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The number of constrictions concept as a mean to predict the filtration behavior of nonwoven geotextile filters

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ABSTRACT: Most of the filtration criteria developed for nonwoven geotextiles are based on the comparison between their filtration opening size (FOS) and an indicative diameter of the soil to be filtered. In recent published experimental data , there is evidence that the FOS might not be the sole parameter controlling the filtration behavior of soil-geotextile systems. Significant behavioral differences have been observed between systems composed with nonwoven geotextiles of similar FOS but with different fibrous structure, ranging from equilibrium to severe piping. It is clear that the nonwoven geotextile structure has a great influence on the filtration of a soil-geotextile system. The number of constrictions concept has been recently proposed as a simple mean to describe the structure on nonwoven geotextile filters. Filtration tests have been performed in order to verify the existence of a correlation between this parameter and the filtration behavior of soil-geotextile systems. Gradient ratio test results showed that high numbers of constrictions may result in the development of a severe piping, and a number of constrictions of 45 represents an acceptable upper limit. Even if theoretical analysis suggests that low number of constrictions could lead to blinding mechanism, tests results revealed no clear evidence.

1 INTRODUCTION

Like granular filters, selection of geotextile filters is based on the verification of two contradictory conditions, namely openings sufficiently large to promote water drainage, but sufficiently small to impede significant particle migration. This last condition is verified with retention criteria implying the filtration opening size of the filter (FOS) and an indicative diameter of the soil to be filtered, which depends on the shape of its gradation curves and its instability potential (Lafleur & al., 1996; Mlynarek, 1998).

Several studies show that the FOS might not be the sole parameter controlling the filtration behavior of nonwoven geotextiles. Lafleur et al. (1996) and Artières & Faure (1997) observed that geotextiles having similar FOS but different fibrous structure may have significantly different filtration behaviour. It is clear that other structural properties of nonwoven geotextiles may affect their filtration performance.

A theoretical approach has been proposed by Giroud (1996) to describe the fibrous structure of nonwoven geotextiles. He notably developed the number of constrictions concept, m, which depends on the geotextile's fibre diameter, thickness and porosity. Since this parameter takes into account several structural properties of the geotextile, it is certainly an interesting way, along with filtration opening size, to explain the filtration behaviour of nonwoven geotextiles (Giroud et al. 1998).

Filtration tests have been performed in order to verify the existence of a correlation between the number of constrictions of geotextiles and their filtration behaviour. The purpose of this paper is to discuss these tests results. It is a logical continuation of a previous paper (Bouthot et al. 2000) where the theoretical aspects of this study were presented. Emphasis will be given on the definition of lower and upper limits of the optimal range of m.

2 DEFINITIONS

2.1 *Constrictions*

The nonwoven geotextile structure is composed of large number of constrictions. The constrictions may be described as "windows" delimited by three or more fibers, in which soil particles could migrate.

2.2 *Filtration paths*

Under the forces induced by fluid flows, soil particles may travel in the geotextile filter along various paths or filtration paths. Each of these paths is composed of a sequence of constrictions of various size and shape.

2.3 *Filtration openings*

A nonwoven geotextile includes numerous filtration paths and, consequently, numerous constrictions. However each filtration path will be characterized by a constriction of minimum size, which is called the filtration opening of a peculiar filtration path. Since they are the controlling constrictions of the filtration paths, the filtration openings play a crucial role in the retention capabilities of a geotextile filter.

2.4 *Constrictions and filtration openings size distributions*

A conceptual definition of the constrictions and filtration openings sizes distributions of all the filtration paths of a geotextile is presented in figure 1. Given that the filtration openings are defined as the smallest constrictions of the filtration paths, their distribution in size will be proportionaly smaller than the constrictions one. By definition, the minimal opening size (O_0) could not be smaller than the smallest constriction (C_0).

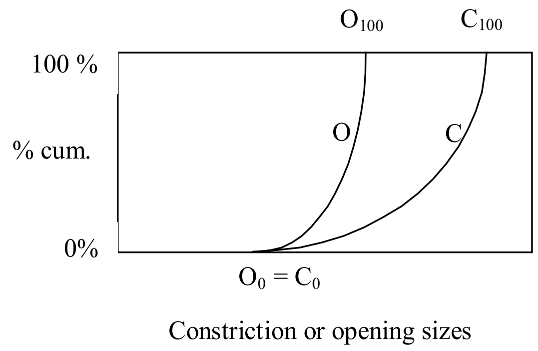

Figure 1. Constriction and Filtration size distribution curves; C: constrictions; O: openings.

2.5 *Number of constrictions*

Giroud (1996) defined the number of constrictions, m, as follow:

$$m = \sqrt{1-n}\,\frac{t_{GT}}{d_f} \tag{1}$$

where n = geotextile's porosity; t_{GT} = thickness; and d_f, = fibers diameter. This parameter could be seen as the average number of confrontations that a particle would met when it crosses the filter.

According to this definition, it can be found that an increase in thickness or a reduction in porosity and fiber diameter produce an increase in the number of constrictions.

3 EFFECT OF THE NUMBER OF CONSTRICTIONS ON THE FILTRATION OPENING SIZE DISTRIBUTION

Based on the concepts developed in the previous section, Giroud et al. (1998) showed that nonwoven geotextiles filters having similar FOS (which may be considered equal to O_{100}) but different constriction numbers may exhibit significantly different filtration behavior.

Figure 2 presents the constrictions and openings sizes distributions of two geotextiles having an identical O_{100}, but where the number of constrictions of filter A is lower than the filter B. It could be noticed that this parameter has a crucial impact on the different curves shape and relative position. A thorough analytical demonstration is presented by Giroud et al. (1998).

The constrictions and openings sizes distribution curves may be used to estimate the probability that a given soil particle would be retained in or on the geotextile or that simply cross it. With figure 2, it could be observed that:

- For soil particle diameters larger than O_{100} (see figure 2, case d_2), the probability that soil will be trapped into a geotextile increases as the number of constrictions increases (filter B vs filter A). Given that these particles may compose the soil skeleton, a high number of constrictions may eventually affect the soil integrity and the geotextile drainage capacity.

- For soil particle diameters lower than O_{100} (see figure 2, case d_1), it could be observed that a high m value leads to an increased probability that a particle would be washed through the filter. On the other hand, the high probability that a particle will be retained on a low m geotextile could eventually lead to the development of the blinding mechanism, notably with internally unstable soils.

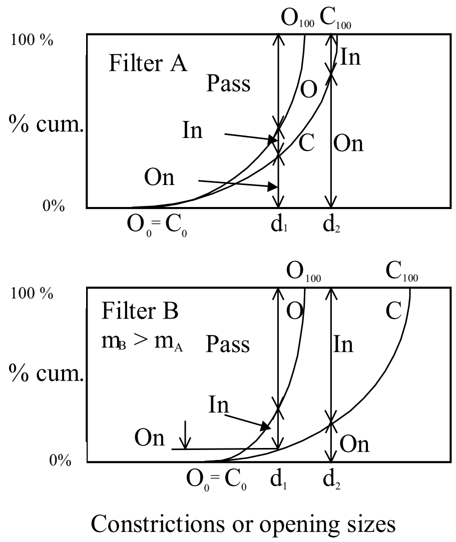

Figure 2. Number of constriction effect on the filtration behaviour of nonwoven geotextiles (adapted from Giroud et al. 1998); filter A has lower number of construction than B.

Despite the conceptual nature of the previous demonstration, it is reasonable to expect the existence of a range of number of constrictions that could lead to optimal filtration behavior. Constriction numbers higher than the upper limit of that range could lead to a critical situation where soil particles movement toward the geotextile could not be restricted.

On the other hand, development of the blinding mechanism could be expected with low constrictions numbers. Moreover, Giroud (1996) and Giroud et al. (1998) have shown theoretically that low m values could be associated to significant FOS variability. In order to verify this conclusion, spatial distribution of FOS of two (2) geotextiles, one of them exhibiting a constriction number of 7, was investigated using the bubble point technique. Theoretical FOS (or O_{100}), FOS_{th}, of the test specimens were also calculated according to Giroud (1996). As indicated in table 1, greater BBP and FOS_{th} variability could be observed with the geotextile F2 even if their average value are similar to those obtain with filter F0. It also appears that the positive skew of their distribution might explain the greater FOS values as measured by the hydrodynamic sieving technique.

Table 1. Effect of m on the FOS variability

Filters	F0	F2
Structure[1]	NW-NP	NW-HB
m	32	7
Porosity, n (%)	3.44	0.65
FOS[2] :		
Average (µm):	102	150
Range (µm):	100-103	140-165
C.V. (%):	1.3	6.2
BBP[3]:		
Average (µm):	103	105
Range (µm) :	81 – 116	83 - > 170
C.V. (%) :	11	24
FOS_{th}[4] :		
Average (µm):	103	111
Range (µm) :	89-123	68-181
C.V. (%) :	10.1	33.8

Notes:
1 : NW = nonwoven; NP = needlepunched; HB = heatbonded;
2 : Test performed according to CAN/CGSB – 148.1-10 method;
3: bubble point technique;
4: Theoretical FOS or O_{100}, as calculated by Giroud (1996).

4 METHODOLOGY

In order to verify the correlation between the number of constrictions and the filtration behavior of soil-geotextile systems, and to eventually define its optimal range, gradient ratio tests were performed on nonwoven geotextiles with similar FOS but of different fiber structures.

4.1 *Test conditions*

Gradient Ratio tests were conducted in 100 mm diameter filtrameters with soil samples of 100 mm in height. Most of the soil-geotextile systems were submitted to an hydraulic gradient of 10. An automatic data collection system was used to monitor the flow rate and hydraulic head at 0, 6, 25, 75 and 100 mm of the soil-geotextile interface.

4.2 *Tested soils*

Soils used in the tests were all mixes of calibrated glass beads. Their gradation curves are exposed on figure 3 and their properties are summarized in table 2. The soils could be classified into two (2) main categories, namely unstable gap graded soils (see soils F, H, J and M) and concave upward soils, some of them being potentially unstable (see soils A and E).

Concave upward soils were installed in the filtrameter in the form of a thick slurry. Gap graded soils were lightly compacted in the permeameter with a low water content (1-2%) in order to minimize the segregation potential.

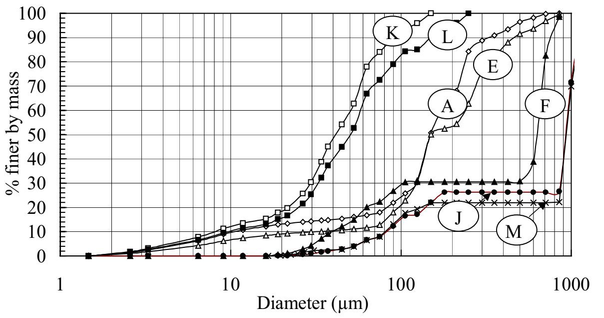

Figure 3. Soils gradation curves.

Table 2. Soils properties (diameters given in µm)

Mix	A	E	F	J	K	L	M
d_{10}	11	31	39	82	8	10	81
d_{20}	82	96	63	139	22	25	131
d_{30}	123	122	104	861	29	33	873
d_{40}	136	136	603	892	35	40	903
d_{50}	149	150	626	925	41	50	935
d_{60}	175	237	651	959	50	58	967
d_{85}	258	388	730	1082	78	123	1087
Cu	16	8	8	12	6.3	6	12
Cc	8	2	2	9.5	2.1	1.9	9.8
Type	CU	CU	Gap	Gap	CU	CU	Gap
Stability	U	U	U	U	S	S	U
d_I	123	122	87	150	78	123	112

Notes :
Cu : coefficient of uniformity; Cc : coefficient of curvature; CU: concave upward; Gap: gap graded; U: internally unstable according to Kenney & Lau (1985) procedure; S: internally stable; dI: indicative diameter according to Mlynarek (1998) filtration criteria, except for gap graded soils, where d_{85} of the fine portion was considered.

4.3 *Geotextile filters*

Geotextiles filters retained for the study were all nonwoven needlepunched or heatbonded products. Their properties are gathered in table 3. They can be divided into three (3) categories according to their number of constrictions, namely i) m < 10 (F1 and F2); ii) m = 20-40 (F3 to F5) and iii) m >40 (F6 and F7).

It should be mentioned that the filter F7 has the particularity of being formed of five (5) layers of a broad geotextile.

Table 3. Geotextiles properties

	F1	F2	F3	F4	F5	F6	F7
t_G (mm)	0.51	0.71	1.79	1.65	3.46	5.68	10.95
μ_G (g/m²)	195	127	220	223	316	610	973
n (%)	58	80	86	85	90	88	90
d_f (µm)	45	43	31	28	47	42	56
m	7	7	21	23	23	47	61
O_{100} (µm)	99	163	88	72	159	102	149
FOS (µm)	99	150	95	103	141	92	n/a
Type	HB	HB	NP	NP	NP	NP	NP

Notes:
t_G = thickness; μ_G = mass per unit area; n = porosity; df = fiber diameter; m = number of constrictions; O_{100} = theoretical filtration opening size as calculated by Giroud (1996); FOS = measured filtration opening size according to CAN/CGSB – 148.1-10; NP = needlepunched; HB = heatbonded; n/a = not available.

4.4 *Experimental program*

Internally unstable soils were used in order to check the influence of low values of m on the potential development of the blinding mechanism. Their selection was based on the retention criteria proposed by the Comité Français des Géosynthétiques, where the FOS should be smaller than the d_{85} of the lower portion of the gap.

In order to study the influence of high values of m on the filtration behavior of soil-filter systems, concave upward soils were combined with geotextiles having FOS slightly larger than what would recommend Mlynarek's (1998) filtration criteria, for the purpose of promoting particle migration. Table 4 summarizes the experimental program conducted for the present study.

Table 4. Experimental program

Pair of tests	Filters	Soil	Comments
1	F3 – F6	K	Effect of high m value
2	F5 – F7	L	Effect of high m value
3	F1 –F4	A	Effect of low m value
4	F1 –F4	E	Effect of low m value
5	F1 –F4	F	Effect of low m value
6	F2 - F5	J	Effect of low m value
7	F1 –F4	M	Effect of low m value

5 RESULTS

5.1 *Influence of high value of m on the filtration behavior of soil-filter systems*

Figure 4 presents the test results of pairs # 1 and 2, where filters with number of constrictions higher than 40 were tested. Despite their similar FOS, it can be seen that higher soil erosion is systematically associated to high values of m. By combining these results to the ones previously presented in Bouthot et al. (2000), one could notice the existence of a relationship between the mass of eroded soil and the number of constrictions. Considering that piping occurs when the eroded soil mass exceeds 2,5 kg/m² (Lafleur et al. 1989), it could be state that a m value of around 55 surely represents a critical limit. A m value of 45 would apparently be a reasonable upper limit.

It should be specified that the previous analysis is based on soil-filter systems where filters' FOS were systematically larger than what would be required with common filtration criteria (by 20 µm on average). It could then be stated that the proposed upper limit is reasonably conservative.

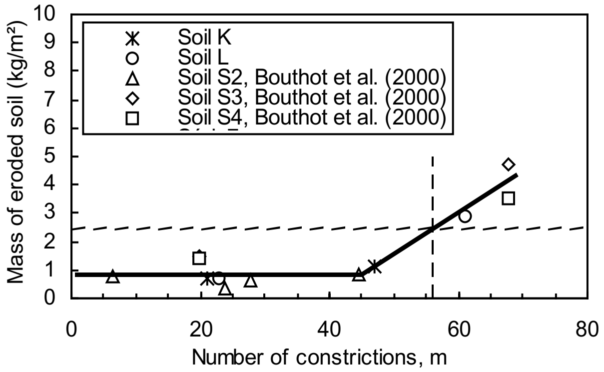

Figure 4. Determination of the upper limit of the number of constrictions.

5.2 *Influence of high value of m on the filtration behavior of soil-filter systems*

Test results implying filters with low m values are gathered in table 5. As it can be seen, there is no clear evidence of a predominant blinding development with these filters, except for pair of tests #4 where head losses distribution reveals higher hydraulic gradients near the interface.

Table 5. Tests results implying low m values

Couple	Filters	Soil	Observations
3	F1 –F4	A	Visible concentration of head losses near the interface in both cases, but not predominant with F1.
4	F1 –F4	E	Slight concentration of head losses near the interface for F1, but barely sufficient to be associated to the development of a blinding mechanism (GR_{ASTM} =1.8 < 2). Similar system permeabilities.
5	F1 –F4	F	Apparent migration of fines particles through the soil matrix. Visible concentration of head losses near the interface in both cases, but not predominant with F1. Similar system permeabilities.
6	F2 - F5	J	Apparent migration of fines particles through the soil matrix. Visible concentration of head losses near the interface in both cases, but not predominant with F1. Similar system permeabilities.
7	F1 –F4	M	Apparent migration of fines particles through the soil matrix. Visible concentration of head losses near the interface in both cases, but not predominant with F1. Similar system permeabilities

6 DISCUSSION

Gradient Ratio tests performed on different combinations of soils and geotextiles of similar FOS confirmed that this parameter is sometimes insufficient to adequately predict their filtration behavior. It seems however that the number of constrictions concept proposed by Giroud (1996) is a interesting way to fill this gap.

It has been shown that for a given FOS, filters with very high number of constrictions are usually associated with greater eroded soil masses, which is consistent with Giroud's et al. (1998) theoretical filtration analysis. Based on the results presented previously, it could be stated that a number of constrictions exceeding 45 could lead to severe piping.

On the other hand, no clear influence of low number of constrictions on the potential development of the blinding mechanism was identified, even for very unstable soils. It should be noticed however that the FOS of the filters that were studied were relatively close to the requirements of common filtration criteria. It is thus conceivable that different filtration behaviour might have occurred with less open geotextile filters (or FOS / d_I <<1). Given that no clear trend was observed, the minimal value of 25, as recommended by Giroud et al. (1998), remains.

7 CONCLUSION

In this paper, it was shown that the number of constrictions concept proposed by Giroud (1996) is an interesting tool to predict the soil-filter system behavior, combined with the filter's filtration opening size (FOS).

From test results and Giroud's et al. (1998) recommendations, it appears that the optimal constrictions numbers should range between 25 and 45. However, more research is needed to define the implication of low constrictions numbers on the prevalence of the blinding mechanism.

8 REFERENCES

Artières, O. & Faure, Y.-H. (1997). Soil Fitration with Geotextile : Feedback and New Developments, *Rencontres 97* : 105-111.

Bouthot, M., Vermeersch, O.G., Blond, E.& Mlynarek, J. (2000). Effet du nombre de constrctions sur le comportement en filtration fdes géotextiles non tissés. Proceedings of the 3rd International Conference Geofilters 2000, Warsaw, Poland: 159-165.

Giroud, J.P. (1996). Granular Filters and Geotextile Filters. *Geofilters' 96*, Montréal, Canada : 565-680.

Giroud, J.P., Delmas, P. & Artières, O. (1998). Theorical Basis for the development of a Two-Layer Geotextile Filter. *Sixth International Conference on Geosynthetics*;Atlanta, USA : 1037-1044.

Kenney, T.C. & Lau, D. (1985). Internal Stability of Granular Filters. *Canadian Geotechnical Journal*, vol. 22 : 215-225.

Lafleur, J., Eichenauer, T. & Werner, G. (1996). Geotextile Filter Retention Criteria for Well Graded Cohesionless Soils. *Geofilters' 96*, Montréal, Canada : 429-438.

Lafleur, J., Mlynarek, J & Rollin, A.L. (1989). Filtration of Broadly Graded Cohesionless Soils, *Journal of Geotechnical Engineering*, vol. 115(12) : 1747-1768.

Mlynarek, J. (1998). Designing Geotextile Filters Part 1: Soil Filtration. *51st Canadian Geotechnical Conference* : 499-505.