A Rational Filter Criterion for Non-woven Geotextiles

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ABSTRACT: A probabilistic retention criterion for non-woven geotextile filters is presented. The criterion is based on important micro-structural properties of the geotextile such as pore size distribution and porosity. A geotextile thickness needed to retain a stable base soil can be predicted for a target reliability. The criterion is verified using data from the literature and good agreement is obtained.

1.0 INTRODUCTION

The basic objective of a filter in drainage applications is to retain the filtered material while allowing free flow of water. The conditions under which a soil particle leaves the soil and finds its way through the fabric filter or is trapped within it depend on: 1) the structural properties of the fabric; 2) the ability of the soil to retain its own fines, i.e, its internal stability; and 3) the flow conditions, i.e., the seepage velocities and hydraulic gradients.

The structural properties of non-woven geotextile filters can be of either micro or macro nature. The micro structure of non-woven geotextiles consists of short fibers or filaments arranged in all directions and bonded together into a planar structure. The filaments or short fibers are first arranged into a loose web, then bonded together mechanically, chemically or thermally. A network of pores is created by the arrangement of fibers. Currently, for most practical situations, the fabric is expressed by a representative pore size which is the apparent opening size (AOS) or O_{95}, which is the pore size supposed to be larger than 95% of all the pores. Alternately, the fabric may be expressed by O_{50} or the median pore size. Important macro-structural properties of the fabric are thickness and porosity. Thickness affects the tortuosity, which reflects the path or distance a soil particle will travel in order to cross the fabric. Although very important, the thickness is neglected in the current filter models.

The soil is represented by a characteristic grain size, usually d_{85} and/or d_{50} and d_{15}, while the other grain sizes and their frequencies are neglected.

Most of the existing filter criteria for geotextiles are empirical and were derived from laboratory tests. In these criteria a characteristic base soil size, d_x, is compared to a characteristic geotextile opening size, O_x, by means of a piping ratio P_r, where:

$$P_r > \frac{O_x}{d_x} \qquad (1)$$

Since both the fabric and the soil are characterized by parameters having a wide range of variation, statistical treatment of the filtration phenomenon will lead to improved predictions.

An attempt is made in this paper to develop a probabilistic retention model for non-woven geotextile/soil systems similar to Silveira (1965) granular filter model. The model is based on the overall pore size distribution of the geotextile, its thickness and porosity. It predicts the geotextile thickness needed to retain a certain soil particle if the pore size distribution, porosity of the geotextile and size of soil particle to be retained are known. It can be extended to consider the effects of geotextile compressibility on retention (Elsharief, 1992). Laboratory test results from the literature are used to verify the model predictions. Finally a retention criterion was developed, based on the model.

2.0 THE MODEL

To evaluate the retention ability of a geotextile filter, the following important assumptions are made: 1) soil units are spherical; 2) the geotextiles openings are circular; and 3) the flow drag is capable of moving soil particles through the filter.

The retention criteria become a geometric problem, i.e., depending on the geometrical characteristics of the filter media, a function of the pore size distribution of the geotextile and the movable grain size of the soil that is to be filtered.

The fabric is considered a set of (m) thin parallel layers (sieves), each having the same pore size distribution and with pores randomly distributed. The solid part of the fabric is distributed between the pores. The value of (m) depends on the filter length (thickness) and the distance (height) between layers, i.e., confrontations. This height is assumed to be equal to the largest pore size O_{max}, in order for a confrontation to contain the largest particle that can practically intrude it. The value of O_{max} can be approximated by O_{98} which is the pore size greater than 98% of the fabric pores, and is obtainable using mercury intrusion porosimetry (MIP).

The average distance traveled by a particle having a diameter (d), where $O_{min} < d < O_{max}$, before being absorbed or caught by the fabric, can be estimated using the Absorbing Markov Chain, if the absorbing and non-absorbing states can be defined. There are three transition states to be considered, one non-absorbing state and two absorbing states. All the pores with diameters greater than (d) are non-absorbing states. The absorbing states include the solid part of the material (1-n; where n is the porosity) plus the cumulative frequency of the pores smaller than the size of the particle to be retained (d).

Figure 1 is a typical PSD obtained by the MIP method. The frequency of each transitional state was obtained by multiplying the ordinates by the porosity (the dashed line in Figure 1). For a particle having a diameter (d) where $O_{min} < d < O_{max}$, the non absorbing states will have a frequency of ($n-p^*$), whereas the absorbing states have a frequency (1-n) for the solid part and p^* for the pore sizes less than (d), i.e., a total of ($1-n+p^*$). The quantity (p^*) is equal to (n times p). Therefore, for this case, the expected number of confrontations (m^-) a particle with a diameter (d), where $O_{min} < d < O_{max}$, will pass before being absorbed is equal to (Elsharief, 1992)

$$m^- = \frac{1}{1-n(1-p)} \tag{2}$$

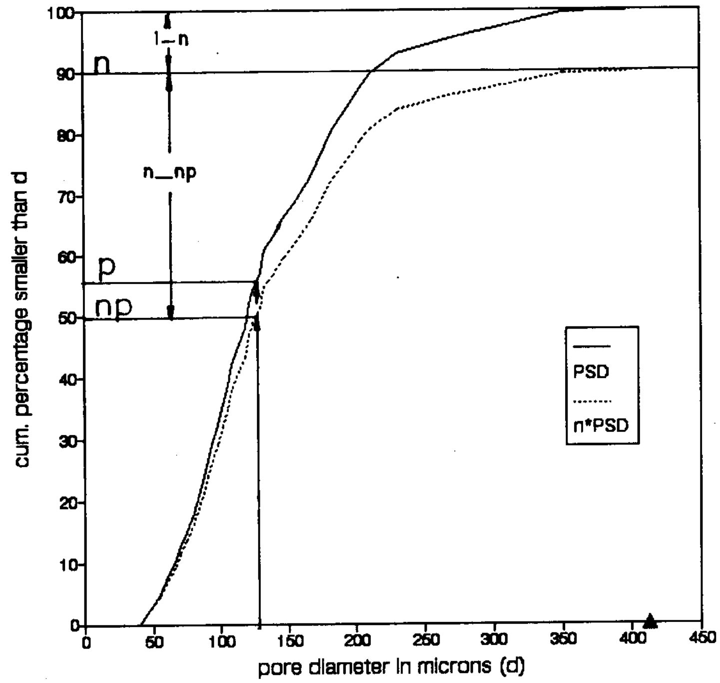

Figure 1 Pore size distribution of a typical non-woven geotextile

If the porosity and the PSD of a certain geotextile fabric are known, the expected number of confrontations, m^-, and hence the average fabric thickness needed to stabilize a certain soil particle with a diameter (d), where $O_{min} < d < O_{max}$, can be estimated. The average thickness is equal to m^- multiplied by O_{98} (the maximum pore size of the non-woven geotextile).

2.1 Reliability Analysis

The failure of a confrontation can be described by its inability to retain a certain soil particle, and the failure probability according to the model is (n-np). The system will be considered to have failed to satisfy the retention criterion for a certain soil particle if and only if all the confrontations fail to retain the soil particle, i.e., it is a parallel reliability system. The reliability of a parallel system with m confrontations will be (Harr, 1987):

$$R = 1-\Pi_{i=1}^{i=m}(1-R_i) \tag{3}$$

R_i is the reliability of confrontation i and is equal to (1-n+np) for all confrontations. Therefore,

$$R = 1-(n-np)^m \tag{4}$$

By rearranging m may be obtained as:

$$m = \frac{\log(1-R)}{\log(n-np)} \tag{5}$$

The design value of (m) is, therefore, a function of the acceptable reliability, porosity and pore size distribution of the geotextile and the size of the particle to be filtered. Figures 2 and 3 show the estimated (m) values for different (n) and R values. As shown in the Figures, the number of confrontations needed to retain a soil particle increases as (p) decreases. The increase in (m) for small particles ($p < 15\%$) is sharper as the porosity increases. Therefore, according to the model, the retention of small soil particles is basically porosity dependent. Knowing the PSD, n, and d, the number of confrontations needed to retain a certain soil particle and hence the fabric thickness can be estimated for a target R. The required geotextile thickness is obtained by multiplying (m) by O_{98} which is the maximum pore size of the geotextile.

2.2 Considerations for Variability in Base Soil Gradation

The effect of the base soil gradation on its filter ability was emphasized by many researchers (Sherard, 1984; Lafleur et al, 1989; and Kenney and Lau 1985). It was found that for granular filters, filter criteria used for base soils that are internally stable will not apply for internally unstable (gap graded and some broadly graded) soils. Another important finding reported by Sherard (1984) is that for well graded base soils, a granular filter sufficiently fine to catch the d_{85} size of a stable soil will also catch the finer base particles. Therefore, for this application, the following assumptions are made based on previous experiences with granular filters: 1) the model applies only for internally stable soils; and 2) for internally stable soils, the geotextile will satisfy the retention criterion if it can retain the d_{85} size for a desired confidence or reliability.

A consistent and rational method to evaluate the potential instability of base soils was given by Kezdi (1969) and was based on Terzaghi's filter criteria. Lafleur et al (1989) and Sherard et al (1984) have shown that the original Terzaghi's criterion with a retention ratio of 4 to 5 is conservative and involves a factor of safety of approximately 2. Sherard et al (1984) showed that there is a very narrow margin between filter failure and success, well defined by d_{15f}/d_{85} equal to 9 (f stands for filter). Therefore, for this study, and in order to avoid conservancy, the method used by Kezdi (1969) was applied with a retention ratio of 9 to evaluate the internal stability of cohesionless soils.

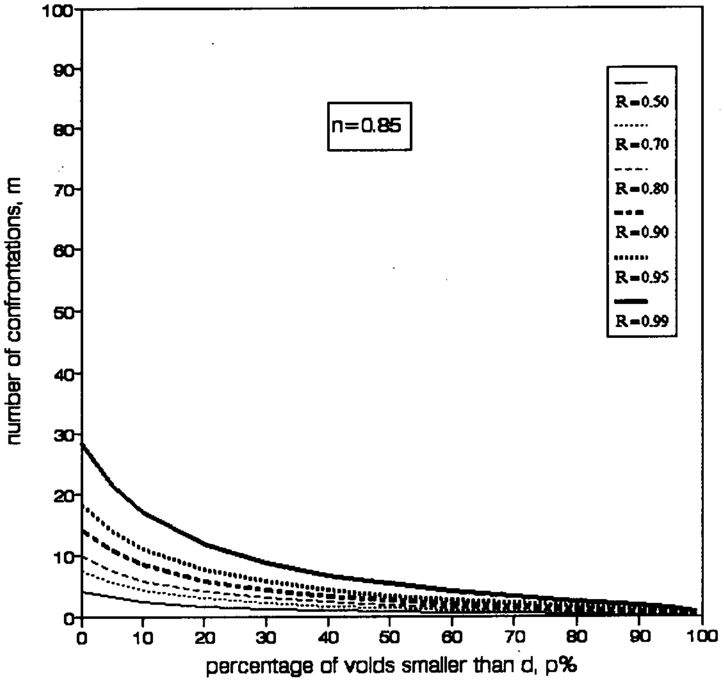

Figure 2 The number of confrontations needed retain a particle, n=0.85

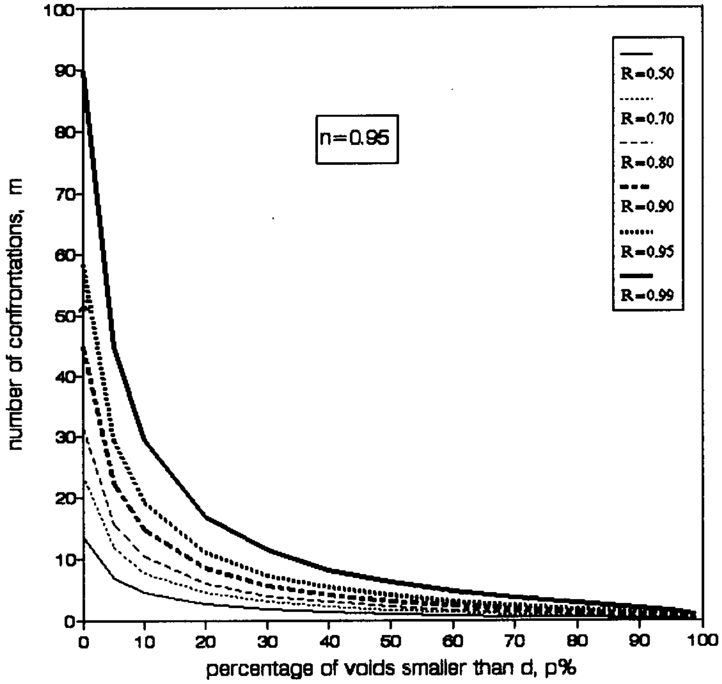

Figure 3 The number of confrontations needed retain a particle, n=0.95

3.0 VERIFICATION OF MODEL PREDICTIONS

The results of long term filtration tests performed by Faure et al, (1986) and Qureshi (1990) are used to verify the model predictions. Faure (1986) performed long term filtration tests using 6 loose base soils and 6 non-woven geotextiles. The properties of the geotextiles are given in Table 1. Of interest are the properties of the first three fabrics (TS-fabrics) because information is available about their structural properties and PSD (Elsharief, 1992). The tests were run for each geotextile with all the soils. The filtrate was collected on a filter paper for each test, and the filter paper was weighed to measure the amount of entrained soil.

All the soils filtered by TS-fabrics were found to be internally stable. The amount of the entrained soil (g/m^2) was plotted against the reliability for each data point, Figure 4. A consistent and sharp decrease in the amounts of entrained materials is observed as the reliability increases. As the reliability approaches 80%, small amounts of entrained material were measured. Faure et al presented a retention criterion based on the test results. According to the criterion, a filter system would be stable if FOS/d$_{85}$ ratio lies between 1 and 2. A plot of FOS/d$_{85}$ versus reliability is made in order to compare the two criteria, Figure 5. The value of FOS/d$_{85}$ consistently decreases as R increases. A reliability of 80% will correspond to a FOS/d$_{85}$ value of about 1.5, which is the average value suggested by Faure et al, (1986). This implies a good agreement between the two approaches.

Table 1. The Structural Properties of the Geotextiles Used by Faure et al, (1986)

fabric	mass/unit area (g/m^2)	thickness (mm)	FOS (μm)
TS500	180	1.9	115
TS600	220	2.2	95
TS700	295	2.7	83
C34	250	2.4	110
N4	175	1.3	100
NP 153	173	1.8	95

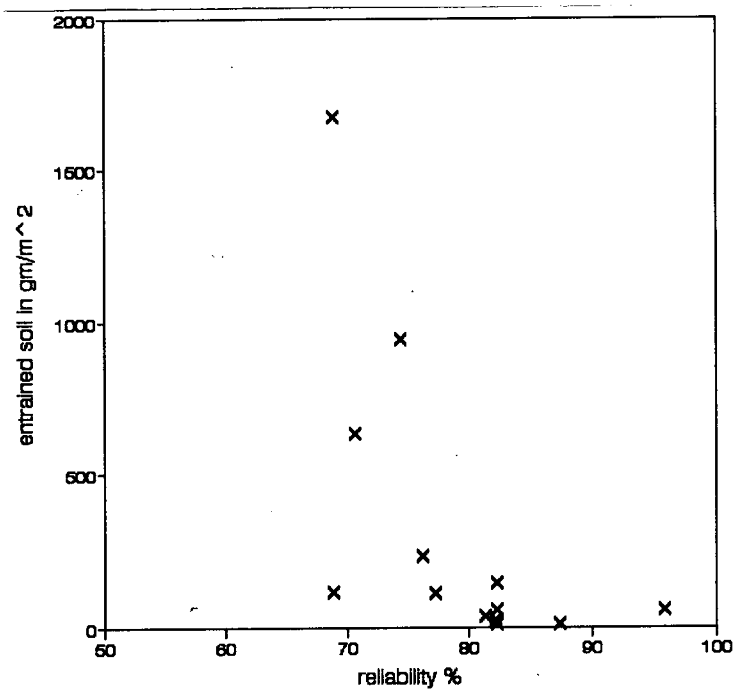

Figure 4 Entrained soil versus reliability (data of Faure et al, 1986)

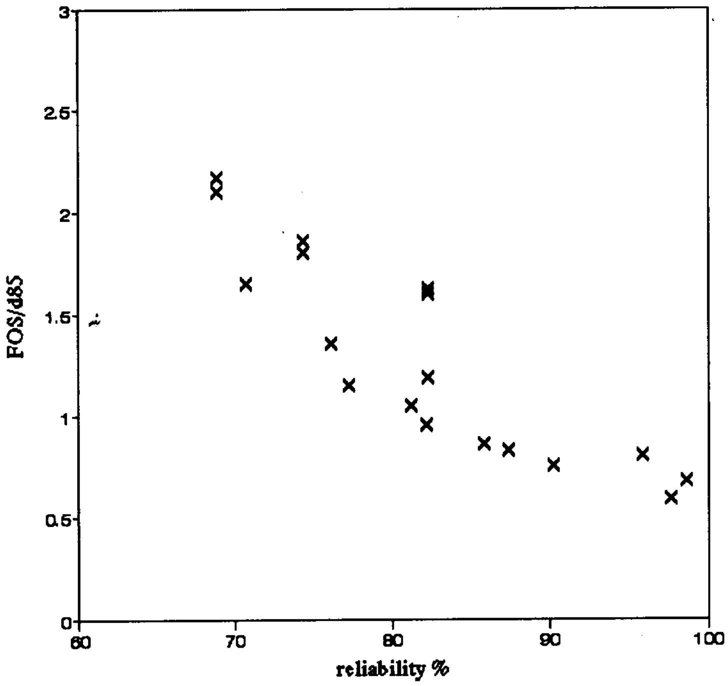

Figure 5 FOS/d$_{85}$ versus reliability (data of Faure et al, 1986)

Qureshi (1990), presented results of an extensive investigation on the long term filtration behavior of non-woven geotextiles when tested with gap graded soils. Six non-woven geotextiles were involved (i.e., three TR-fabrics and three Ph-fabrics) with three gap graded silts. The structural properties of the fabrics are given in Table 2. The TR-fabrics are needle punched while Ph-fabrics are needle punched and heat treated. The PSD of these fabrics have been measured (Elsharief, 1992).

Table 2. The Structural Properties of the Geotextiles Used by Qureshi, (1990)

fabric	mass/unit area (oz/yd^2)	AOS (μm)	FOS (μm)	thick-ness (mm)
TR1114	4.2	210	195	1.65
TR1125	7.4	210	103	2.79
TR1145	13.5	-	-	4.44
Ph4	4.0	180	105	1.016
Ph8	8.0	210	100	2.03
Ph12	12.0	210	117	3.05

The amount of entrained material was plotted against reliability, Figure 6, for all the fabrics and soil combinations used by Qureshi, excluding one soil which was found to be internally unstable. The Figure shows that as the reliability increases the amount of entrained material sharply decreases. Small amounts of entrained material was collected for a reliability higher than 80%. A plot of FOS/d85 versus reliability shows a consistent decrease in FOS/d_{85} as the reliability increases (Figure 7). A reliability of 80% will correspond to FOS/d_{85} of about 2. The suggested retention criterion by Qureshi was FOS/$d_{85}>3.0$. Qureshi justified the selection of this very high limit by the fact that his criterion was developed for gap graded soils, therefore, higher opening sizes are needed to guard against clogging and blinding.

The above analysis shows a good agreement between the model predictions and results of retention tests from the literature. It is important to mention that only limited good retention data has been found in the literature. The writers were able to find only these two complete sets of data. The analysis of the results also shows that a reliability of 80% will always assure minimum piping through the geotextile. Therefore, for normal applications, i.e., unidirectional flow conditions, non-woven geotextiles can be designed for a target reliability of 80%.

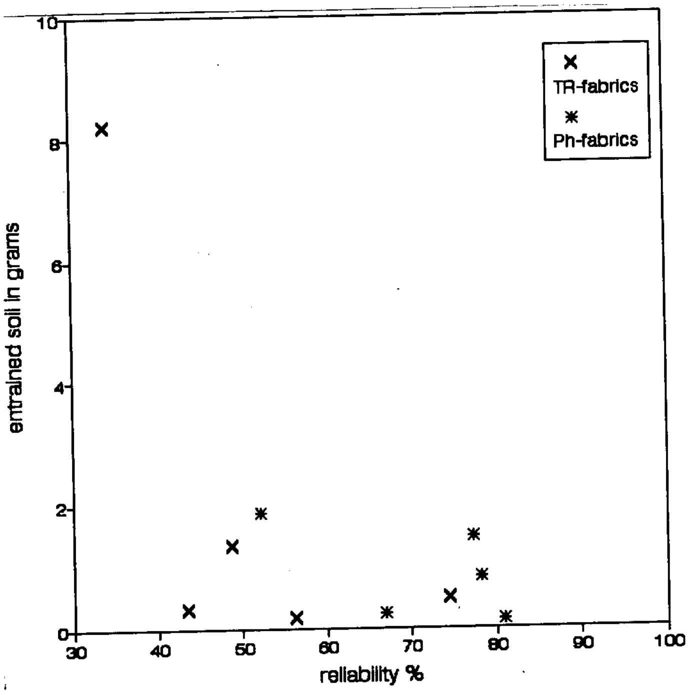

Figure 6 Entrained soil versus reliability (data of Qureshi, 1990)

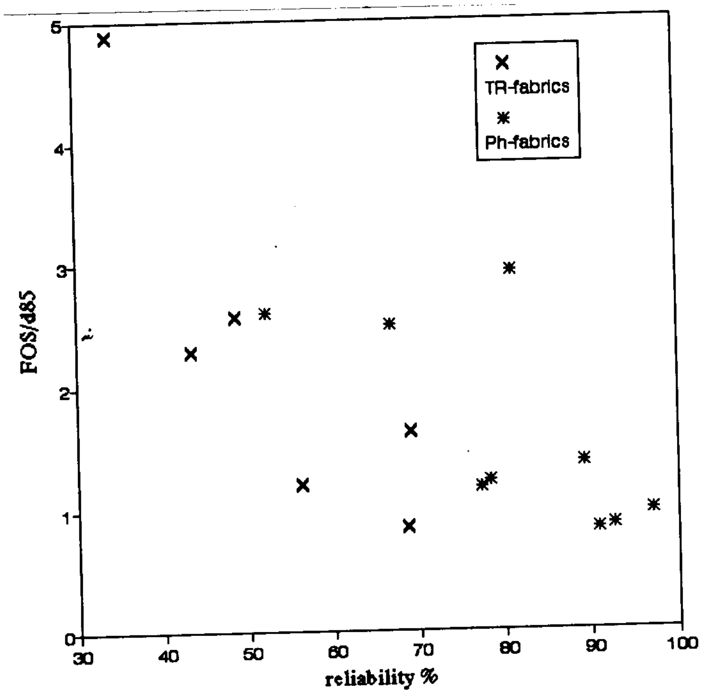

Figure 7 FOS/d_{85} versus reliability (data of Qureshi, 1990) .

4.0 CONCLUSIONS

A probabilistic model to evaluate the retention capacity of non-woven geotextile filters was presented in this paper. The model assesses the effect of pore size distribution, porosity, thickness of a fabric on its ability to retain soil particles. To apply the model the overall pore size distribution of the geotextile should be known. This writer suggests that the mercury intrusion porosimetry method be used to determine the pore size distribution of the geotextile filter because of its simplicity and acceptable accuracy.

In order to consider the effect of base soil gradation, it was assumed, based on previous experiences with granular filters, that the model applies only for internally stable soils.

The model predictions were verified with laboratory data and good agreement was obtained. A reliability of 80% was determined, above which the stability of the base soil is insured (only minor losses will be experienced).

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