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Analysis of filtration systems by probabilistic theory and simulation methods

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ABSTRACT: Geotextiles have been used as filtering element in all the world, being this one actually their most important application. Particularly in environmental works they represent a versatile solution easily applied and controlled, presenting a good performance. The work presents new methods for the analysis of the textiles filters behavior: a rational design method based on the probabilistic theory, with new procedures to evaluate the geotextile parameters and a computational simulation of the filtering system, which permits to analyze the long time behaviour of the system.

1 INTRODUCTION

The successful geotextile filter design can often be achieved considering the following criteria: retention, permeability, survivability and clogging resistance.

There are numerous design criteria proposed for geotextiles filters, however current empirical methods do not evaluate adequately long time filtering behavior. This work presents new methods for the analysis of the textiles filters behavior: a rational design method based on the probabilistic theory, and a computational simulation of the filtering system.

The rational design method, first presented at the Sixth International Conference on Geosynthetics (Urashima & Vidal 1998), evaluate the capacity of filter retention for a defined confidence level, when the geotextile pore distribution and the unit step walk covered by the particle for each confrontation on the filter are known. This paper will present a new proposition to that analysis using image analysis to determine the pore distribution curve and new results from variable hydraulic head filtration tests to obtain the unit step walk.

Engineering work related to environmental protection needs filtration system in situations as: erosion control, silt fences and particle retention in mined areas, for example. Filtration problems could be separated in two main types: filtration of porous media and filtration of in suspension particles. In the last type, filtering systems need replacement or periodic cleaning. This problem becomes extremely serious in the case of very fine particle filtration (clay or silt), which can reduce the system permeability to the point of needing very frequent maintenance (Urashima & Vidal 2000a).

The rational design method is particularly important for application in environmental work because it is the only one that allows to evaluate the level of retention reliability. The possibility of evaluating the reliability level solves only a part of the in suspension particles retention problem because it is still necessary to know the behaviour of the filter during its lifetime, evaluating the permeability of the system throughout time and the changing and/or washing period. Simulation techniques can solve this problem. This work also presents a new proposition to analyze geotextiles filters behavior based on simulation computational techniques.

The simulation of filtration systems permits to evaluate the long time filtering behaviour considering porous media and in suspension particles flow. In this case the simulation evaluate the hydraulic head development on time due to the soil retention in the filtering system. For the evaluation of particles retention filter capacity using simulation techniques it is necessary to study the geotextile porometric structure and define the statistic particles arrival. The base material can be represented by a probabilistic distribution. In addition, the simulation allows considering the flow type and intensity in the system. Several flow situations could be tested in simulation model through mathematical expressions.

2 THE RATIONAL DESIGN METHOD

Silveira (1965) proposed a probabilistic analysis to study the carrying of soil particles in a filter. This analysis gives us the filter thickness needed to retain the soil particles, when the pore distribution and the unit step walk covered by the particle for each confrontation on the filter are known.

As a manufactured product, geotextile filters have determined characteristics, which are submitted to the industrial quality control. These characteristics depend on manufacturing procedures, could be changed face either to a specific purpose or to a control quality failure. Generally one chooses for pattern products, which have defined thickness, and the rational method may be applied to verify the level of retention reliability, P', for a determined soil particle.

The level of retention reliability, of a defined diameter particle, d, to be retained by a pore size smaller than it, before a number N of confronts, assuming that each confrontation is a independent event, is done by:

$$P' = 1 - P^{N} \qquad (1)$$

Being P the probability of the filter to have pore sizes bigger than d.

Considering the unit step walk covered by the particle for each confrontation on the filter as s and the filter thickness, t_{GT}, N is given by:

$$N = t_{GT}/s \qquad (2)$$

To verify the retention criteria the designer needs only to define the soil particle diameters to retain (for example, d_{85} in well graded soil or d_{50} or an other value in function of soil characteristics) and the level of retention reliability desired. The geotextiles which characteristics (pore size distribution curve, the unit step walk covered by the particle for each confrontation on the filter and thickness) indicates a level of retention reliability, obtained from equations 1 and 2, satisfying the specified value, could be selected.

It is necessary to remember that Silveira's proposition (1965) takes into consideration the most critical situation, i.e. the particle is been transported by flow.

Therefore, to carry out this analysis it is necessary to know the probability of the particle finding a pore size smaller than itself, represented by the pore size distribution curve, and the unit step walk covered by the particle for each confrontation on the filter.

3 PORE SIZE DISTRIBUTION CURVE

Filtration characteristics and pore size distribution of geotextiles have been largely discussed in literature (Bathia et al. 1994, Gourc 1982, Christopher et al. 1993). The usual methods to analyse the filtration parameters of geotextiles are based in different conception and generally they are not applicable to obtain the geotextile pore size distribution.

Different techniques have been developed to measure the geotextile pores size and frequency. The pore size distribution curve has been evaluated in the past years by theoretical evaluation or direct and indirect measurement methods.

This paper presents a proposition to evaluate the pore size distribution curve obtained by image analysis. It is a direct measurement method based on new digital image processing techniques. This proposition permits to recognize and measure particular image attributes making use of digital procedures.

Geotextile porometric structure images can be taken from pictures generated by a video camera connected to a microscope with 50 to 300 time magnifying capacity and examined in real time with a monitor plugged in a computer that allows to capture the image with a specific software (Global Lab Image).

To analyze the image attributes is necessary to identify and separate the pores inside the filaments or fibers that compose the taken image of the geotextile. The pores are defined by the void spaces between the detected filaments or fibers. This pore delimitation is necessary to calculate the attributes to be analyzed in order to obtain the pore size distribution curve.

The digital images are submitted to boundary detection and morphologic filters. Subsequently they are segmented in homogeneous regions to extract the chosen geometric attributes: area, major and minor axes of a inserted ellipse and roundness.

The geometric parameter chosen to obtain the pore size distribution curve is the diameter calculated from the minor axes, taken directly as a diameter.

In a rational analysis the effect of the third dimension (geotextile thickness) is considered from the average distance between confronts (unit step walk, s). This proposition considers that the particle has a linear walk, perpendicular to the filter. The retention criteria consider the planes of confrontations separated by the unit step walk.

The statistical procedure to evaluate the number of images to be analyzed for representative sampling of the entire sample should be considered. To estimate this number it should be first considered that the pore diameters are distributed alike a normal. From the T Student distribution with a defined significance is possible to verify if the number of taken images is sufficient to define a representative pore size distribution curve.

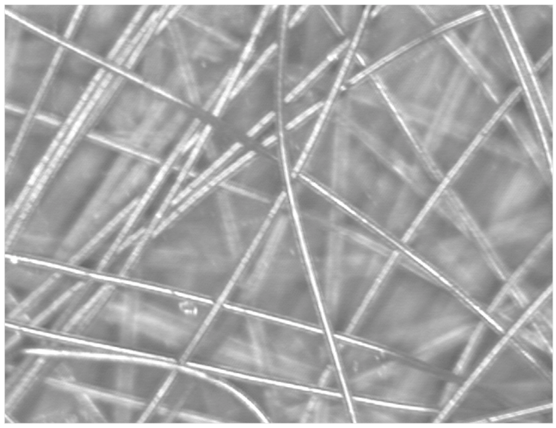
A polyester needle-punched continuous filaments nonwoven geotextile had its pore size distribution curve evaluated to explain the procedure through example. Physical characteristics of this geotextile are presented on Table 1.

Table1. Geotextile physical characteristics

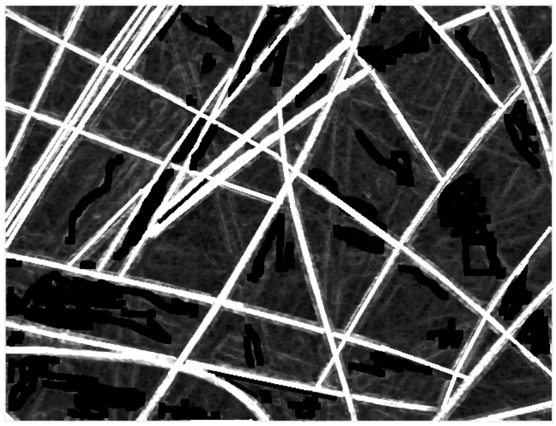
Characteristics	Value
Fiber diameter (mm)	0,022
Thickness (mm)	1,33
Mass per unit area (g/m^2)	1,58
Porosity (%)	91,4

Figure 1 shows one image magnified 50 times being generated in the TIFF format (Tag Image Format File) with 640 x 480 pixels, each pixel with approximate 0,002 mm, obtained from the image acquisition equipment calibration and the processed image.

The Figure 2 presents the pore size distribution curve obtained by image analysis and the theoretical pore size distribution curve obtained from Gourc's proposition (Gourc 1982).



(a)



(b)

Figure 1. Taken and processed fabric geotextile images (x50)

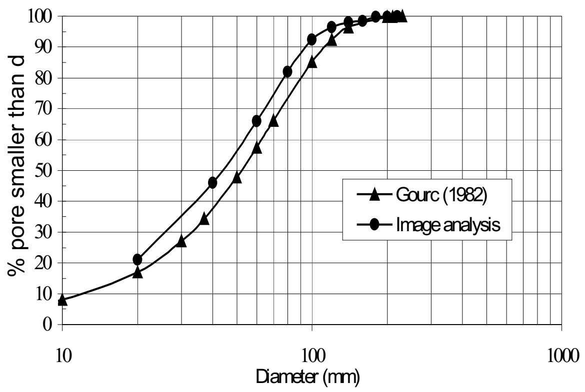


Figure 2. The pore size distribution curve obtained from image analysis and Gourc's proposition (1982).

4 THE UNIT STEP WALK

From the results of special variable hydraulic head filtration tests, conducted according to the probabilistic theory suppositions, and the pore size distribution curve obtained by image analysis, it is possible to estimate the unit step walk covered by the particles for each confrontation.

In 1992 Silveira suggested an experimental procedure to determine the pore size distribution by retro analysis, using the in-suspension filtration test results and considering that the unit step walk is known. In fact, for granular filters the unit step walk is easily evaluated because it is function of the filter particle diameters and density, and the problem, in this case is to determine the pore size distribution curve.

In the case of the geotextile filters, the filaments or fibbers do not necessarily have full contact points and the pore size are function of manufacturing procedures. The pore size distribution curve being evaluated from theoretical propositions (Gourc 1982) or image analysis (item 3) the unit step walk could be evaluated by the retro-analysis of filtration tests considering a similar procedure that one proposed by Silveira (1992).

Studies and analyses of the results obtained by traditional in-suspension filtration tests (Urashima & Vidal 1997, 1998) shows that this methodology could not be extended for specimens of larger areas, as suggested by Silveira (1992), because the amount of required rate of flow would be huge. However, an augmentation in the specimen surface would allow an increase in the amount of passing base material, what would facilitate its analysis, also making possible the use of a standard soil instead of soil fractions.

To satisfy Silveira's (1992) hypotheses and to allow a better value of the unit step walk, including fabrics with mass per unit area greater than 200 g/m^2, a new test method was proposed by Urashima & Vidal (2000b). The main differences between the new methodology and the other are: the specimen size, the hydraulic load (tests are made with variable loading instead of constant loading), and the base material preparation.

The equipment proposed for the variable hydraulic head filtration tests, with 0.61 m^2 area specimens, consists of a rectangular reservoir (0.87 x 0.80 x 0.35 m), which bottom is fixed by an electro magneto system. The device assemblage is illustrated on Figure 3. Urashima & Vidal (2000b) describe the equipment and the tests procedure.

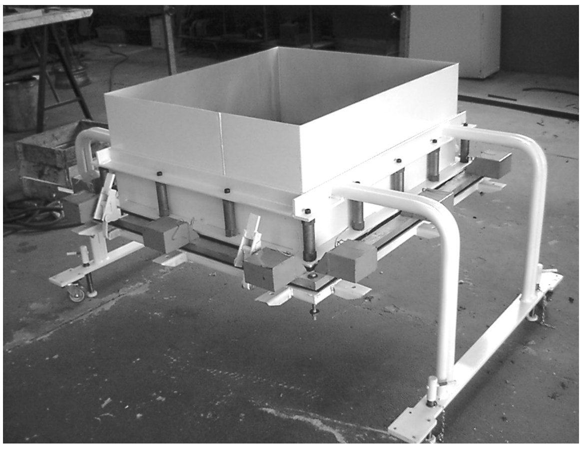


Figure 3. Equipment utilized in the variable hydraulic head filtration tests.

The method proposed allows to analyse geotextiles specimen of greater dimensions, obtaining a larger amount of passing material, making possible a better analyses of the particle size distribution of the passing material. They could be conducted to evaluate the bigger particle passing across the filter on the first seepage front, under severe flow conditions.

Table 2 permits to compare the different values obtained for the geotextile selected to exemplify the analysis described on Table 1, from the in-suspension filtration tests at hydraulic constant head (Urashima 1996), the new variable hydraulic head tests (Urashima 2000) and the values obtained by hydrodynamic sieving (NF G 38017 1986) and the characteristic opening size (ISO 12956 1999). Table 3 presents the unit step walks, s, evaluated considering the several pore size distribution curves that could be obtained.

Table 2. Bigger particle size determined by different test methods for the geotextile selected to exemplify the analysis.

$d_{95,S}$ [1] (mm)	$d_{95,v}$ [2] (mm)	$O_{95,H}$ [3] (mm)	O_{90} [4] (mm)
0.070	0.069	0.210	0.90

[1] in-suspension filtration test at constant head
[2] filtration test at variable head
[3] NFG 38017 (1986)
[4] ISO 12956 (1999)

Table 3. Unit step walk from different pore size distribution curves for the geotextile selected to exemplify the analysis.

s[1] (mm)	s[2] (mm)	s[3] (mm)
0,380	0,365	0,270

[1]variable hydraulic head filtration test
[2]constant hydraulic head (in-suspension) filtration test
[3] theoretical (Gourc, 1982)

Knowing the pore size distribution curve and the unit step walk covered by the particle for each confrontation on the filter, it is possible to verify the retention criteria as described in 2. Whenever it is necessary to know the behaviour of the filter during its lifetime, simulation techniques can be applied to analyse the system behaviour.

5 ANALYSIS OF FILTRATION SYSTEMS BY SIMULATION METHODS

The simulation of filtration systems based on Logic - mathematics models representing the dynamics of the system permits to evaluate the long time filtering behaviour considering porous media and in suspension particles flow. In this case the simulation evaluate the hydraulic head development on time due to the soil retention in the filtering system.

The proposed model considers a statistical distribution from the given set of the base materials particles that will be filtered. These particles present several diameters that can be randomly generated by statistical distribution. The geotextile fabric is represented from image analysis.

Whenever the base materials is well graded, the particle diameter can be generated randomly considering a normal distribution with the average μ and the variance σ^2, defined from the characteristics diameters: d_{16}, d_{50} e d_{84}. The generated diameters are limited by $[d_o, d_{100}]$. When the base material presents a uniform grain size distribution curve, the particle diameter can be generated randomly using a uniform distribution defined between $[d_o, d_{100}]$. In case of a poorly graded grain size distribution, none of the statistical distribution can be considered and the diameters are randomly generated between $[d_o, d_{100}]$ Urashima & Vidal (2000a).

To evaluate the capacity of retention of the textile filters by simulation techniques, it is necessary to analyse the geotextile fabric. The geotextile porometric structure images can be taken from pictures generated by a video camera connected to a microscope and connected to a computer that allows to capture the images and digital images processing techniques, as described on item 3. This method permits consider the real form and dimension of the geotextile pores, analysing a set of binary images, archived on a database and randomly chosen. The filter thickness is defined applying equation 2.

This technique can be applied to simulate the most diversified situations. To show the results that could be obtained on can take, for example, the long time behavior analysis of a filtering system with an in suspension particles flow, considering:

a) granular base material - a stone powder of 27 kN/m^3 solid unit weight, with high strength particles, with d_{16} = 0,038 mm, d_{50} = 0,060 mm, d_{84} = 0,085 mm and d_{60}/d_{10} = 9;

b) filter – the same one illustrated on item 3 and 4;

c) in suspension particle concentration = 1kg/m^3

Figure 4 illustrates one of the results that can be obtained by simulation techniques for this filtering system analyzing during five hundred hours, under these conditions.

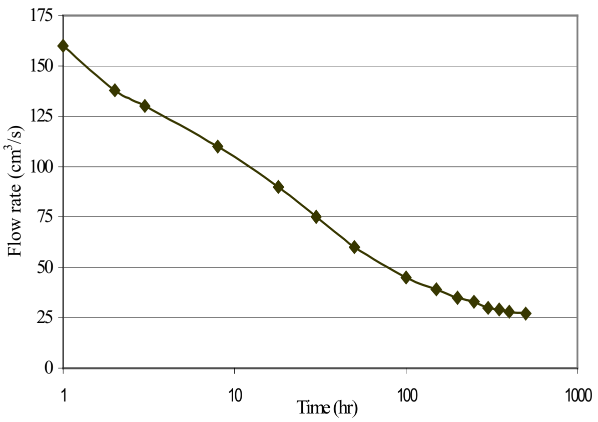


Figure 4. Time x flow rate obtained by simulation techniques for the adopted example.

6 CONCLUSION

This paper presents a new method for the analysis of the textiles filters behavior by simulation techniques and new techniques to obtain the geotextile parameters needed on rational filter design: the pore distribution and the unit step walk covered by the particle for each confrontation.

The rational design method is particularly important for application in environmental work because it is allows to evaluate the level of retention reliability in complex situations.

The authors suggested the use the image analysis method to determine the pore size distribution of geotextiles. With this information, the unit step walk could be evaluated by the retro-analysis of filtration tests. In the case of the geotextile analysed in this paper (Tables 1, 2 and 3), the differences between the values obtained by the different methods don't signify a difference on the level of retention reliability in the analysed situations, probably due to compensations (the unit step walk increase but the retention probability decrease).

The simulation of filtration systems permits to evaluate long time filtering behaviour considering porous media and in suspension particles flow.

The use of processed digital images in model simulation of filtering system behavior and in the determination of the geotextile pore size distribution curve seems to be a promising tool in model simulation of filtering systems.

The statistical definition of particles arrival conditions permits to consider different soils types, just knowing their characteristic diameter values.

Simulation techniques are a versatile tool to analyze the most different situations, permitting to consider fabric peculiarities, various flow and particles conditions and relationships.

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