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# MINIMUM PORE SIZE AND PERCENT OPEN AREA — SOME NEGLECTED FACTORS IN GEOTEXTILE FILTER DESIGN

*P.D.J. Watson[1] and N.W.M. John[2]*

[1] School of Civil Engineering, Kingston University, Kingston-upon-Thames, Surrey, KT1 2EE, U.K.
[2] Civil Engineering Department, Queen Mary and Westfield College, University of London, London E1 4NS, U.K.

## ABSTRACT

The design of geotextile filters currently tends to focus on defining the maximum value of a representative geotextile pore size, often $O_{90}$ or $O_{95}$. This is usually based on the soil grading characteristics which might be expressed in terms of the soils average particle size $d_{50}$ and coefficient of uniformity $C_U$. Sometimes another representative particle size such as $d_{90}$ may be used, as well as the linear coefficient of uniformity. In some cases the soil density may also be taken into account.

To investigate the design criteria for geotextile filters a series of Calhoun Permeameter tests were carried out on woven and non-woven geotextiles. Thick compressible non-wovens were deliberately excluded to eliminate the effect of geotextile compression when buried in the soil.

The results enabled the establishment of suggested design criteria based on upper limit values for the $O_{90}/d_{90}$ ratio related to the soil's uniformity coefficient. The behaviour of a few soil-geotextile combinations appeared to conflict with this simplistic approach. Further investigation revealed that two other parameters were also influencing filter formation, namely the percent open area and the minimum acceptable $O_{90}$ value.

The importance of these factors can be highlighted by considering the use of a geomembrane. Although this theoretically meets geotextile filter design criteria based solely on an upper limit $O_{90}$ it clearly would not function as a filter. Additional constraints on the permeability of the geotextile would prevent such a nonsensical design being accepted. However, the permeability constraints primarily arise from the need to prevent any build-up of pore water pressure at the geotextile interface. A more detailed consideration of the effect of the percent open area and the lower limit for $O_{90}$ on the formation of soil particle bridges at the filter interface is justified.

This paper presents the laboratory results and discusses these two factors. Comparisons are made between the design of geotextile filters and granular filters, and design recommendations are given.

## INTRODUCTION

The role of a filter is to permit the free flow of water from the in-situ soil to a drain, without allowing significant long-term loss of the soil particles. These two requirements are contradictory to one another, and can therefore cause problems for the design engineer. For soil retention to be most effective, the filter's openings would ideally be very small, whereas for rapid flow of water they would ideally be very large.

Traditionally in granular filter design, for soil retention the particle sizes of the filter soil are related to those of the in-situ soil. It has been shown that the filter openings need restrain only the coarsest 15%, or the $d_{85}$, of the in-situ soil. These coarser particles, $d_{85}$ and larger, will collect over the openings in the filter, restraining the smaller particles in the natural soil. This means that for an aggregate filter the effective diameter of its voids must be less than the $d_{85}$ of the soil being filtered. On this basis, Terzaghi & Peck (1.) proposed the following filter criterion :-

$$d_{15(\text{filter})} \leq 4d_{85(\text{soil})}$$

In geotextile filter design a geotextile pore opening size is related to a base soil particle size (2.).

$$O_n < \lambda . d_n$$

This is a logical progression from granular filter design, as it is still necessary for soil particles to collect over the openings in the filter - in this case the pores of a geotextile - in order for a filter to be established in the soil.

For a granular filter to allow the free drainage of water, it must be much more pervious than the soil, such that Terzaghi & Peck (1.) proposed the following permeability criterion:-

$$d_{15(\text{filter})} \geq 4d_{15(\text{soil})}$$

In geotextile filter design, the majority of criteria also agree that the filter must be much more pervious than the soil, and it would seem logical to expect the permeability criteria to relate a pore opening size to soil particle size. However the permeability criteria stated, are often simply formed on the basis that the coefficient of permeability of the geotextile should not be less than that of the soil. This prevents any build-up of pore water pressure at the geotextile interface but does not necessarily allow the free drainage of water (3.). Therefore, for a basic geotextile filter :

$$k_g \geq k_s$$

Specifying the geotextile's permeability in relation to the soil's permeability is therefore an indirect way of specifying a minimum or lower limit for the $O_{90}$ pore size based on the soil grading. This aspect of specifying a lower limit was investigated with regard to a filter criteria developed by John & Watson (4.), as shown in Figure 1.

## MINIMUM $O_{90}$ PORE SIZE VALUE

The design criteria developed by John and Watson (4.) used the concepts of positive retention and positive wash through (5.) to specify its upper and lower limits (see Figure 1.). The upper limit was designed to positively retain specified soil particles to ensure adequate filter formation, whilst the lower limit was designed to positively lose specified soil particles to ensure adequate permeability and resistance to clogging.

The upper limit had been developed from tests involving model soil particles and model geotextile pores (4.). A geomembrane however, clearly meets this criterion as it would retain all the specified soil particles, even though it could not possibly function as a filter. Similarly, a geotextile might also meet this criterion even though it subsequently fails due to clogging. This clearly demonstrated the fact that a lower limit needed to be determined to specify a minimum $O_{90}$ pore size.

The lower limit was derived from further analysis of the results from the model tests. These revealed that soil particles below a certain size would be of 'no significant use' in filter formation, and are such that they are the target size for the concept of positive wash through. These particles were defined as being :

$$\text{Smallest particle size} = 0.228\ O_{90}\ \text{Pore size}$$

By applying this to the upper limit criterion a lower limit was obtained, resulting in the geotextile filter criteria shown in Figure 1.

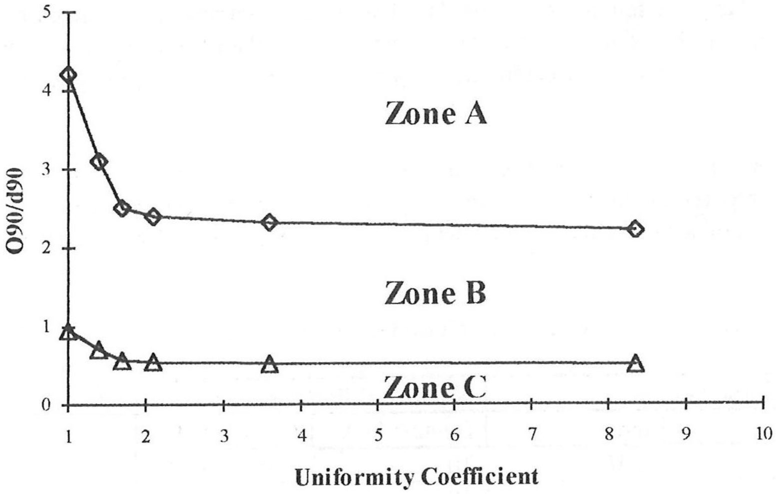

**Figure 1** Filter Design Criteria Showing Filter Formation Zones (4).

Figure 1 shows the design criteria split into zones. These zones allow the designer to determine the type of filter formation that would occur. Basically, if a soil-geotextile filter design were to plot in Zone A, then the designer would have to expect a filter not to be formed as this is above the upper limit for positive soil retention. If the design were to plot in Zone B then an efficient filter should be formed, whilst if the design plotted in Zone C an inefficient filter would result.

As this filter design criteria was developed solely from model tests, extensive tests involving real soils and geotextiles were needed to verify the criteria's validity. These tests were carried out in Calhoun constant head permeameters and thoroughly examined whether the design criteria correctly predicted the formation of a filter for different soil/geotextile combinations. By plotting each soil/geotextile combination on the design chart, it was possible to predict if filter formation would occur before a constant head test was carried out. The results of these permeameter tests have been reported by John & Watson (5.) elsewhere. However, these tests did show that care should be taken when designing filters with soil/geotextile combinations that plotted either in Zone C or near to or on the boundary between Zones B and C. This suggests that soil/geotextile combinations that occur near to or below the lower limit in Figure 1 are sensitive to other factors, such as the per cent open area of geotextiles or the relative spacing between the pores in geotextiles.

## PER CENT OPEN AREA

Initial consideration of the number, size, and spacing of pores in a geotextile appears to suggest that these properties can be represented by the per cent open area of a geotextile. This geotextile property was first proposed by Calhoun (6.) as a measure of the actual openness of a geotextile.

The per cent open area was calculated by simple area comparison determined from magnified woven geotextiles. From the magnified image, a block of 100 pore openings was selected of which 20 random pore openings were measured. For each opening, the total individual area, in which it was enclosed, and the area of the individual opening were determined. The per cent open area was then determined as the ratio of the sum of the individual opening areas to the sum of the total individual areas.

This simple determination of the per cent open area however, results in widely differing values for the same geotextile, due to the small total geotextile area tested. Also, determination of pore opening areas other than square or rectangular areas is not recommended. Therefore, the above method was found to be of no real use for geotextiles other than for wovens with distinct pore openings. Further tests to directly determine the per cent open area of a geotextile have yet to be developed.

Also, the per cent open area of a geotextile only indicates the actual openness of a geotextile, and does not take into consideration the spacing of the pores in the geotextile (7.). This can be explained with reference to Table 1, which details the relevant properties for two ideal geotextiles, A and B.

**Table 1** Basic Values for the Openness of Two Geotextile Sheets

| Geotextile Pore Size | | Number of Pore Openings | |
|---|---|---|---|
| - | mm | Geotextile A | Geotextile B |
| $O_{100}$ | 1.10 | 10 | 100 |
| $O_{90}$ | 1.00 | 10 | 100 |
| $O_{80}$ | 0.90 | 10 | 100 |
| $O_{70}$ | 0.80 | 10 | 100 |
| $O_{60}$ | 0.70 | 10 | 100 |
| $O_{50}$ | 0.60 | 10 | 100 |
| $O_{40}$ | 0.50 | 10 | 100 |
| $O_{30}$ | 0.40 | 10 | 100 |
| $O_{20}$ | 0.30 | 10 | 100 |
| $O_{10}$ | 0.20 | 10 | 100 |
| $O_{0}$ | 0.10 | 10 | 100 |

In Table 1, the two geotextiles A and B are taken to be of equal dimensions. It can then be shown, that although both geotextiles have the same pore size distributions and hence $O_{90}$ pore opening sizes, the actual openness of geotextile B is ten times greater than that for geotextile A. However, the table also shows that the spacing of the pores in the geotextiles is not taken into consideration. This is shown from the fact that as geotextile B has a larger open area than geotextile A, the spacing between the pores in geotextile B is therefore smaller than the spacing between the pores in geotextile A. This aspect is illustrated further in Figure 2 below for two geotextiles C and D.

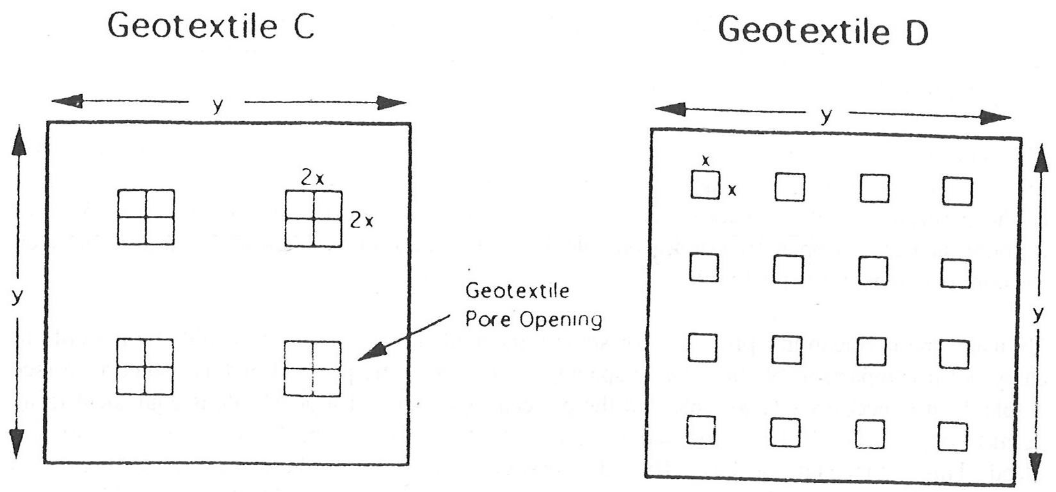

**Figure 2** Plan Views of Geotextiles C and D

From Figure 2, it can be shown that both geotextiles C and D have the same per cent open area. However, the pore spacing and pore sizes of the two geotextiles differ considerably. This figure also shows that the per cent open area of a geotextile is in fact related to the permeability of the geotextile.

Further, it could also be suggested that geotextile D will act as a better filter than geotextile C. The figure shows that geotextile D has numerous small pore openings spaced more frequently than the large pore openings of geotextile C. Therefore, as filter formation is taken to be the result of the soil particles forming a bridge over a geotextile pore, geotextile D with its greater number of pore openings will form a filter more easily than geotextile C (see Figure 3).

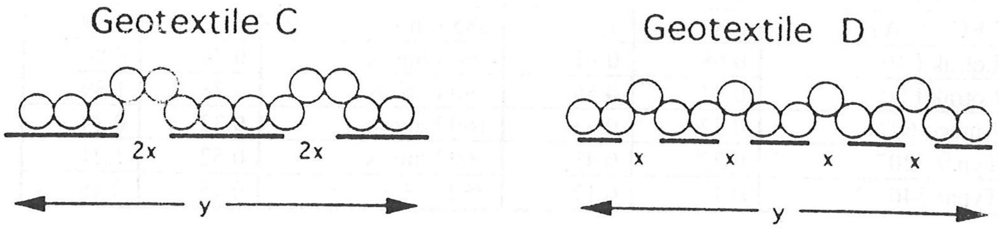

**Figure 3** Filter Formation with Geotextiles C and D

From a combination of the findings from Table 1, and Figures 2 and 3, it can be shown that a relationship exists between the number, size, and spacing of pores in a geotextile. This indicates an apparent problem in the specification of filter design criteria.

The majority of filter criteria are specified with a permeability criteria, so as to prevent clogging of the geotextile. However, it has been shown that the per cent open area of a geotextile is related to the permeability of the geotextile. Therefore, whilst the majority of filter criteria take into account the per cent open area of a geotextile, little or no account is taken of the spacing between the pore openings in the geotextile.

By using the permeability properties of some typical filter geotextiles, it should be possible to carry out a comparison of the relative spacing of the geotextile pores. For this comparison (see Table 2), it is necessary to assume that the per cent open area of a geotextile is equivalent to its permeability. It should be noted that the permeability quoted is the 'Permeability at 100 mm Head'. This is a measure of the coefficient of permeability normal to the geotextile, and expressed in terms of the quantity of water passing per unit area, per unit time, under the specified head loss (100 mm). Permeability is expressed in this form to avoid the problem of measuring the relevant thickness of compressible thick geotextiles.

In order to determine relative values for the spacing of the pores in the geotextiles listed in Table 2, it was necessary to introduce some datum values. These datum values are those shown for the typical geotextile. Ratio 1 in the table relates to the ratio of the pore opening size of the filter geotextile to the pore opening size of the typical or datum geotextile. Similarly, ratio 2 relates to the ratio of the permeability of the filter geotextile to the permeability of the typical or datum geotextile. Therefore ratio 3, which is ratio 2 divided by ratio 1, is a measure of the spacing of the pores in the filter geotextile to those in the typical geotextile.

**Table 2** Comparison Values for Typical Filter Geotextiles

| Geotextile | $O_{90}$ (mm) | Ratio 1 | Permeability at 100 mm Head | Ratio 2 | Ratio 3 |
|---|---|---|---|---|---|
| | | | | | |
| Typical | 0.75 | 1.00 | 500 l /m$^2$ /s | 1.00 | 1.00 |
| | | | | | |
| UCO HF1300 | 1.33 | 1.77 | 1500 l /m$^2$ /s | 3.00 | 1.69 |
| Lotrak F30 | 1.00 | 1.33 | 400 l /m$^2$ /s | 0.80 | 0.60 |
| LEC 215WF | 0.80 | 1.07 | 585 l /m$^2$ /s | 1.17 | 1.09 |
| Lotrak F40 | 0.68 | 0.91 | 390 l /m$^2$ /s | 0.78 | 0.86 |
| Lotrak F50 | 0.42 | 0.56 | 390 l /m$^2$ /s | 0.78 | 1.39 |
| Amoco 6071 | 0.32 | 0.43 | 160 l /m$^2$ /s | 0.32 | 0.74 |
| Typar 3207 | 0.32 | 0.43 | 260 l /m$^2$ /s | 0.52 | 1.21 |
| Typar 3407/2 | 0.13 | 0.17 | 75 l /m$^2$ /s | 0.15 | 0.88 |

From the values shown in Table 2, it can be seen that a geotextile with a large $O_{90}$ pore opening size may not necessarily have a respectively high permeability (high per cent open area), or close spacing between its pores. This is clearly shown with the geotextile Lotrak F30, which although has a large pore opening size does not have the high permeability (high per cent open area) to complement it. Conversely, the geotextile Typar 3407/2 would initially appear to have inadequate spacing between its pores, since it has a small pore opening size and a low permeability (low per cent open area). However, ratio 3 in the table suggests that Typar 3407/2 has a relatively closer spacing between its pores than Lotrak F30.

## PERMEAMETER TESTING

In order to confirm that the spacing of the pores in a geotextile is a controlling factor in filter formation, a limited number of permeameter tests were carried out. These tests used soil/geotextile combinations that were either close to or below the lower limit of the filter design criteria (see Figure 1).

Two soils were tested against four of the geotextiles shown in Table 2. The soils tested were both typical filter sands, and their properties together with the results of the permeameter tests are shown in Table 3.

**Table 3** Comparison of Permeameter Test Results to Pore Spacing

| Geotextile | | Soil 1 | | | Soil 2 | | | Pore Spacing Ratio | Filter Design Prediction |
|---|---|---|---|---|---|---|---|---|---|
| Name | $O_{90}$ mm | $C_U$ - | $d_{90}$ mm | Test Result | $C_U$ - | $d_{90}$ mm | Test Result | | |
| LEC 215 WF | 0.80 | 3.65 | 1.50 | Fail | | | - | 1.09 | Pass? |
| Lotrak F50 | 0.42 | 3.65 | 1.50 | Pass | | | - | 1.39 | Fail |
| Amoco 6071 | 0.32 | | | - | 9.23 | 0.60 | Pass? | 0.74 | Pass? |
| Typar 3407/2 | 0.13 | | | - | 9.23 | 0.60 | Fail | 0.88 | Fail |

From Table 3, it should be noted that for those soil/geotextile combinations whose $O_{90}/d_{90}$ ratio plots above but close to the lower limit of the design criteria, the filter design predictions are denoted by Pass?. It has previously been shown that care should be taken when specifying geotextiles in this situation for filter design (5.).

For Soil 1, the results shown in Table 3 indicate the real effect of pore spacing. For the geotextile Lotrak F50, the design criteria predicted that filter formation would not occur, since its $O_{90}$ pore opening size was too small resulting in clogging of the geotextile. However Lotrak F50 actually formed a filter, as its pore spacing is the best of those geotextiles shown in Table 3.

Conversely, the geotextile LEC 215WF was predicted to form a filter with Soil 1, although the corresponding $O_{90}/d_{90}$ ratio plots close to the lower limit of the design criteria. However, large gradient ratios occurred, which suggests that the geotextile had in fact clogged. This can be confirmed by the pore spacing value, which is significantly lower than the corresponding value for Lotrak F50.

For Soil 2 in Table 3, it can be seen that for Typar 3407/2 filter formation did not occur, as put forward by both the design criteria and small value of the pore spacing ratio. However, for Amoco 6071 the gradient ratios showed that a filter was struggling to form, as the ratio values ratios varied between 1.5 and 4.0. This suggests that although the $O_{90}$ pore size of the geotextile was adequate for filter formation, the pore spacing was not. This is shown by the fact that its pore spacing is the lowest of those geotextiles shown in Table 3.

From these results it can be therefore be shown that:

1. Specification of the per cent open area of a geotextile as a separate property is required.
2. Care should be taken when specifying a geotextile for filter design with a soil/geotextile combination either near to or on the limits specified in the design criteria.

## CONCLUSION

The results detailed in Tables 2 and 3, show that the spacing between the pores in a geotextile must be quantified as a separate property. It will not always be possible to compare a range of geotextiles in order to determine their relative openness. Specification of this property, will therefore ensure that clogging of a geotextile filter is kept to a minimum, resulting in improved performance and longevity of geotextile filters.

## REFERENCES

1. Terzaghi, K. and Peck, R.B. (1948). *Soil Mechanics in Engineering Practice*, John Wiley & Sons Inc., New York.

2. Bertacchi, P. and Cazzuffi, D. (1984). The Suitability of Geotextiles as Filters. *Proceedings of the International Conference on Materials for Dams*. December 1984, 2: 1-26, Monte Carlo.

3. John, N.W.M. (1987). *Geotextiles*, Blackie, Glasgow.

4. John, N.W.M. and Watson, P.D.J. (1994). Geotextile Filter Criteria and Soil Particle Bridging. *Proceedings of the 5th International Conference on Geotextiles, Geomembranes and Related Products*. September 1994, 2: 683-686, Singapore.

5. John, N.W.M. and Watson, P.D.J. (1996). Soil Particle Bridge Development at the Soil-Geotextile Interface. *Proceedings of the 2nd International Conference on Geofilters.* May 1996, pp. 237-246, Montréal, Canada.

6. Calhoun, C.C. (1972). Development of Design Criteria and Acceptance Specification for Plastic Filter Cloths. *Technical Report No. S-72-7.* June 1972, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, U.S.A.

7. Luettich, S.M., Giroud, J.P. and Bachus, R.C. (1992). Geotextile Filter Design Guide. *Geotextiles and Geomembranes*. 11: Nos. 4-6, 355-370.