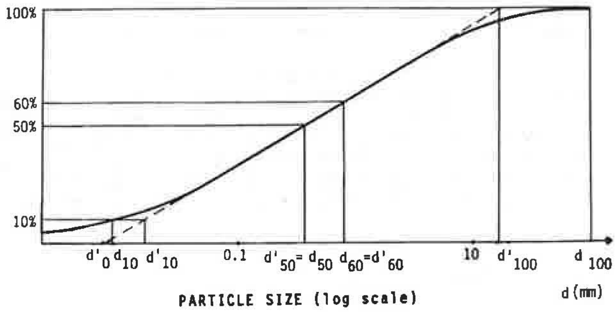
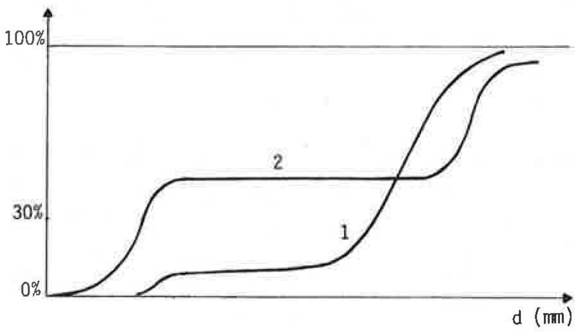


Fig. 2. Particle size distribution curve of Valcros Dam (d'_{100} = 17 mm; d'_0 = 0.007 mm; $C'_u = \sqrt{17/0.007} = 49$).



PARTICLE SIZE (log scale)

Fig. 3. Particle size distribution curves of two typical gap-graded soils.

APPENDIX 1. DEFINITIONS

Definitions related to soils. A typical curve representing the particle size distribution of a soil is shown in Fig. 2. The slope of this curve is traditionally evaluated using the coefficient of uniformity, $C_u = d_{60}/d_{10}$. To express the retention criterion, it is more appropriate to use the slope of the central portion of the curve, thus eliminating the coarsest and finest particles which have a negligible influence on the stability of the soil structure in the filtration process. A straight line is drawn as close as possible to the central portion of the curve and a "linear coefficient of uniformity" is defined as $C'_u = d'_{60}/d'_{10}$ (d'_{60} and d'_{10} being related to the straight line). Because of the log scale:

$$C'_u = \frac{d'_{50}}{d'_0} = \frac{d'_{60}}{d'_{10}} = \;\dots\; = \frac{d'_{90}}{d'_{40}} = \frac{d'_{100}}{d'_{50}} = \sqrt{\frac{d'_{100}}{d'_0}} \qquad (4)$$

It is impossible to draw a straight line with a gap-graded soil (Fig. 3). Two typical cases are: (i) in a silty or clayey gravel including less than 30% fine particles (soil 1 in Fig. 3) the space between the gravel particles is not filled and the soil structure is not stable when water is flowing; and (ii) in a silty or clayey gravel including more than 30% of fine particles (soil 2 in Fig. 3), the gravel particles are not in contact with each other and they "float" in the fine-soil matrix; in this case, one will consider only the particle size distribution curve related to the fine portion of soil for the retention criterion.

Two values of the linear coefficient of uniformity are particularly interesting:

- C'_u = 1. The soil has a uniform particle-size distribution (in other words, all the particles have the same size), and the void space between particles is large (even after compaction).
- C'_u = approximately 3. It has been shown theoretically and experimentally (3) that soils with a coefficient of uniformity of approximately 3 obtain the highest densities (that is, the most complete filling of space with maximum interlocking of particles), if appropriate compaction is applied.

When C'_u is greater than 3, the soil grain-size distribution is too spread out to obtain a perfect interlocking: there are not enough particles of each dimension. If C'_u is between 1 and 3, it is possible, with appropriate compaction, to obtain the maximum interlocking of particles.

The stability of the structure of a cohesionless soil is related to its density index I_D (relative density):

$$I_D = \frac{e_{max} - e}{e_{max} - e_{min}} \times 100\% = \frac{\rho_{dmax}}{\rho_d} \times \frac{\rho_d - \rho_{dmin}}{\rho_{dmax} - \rho_{dmin}} \times 100\% \qquad (5)$$

where: e, e_{max}, e_{min}, = void ratio of the soil in place, in its loosest and densest state respectively (dimensionless); ρ_d, ρ_{dmax}, ρ_{dmin} = dry density of the soil in place, in its densest and loosest state respectively (kg/m^3).

The soil property used in the permeability criterion is its hydraulic conductivity (coefficient of permeability), k (m/s).

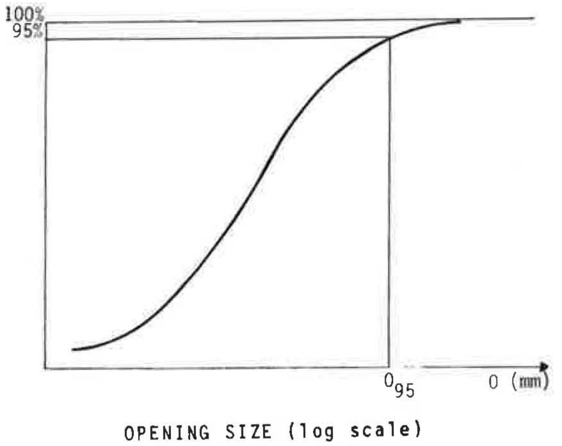


Fig. 4. Opening size distribution curve ("porometric curve") of a geotextile.

Definitions related to the geotextile. A typical "porometric curve" representing the opening size distribution of a geotextile is shown in Fig. 4. This curve can be obtained, with more or less accuracy, by sieving calibrated glass beads through the considered geotextile. The retention ability of a geotextile is governed by its largest openings. Consequently, the upper part of the porometric curve is the most important and it is usually characterized by the O_{95} (Fig. 4), often called apparent opening size.

The hydraulic conductivity, k (m/s), of the geotextile used in this study is related to a flow of water normal to the plane of the geotextile. Tests in a permeameter give the hydraulic permittivity, ψ (s^{-1}), of the geotextile. Hydraulic conductivity is deduced using $k = \psi T_g$, where T_g = thickness of the geotextile (m).

APPENDIX 2. PERMEABILITY CRITERION

Eq. 3 has been established as follows.

Principle. As mentioned in Section 1, disturbances to water flow due to the filter should be negligible. Two disturbances must be considered: the decrease in flow and the increase in pore water pressure within soil. The analysis shows that these two disturbances result in the same criterion.

Assumptions. As indicated in Section 1, it would be very difficult to take into account all the parameters and simplifying assumptions must be made. We consider the simple case of a saturated soil (to eliminate capillarity) where water flows vertically (to simplify the influence of gravity) (Fig. 5).

Theoretical analysis. The following results were established using Darcy's formula:

- Flow per unit area with a filter:

$$\frac{Q}{A} = \frac{h}{\frac{T_f}{k_f} + \frac{T_s}{k_s}} \qquad (6)$$

- Flow per unit area without a filter:

$$\frac{Q'}{A} = \frac{hk_s}{T_s} \qquad (7)$$

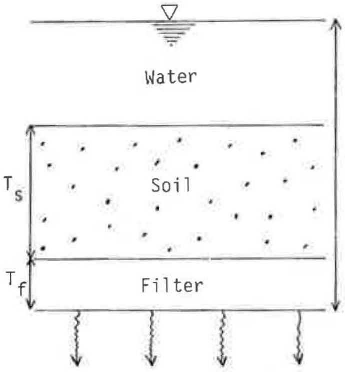


Fig. 5. Vertical flow through soil and filter.

- Increase of pore water pressure within the soil caused by the filter:

$$\Delta p = \left(\frac{h}{1 + \frac{T_s\,k_f}{T_f\,k_s}} H_f\right) \rho_w g \qquad (8)$$

where: h = hydraulic head (m); T_s,T_f = soil and filter thicknesses, respectively (m); k_s,k_f = hydraulic conductivities of soil and filter respectively (m/s); ρ_w = water density (kg/m^3); and g = gravity (m/s^2).

For both the flow and pore water pressure disturbances caused by the filter to be small, $T_f k_s/(T_s k_f)$ must be small compared to 1. In geotechnical engineering, a disturbance is usually considered as negligible when it is lower than 10%. Furthermore a safety factor of 10 is recommended for calculation when soil permeability is involved. The condition may then be stated as follows:

$$\frac{T_f k_s}{T_s k_f} < 10\%/10 = 0.01 \qquad (9)$$

The T_f value is of the order of 1 m for granular filters and 1 to 10 mm for geotextiles (10 mm is used since this is conservative with respect to this calculation). The length T_s corresponds to the final part of the flow through the soil where the water speed increases as it comes close to the drain. An order of magnitude of 10 m is reasonable. The following permeability criteria are then deduced from Eq. 9:

k_f > 10 k_s for a granular filter (10)

k_f > k_s/10 for a geotextile filter (11)

Comments. (i) According to the calculations above, the hydraulic conductivity of a granular filter must be 10 times larger than the hydraulic conductivity of the soil. This is in perfect agreement with the classical Eq. 1, as discussed in Section 2 and checks the validity of our calculations. (ii) Using the same calculations for a geotextile, it appears that the hydraulic conductivity of a geotextile filter must be larger than only one tenth of the hydraulic conductivity of the soil. Therefore it may be concluded that specifications, requiring that the hydraulic conductivity of the geotextile filter be larger than the hydraulic conductivity of the soil, are exaggerated. They demand more of geotextiles than classical criteria demand of granular filters.

APPENDIX 3. RETENTION CRITERION

The retention criterion presented in Table 1 and Fig. 1 (Section 3) has been established as follows.

Principle. As indicated in Section 1 only a simplified analysis is possible. But, the analysis must not be oversimplified: it would be very simple, but unrealistic, to choose a filter as a sieve that is agitated until all the particles smaller than mesh openings pass through. It is known, by experience, that filters are able to retain soils including numerous particles which, individually, would be able to pass through their openings.

Soil retention by a filter depends on the stability of the soil structure which is governed by the following parameters: soil properties, geometric characteristics of the soil-geotextile system and applied loads (flow drag, gravity, external loads, contact actions between filter and soil).

Assumptions. As indicated in Section 1, it would be very difficult to take into account all the parameters and simplifying assumptions must be made.

Soil properties having an influence on the stability of the soil structure are cohesion (which governs attraction between particles), and density and grain size distribution (which govern interlocking between particles). In this study, only cohesionless soils are considered because cohesive soils are more stable in filtration process.

Geometric characteristics of the soil-geotextile system are the sizes and the shapes of soil particles and geotextile openings. In this study, shapes are not taken into account. Each soil particle is characterized by only one dimension (i.e., it is considered as a sphere). Each geotextile opening is characterized by only one dimension (i.e., it is considered as a circular hole). In fact, shapes of openings of various types of geotextiles (wovens, nonwovens) are quite different and might have a significant influence on the mechanism of filtration.

Flow drag (proportional to hydraulic gradient) plays an important part, but is difficult to evaluate. It is conservative to consider that the flow drag is significant enough to move soil particles that are not in direct contact with solid elements of the filter or confined in the soil structure. Nevertheless, we do not consider the extreme case of a soil structure systematically destroyed by a turbulent and alternating water flow as it is the case for filters exposed to wave action. This case is similar to sieving where the particles, permanently agitated, pass through the filter if they are smaller than filter openings.

Gravity and external loads (except vibrations and shocks) usually improve the stability of a cohesionless soil, through interparticle friction. This effect does not seem essential. It is neglected in this study, which is conservative in most cases.

Contact actions include physico-chemical filter-soil attractions (which are usually negligible in cohesionless soils) and stresses at filter-soil contact. To evaluate the effect of these stresses upon the stability of the soil structure, the mechanical behavior of the soil should be taken into account. To simplify the evaluation, the considered filter-soil stresses are such that the soil particles in contact with the solid elements of the filter are perfectly immobile. In other words, the only soil particles supposedly able to move (under a water flow effect) are those which are in front of the filter openings and those that are immediately behind them.

As a result of these simplifying assumptions, the retention phenomenon becomes a geometric problem, the parameters of which are: (i) diameter of soil particles and geotextile openings; and (ii) interlocking of soil particles (governed by density index I_D and linear coefficient of uniformity C'_u). These parameters are defined in Appendix 1.

Theoretical analysis. Filter opening sizes are compared to soil particle sizes in two cases depending on C'_u. In each case, two sub-cases are considered, depending on I_D.

If C'_u is lower than 3, all the soil particles are interlocked, yielding a stable structure, as indicated in Appendix 1. The only requirement, therefore, is that the filter retains the coarsest particles so that the entire soil will be retained. As the stability is also a function of density, let us consider two sub-cases: dense soil and loose soil.

In the sub-case of a dense soil, two of the coarsest particles must move simultaneously to leave the soil structure unstable (Fig. 6a). As mentioned in Appendix 1, the coarsest particles of the straight line distribution (d'_{100}) must be considered instead of the actual coarsest particles (d_{100}). Consequently, the retention criterion is:

$$O_{95} < 2d'_{100} \qquad (12)$$

That is, from Eq. 4 and Fig. 2:

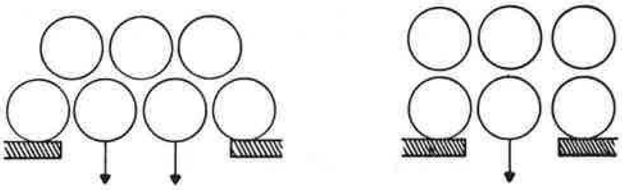
$$O_{95} < 2C'_u d'_{50} = 2C'_u d_{50} \qquad (13)$$

In the sub-case of a loose soil, it is sufficient that one of the coarsest particles moves to leave the soil structure unstable (Fig. 6b). The retention criterion then becomes:

$$O_{95} < C'_u d_{50} \qquad (14)$$

If C'_u is greater than 3, the soil particles are not able to interlock perfectly and, then, do not form a stable structure (as mentioned in Appendix 1). Therefore, when $C'_u > 3$, it is not sufficient that the filter retains the coarsest particles to allow the entire soil to be retained. To prevent migration of fine particles, the filter must be designed considering only the particles finer than a certain size d'_x. These particles must have a linear coefficient of uniformity of 3, in order to ensure that their structure is stable. Consequently, Eq. 12 for a dense soil becomes:

$$O_{95} < 2\,d'_x \qquad (15)$$



(a) (b)

Fig. 6. Influence of the soil density on the retention criterion: (a) dense soil; (b) loose soil.

where: $d'_x = (3)^2 d'_o$ (because d'_x plays the part of d'_{100} for the finer fraction of the soil).

According to Eq. 4:

$$d'_o = d'_{50}/C'_u = d_{50}/C'_u \tag{16}$$

Hence:

$$O_{95} < 18\ d_{50}/C'_u \tag{17}$$

For a loose soil, the factor 2 should be removed from Eq. 15 as it is seen by comparing Eq. 13 and 14. Consequently, in Eq. 17, valid for a dense soil, 18 must be replaced by 9 in the case of a loose soil. The curve related to a medium dense soil has been arbitrarily drawn half way between the curves related to dense and loose soils.

Comments. The retention criterion established as explained above and presented in Table 1 seems logical because it depends on two parameters, C'_u and I_D, governing the interlocking of soil particles and, consequently, the stability of the soil structure. A simpler criterion is often mentioned: $O_{95} < d_{85}$. In order to compare the two criteria, Fig. 1 is transformed into Fig. 7, using Eq. 18 deduced from the equation of the straight line of Fig. 2 (assuming $d_{85} = d'_{85}$):

$$d_{85} = d_{50}\ C'^{\,0.7}_u \tag{18}$$

It is seen on Fig. 7 that: (i) for small values of C'_u, the simplistic $O_{95} < d_{85}$ criterion leads to excessively small values of O_{95}, thus increasing the risk of clogging; and (ii) for large values of C'_u, the simplistic $O_{95} < d_{85}$ criterion leads to values of O_{95} too large, thus increasing the risk of piping, as already mentioned in section 4.

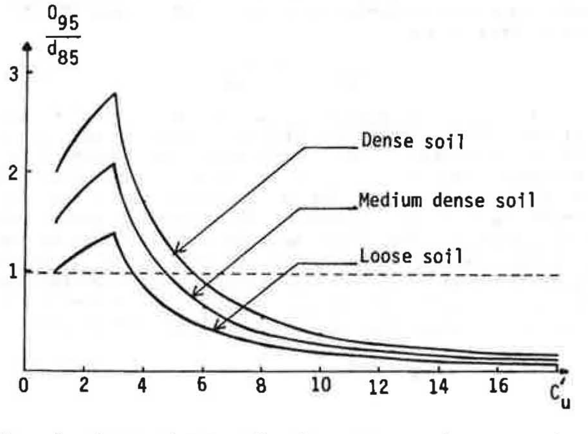


Fig. 7. Comparison of the proposed retention criterion (solid curves deduced from Fig. 1 using Eq. 18) with the simple criterion $O_{95} < d_{85}$ (dashed line).

APPENDIX 4. EXPERIMENTAL DATA

Tests on various types of geotextiles, with medium dense soils having different values of the coefficient of uniformity, have been conducted by Schober and Teindl (4). Results related to needlepunched geotextiles are close to the curve for dense soils while results for other geotextiles (wovens and heatbonded nonwovens) are close to the curve for loose soils. A possible explanation is that soil particles in contact with a smooth geotextile (such as a woven or a heatbonded nonwoven) are rather free to move and have a tendency to loosen, while soil particles in contact with a rough geotextile (such as a needlepunched nonwoven) are kept in a dense state. As a result: (i) the upper curve in Fig. 1 could be used in the case of dense soils with a needlepunched geotextile filter; and (ii) the lower curve in Fig. 1 could be used in the case of loose soils, regardless of the type of geotextile, and in the case of smooth geotextiles (wovens, heatbonded nonwovens) regardless of the density of the soil.

McGown, Murray and Kabir (5) have established correlations between test data from various investigators. These test data are in good agreement with the theoretical curves presented in Fig. 1.

CONCLUSION

The following criteria are often used to select geotextile filters: (1) a permeability criterion, requiring that the geotextile be more permeable than the soil; and (2) a retention criterion requiring that the apparent opening size, O_{95}, of the geotextile be smaller than the d_{85} of the soil. As it is shown in this paper, these criteria cannot be recommended: (1) the permeability criterion is excessively demanding and can eliminate geotextiles that are actually suitable; and (2) the retention criterion is unrealistic and can be dangerous. The two criteria are misleading because they look like well known criteria for granular filters and, therefore, are easily accepted by engineers.

Using a rational approach, filter criteria have been established for geotextiles. Although these criteria may not "look like" the well known criteria for granular filters, they are probably as valid because they are established on a comparable basis. The proposed criteria have been tested on several projects and they are now used as a routine design method by engineers at Woodward-Clyde Consultants.

ACKNOWLEDGEMENTS

The author is indebted to J-Y. Perez, R. R. Davidson and E. Melikov for comments and assistance for editing.

REFERENCES

(1) Terzaghi, K., "Der Grundbruch an Stauwerken und seine Verhutung", Die Wasserkraft, Vol. 17, No. 24, (1922), 445-449.

(2) Giroud, J. P., Gourc, J. P., Bally, P., Delmas, P., "Comportement d'un textile non-tissé dans un barrage en terre", Coll. Int. Sols et Textiles, Vol. II, (Paris, April 1977), 213-218.

(3) Horsfield, H. T., "The Strength of Asphalt Mixtures", J. Soc. Chem. Ind., 53, (1934), 107-115.

(4) Schober, W., Teindl, H., "Filter-criteria for Geotextiles," Proc. Seventh European Conf. on Soil Mechanics and Foundation Eng., Vol. 2, (Brighton, England, September 1979), 121-129.

(5) McGown, A., Murray, R. T., Kabir M. H., "The Compressibility and Hydraulic Conductivity of Geotextiles" Proc. of the Second International Conf. on Geotextiles, (Las Vegas, USA, August 1982).