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Soil Filtration Phenomena of Geotextiles
Phénomènes de filtration des sols par des géotextiles

The mechanism of soil-filtration in porous media is rather complicated. Granular and fabric filters seem to be different in their behaviour. Based on an objective comparison, which takes into account the real geometrical parameters as pore-openings of soils and opening-sizes of fabric filters, respectively their maximum values, it is demonstrated, that in relation to the elements of the different media (grains, fibres) the filter characteristics are similar. Except woven filter fabric, which shows a real sieve-filtering, all other filter media (non-wovens and granular filters) are influenced in their particle-retaining ability by the so-called filtration-length (filter-thickness).

Le mécanisme de filtration des sols en milieu poreux est très compliqué. Le milieu granulaire et les textiles semblent se comporter differemment. En se basant sur une comparaison objective, qui prend en compte les paramètres géometriques veritables, tels que l'ouverture des pores du sol et les ouvertures du textile, en particulier leurs valeurs maximales, on montre que les caractéristiques du filtre sont comparables à celles du milieu granulaire à l'échelle du grain et de la fibre. A l'exception des filtres tissés qui filtrent comme à travers un tamis, tout les autres filtres (non-tissés et granulaires) sont influencés, dans leur capacité à retenir des particules, par la longueur de filtration (épaisseur du filtre).

1 INTRODUCTION

The mechanism of soil-filtration in porous media (soils and fabrics) is rather complicated and thus, the approaches in engineering practice are mainly based on empricism. Only few and sometimes very simplified models have been established, to get a better understanding of the fundamental mechanism. Due to sometimes rather complicated hydraulic boundary conditions (stationary and instationary loading of filter interfaces), which in most cases cannot be quantified precisely, the safest approach is based on geometry of the filter media. Geometrical parameters are pore-openings for mineral filters (sand, gravel, etc.), mesh-sizes for woven geotextiles and opening-sizes for non-woven geotextiles. Filter criteria can then be established by comparing grain-sizes of the soil to be filtered (base-material) with the former described geometrical characteristics of the filter media.

Latest research work on mineral filters (Wittmann (1)) has pointed out the influence of filter-thickness, the so-called filtration-length, which was not taken into account so far in existing criteria. Based on pore-measurements of granular media (sand and gravel) these mineral filters are now directly comparable to fabric filters. This comparison of different filter media is exemplarily done in this paper, mainly dealing with the pore-size and opening-size characteristics and the filtration-length. A complete review of existing filter criteria is not given in this paper. For this it is referred to Heerten (2), Wittmann (3), etc.

2 CHARACTERIZATION OF POROUS MEDIA

Filter media (soils, geotextiles) are geometrically characterized in regard to their particle-retention ability (soil-filtration) by opening-sizes between the grains or fibres. Only for woven geotextiles with simple structures, optical methods can be used to determine the "mesh-openings". All other structures (non-woven geotextiles and soils) are rather complicated and thus direct measurements have to be replaced as for example by sieving-tests for non-wovens. These sieving-tests with glass-ballotini or natural soils identify the range of existing opening-sizes and especially the maximum opening-size, if sieving time, amount of fines, amplitude and frequency of sieving are being optimized, to give the extreme values. For granular filters these sieving tests were not applied so far. Filter tests under hydraulic loading (percolated samples) were those tools, being used to establish the well-known grain-size-ratios (filter criteria) for granular filters (Examples: Terzaghi, US Bureau of Reclamation, etc.).

So far, pore-sizes of granular media are only calculated on model assumptions of regular sphere-packings, as for example minimum pore-size $d_{p,min}$ in dense packing

$$d_{p,min} = 0.155 \cdot D_{min} \qquad (1)$$

or on Atterberg's assumption, that the average pore-diameter $d_{p,a}$ is equivalent to

$$d_{p,a} = 0.2 \cdot D_{10} \qquad (2)$$

Further information on the pore characteristic of soils was not available.

3 NEW PORE MEASUREMENTS OF GRANULAR MEDIA

Because of the complexity of the granular media, spatial pore measurements are not successful. This was the main reason, why new measurements were done at slices, being produced by cutting resin bonded samples of granular media. Photographs were taken from these slices (see figure 1) and pore-size-distributions were determined at these plan reproductions of the porous medium by a digital curve integrator. The results of these measurements showed a good reproducibility. Figure 2 represents a typical pore-size-distribution for a rather uniform soil in a dimensionless graph. The minimum pore-size of these measurements was in good accordance with the value of equation (1).

Fig. 1 Slice for pore-measurements of soils, taken from a resin bonded gravel

4 FILTRATION-LENGTH OF GRANULAR MEDIA

The measured pore-size-distribution is valid for each slice being taken from the soil sample, if the soil is homogeneous and isotropic. The spatial pore-size-distribution can be evaluated from the measured pore-size-distribution by "putting these slices in series, with distances of the grain-diameter respectively the average grain-diameter between the slices". This model simulates the narrowing and widening of pores along the so-called pore-channel in the direction of water-flow. Big pores are thus isolated by meeting smaller pores. With increasing thickness of the filter - the so-called filtration-length, which can be expressed as filter-thickness L_F divided by the grain-diameter D of the filter (dimensionless parameter $m = L_F/D$) - the amount of bigger pores decreases, being visible in the shifting of the pore-size-distribution around the minimum pore-size $d_{p,min}$ (see figure 3). For a filter of infinite length the pore-size-distribution yields to a straight vertical line passing $d_{p,min}$.

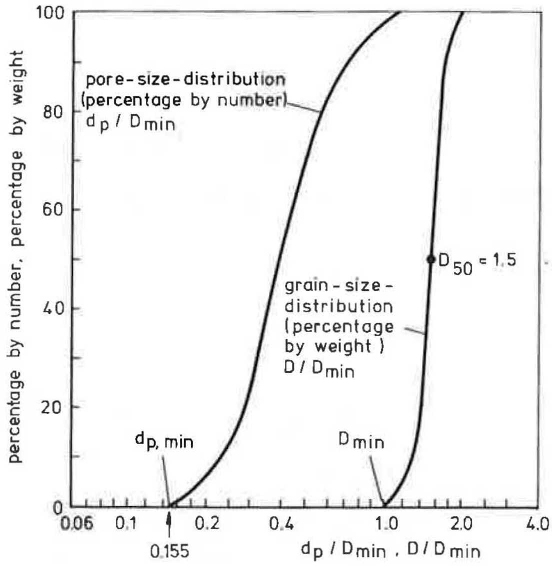

Fig. 2 Measured pore-sizes and grain-sizes divided by the minimum grain-size of the filter

Different steps between for finite filtration-lengths can be calculated by superimposing the pore-size-distribution for m = 1 probabilistically with itself. The result can be seen in figure 3 for m = 2 to m = 100. A detailed description of this method is given by the author in reference (1).

4 COMMENT ON EXISTING FILTER CRITERIA

This model teaches the influence of filter-thickness, which was not taken into account so far. It's validity was proved in the former mentioned sieving-tests. Granular filters of different length were used as "sieves" with fine particles being applied to identify the pore-openings. In these tests a confidence level of 99.99 % was found to be a safe approach, which means that for a certain filtration-length, the pore-diameter $d_{p,99.99\%}$ is a safe prediction of the maximum pore-opening $d_{p,max}$.

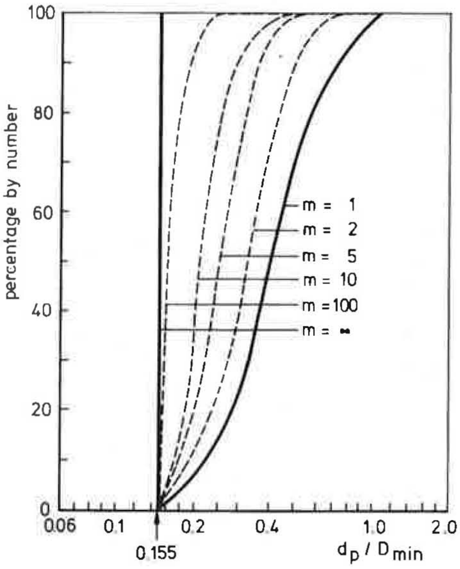

Fig. 3 Changing of pore-size-distribution with increasing filtration-length m

Using this model, it can be demonstrated that filter criteria based on grain-size-ratios as for example $A_{50} = D_{50}/d_{50}$ (D - grain-diameter of filter; d - grain-diameter of base-material) are geometrical safe, only if a certain length of the filter is given. The aspect of geometrical safety means, that a base material grain cannot pass the pores of the filter even under extreme hydraulic loading. For rather uniform base and filter material the grain-sizes d and D are well represented by d_{50} and D_{50} and with $d_{50} > d_{p,max} = d_{p,99.99\%}$ the following ratios $A_{50} = D_{50}/d_{50}$ are geometrically safe for the presented filtration-lengths $m = L_F/D_{50}$.

$A_{50} = D_{50}/d_{50} = 1.5$	m = 2.6
$A_{50} = D_{50}/d_{50} = 3.0$	m = 7.6
$A_{50} = D_{50}/d_{50} = 5.0$	m = 35.2
$A_{50} = D_{50}/d_{50} = 8.0$	m = 179.6

With the definition of filtration-length it is pointed out, that a grain-size-ratio of $A_{50} = 5$, which is the lower boundary of the filter criterion by the US Bureau of Reclamation, needs a filtration-length of about 35 grains, to be geometrical stable. A gravel filter with D_{50} = 10 mm thus needs a thickness of about 350 mm to retain base material with d_{50} = 2 mm. A sand filter with D_{50} = 1 mm shows the same particle retention for 0.2 mm base material at a filter thickness of 35 mm, which is almost below those thicknesses used in earth constructions. For these rather uniform soils a ratio A_{50} = 10, which is the upper limit of the filter criterion of the US Bureau of Reclamation, does not yield to a geometrically safe filter design. Differential analysation of this concept demonstrates that particle filtration at the interface base-material/filter (cake-filtration) is only given for very low grain-size-ratios ($A_{50} < 3$). For bigger values, filtration takes place at this interface and inside the filter.

This concept can also be applied to non-uniform soils, which is analysed in reference (4).

6 COMPARISON OF GRANULAR FILTERS AND FABRIC FILTERS (GEOTEXTILES)

Geometrical characterizations of textile filters in practice are based on sieving-tests, to gain information on the maximum opening-sizes and on the opening-size spectrum. Direct measurements of opening-size characteristics up to now were only done by Rollin et al. (5) at cross-sections of geotextiles. A similar technique of sample preparation was used as described in chapter 3. Pore-size histogramms were determined using an image-analyser. The according theory is only valid for thick geotextiles (h > 1.5 mm) and the measurements being done at cross-sections cannot be directly compared to the results from granular media in perpendicular planes.

Therefore as a first approach to this problem data being available from producer´s references in literature and prospectus is analysed in regard to filtration characteristics.

The maximum pore-size $d_{p,max}$ of granular filters is comparable to opening-sizes of geotextiles. These openings are often taken near to the maximum opening, with according geometrical safety being considered in filter criteria, asking for a certain percentage of base material being bigger than the used opening value. Opening-values being used so far are O_{90} or O_{95} (French geotextile committee (6)) or O_{98} (Ogink (7)) or effective opening-sizes D_w (Heerten (2)).

As these measurements of opening-sizes are being done on nearly unloaded geotextiles, according thickness values at low loads (0.005 to 0.02 bar) have to be used in calculation. To establish a filtration-length m* for geotextiles, the thickness h of the textile is divided by the diameter d_f of the fiber or filament. This characterization is valid for mechanically bonded geotextiles without further treatments of the fiber structure (thermal or chemical bonding).

O_{95}-values of six products (needle-punched geotextiles of polyester and polypropylene) are related to the filtration-length $m^* = h/d_f$ and are plotted in figure 4. As being expected, the thickness and therefore the filtration-length m* are of influence on the opening-size. This influence of filtration-length, as being demonstrated in the graph, is

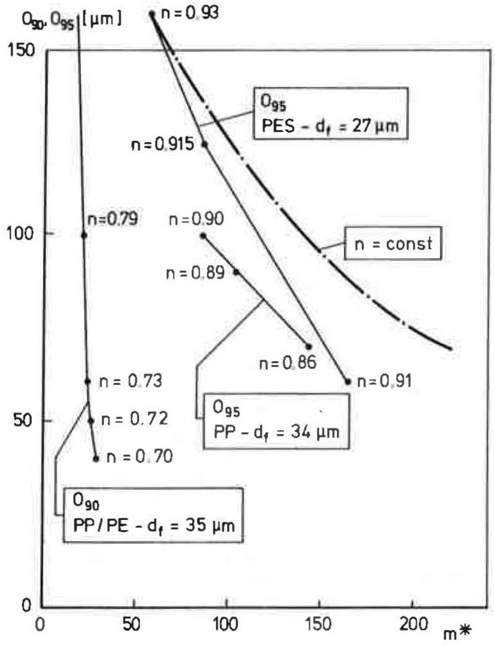

Fig. 4 Opening-sizes of geotextiles as function of filtration-length m*

not objective, because the compressibility of geotextiles is not considered up to here. As can be seen in figure 4, the according porosities are not constant but decreasing with increasing filtration-length. Thus the compressibility of geotextiles leads to a reduction of filtration-length - factors of 1.5 to 2 can be observed between light-weight and heavy geotextiles - and to a reduction in opening-size.

For constant porosity (n = const.) the estimated phenomenological curve is plotted in figure 4, because a precise quantification is not yet possible. It can be seen, that without compressibility the increasing filtration-length leads to a slighter decrease in opening-size und thus can be called uneconomical for large filter thicknesses. The influence of compressibility is again demonstrated for a thermally bonded geotextile in figure 4 by plotting O_{90} as a function of m*. But this influence is overstressed by the different manufacturing process. Further research work could thus reveal the influence of fiber diameters and different types of bonding on the opening-size characteristics.

The validity of the estimated curve for constant porosity in figure 4 is confirmed by experiments of Partenscky and Grabe (8). They showed, that several layers of non-wovens do not change the effective opening-size and the filtration characteristic significantly in regard to the value of a single layer, although retained fines are increasing to a certain amount. This result is presented in figure 5, being a good proof for the constant porosity assumption.

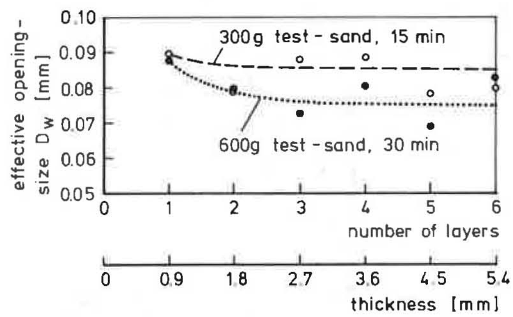

Fig. 5 Influence of filtration-length on effective opening-size D_w (reference (8))

The reduction of opening-sizes by compression of geotextiles is accompanied by a reduction in permeability, whereas increasing filtration-length without compression would not influence the permeability. The influence of filtration-length on particle-retention signifies, that particles migrate into the geotextile to a certain extent, which was also observed by microscopic observation (Rollin et al. (5)). Further calculations of these phenomena, being also described in reference (8) can contribute to clogging effects and permeability changes in relation to the virgin fabrics.

The comparisons of granular filters with maximum pore-sizes $d_{p,99.99\%}$ to fabric filters with opening-sizes O_{95} lead to the result, that both structures show similar filtration characteristics, if the element is taken into account. This is finally demonstrated in figure 6, which shows maximum pore-sizes of mineral filters in the same range as those of geotextiles in figure 4. The filtration characteristics in regard to m respectively m* are similar, especially if that filter with D_{50} = 0.75 mm (fig. 6) is compared with the estimated line for geotextiles at n = const. (fig. 4). This comparison is also valid for the hydraulic parameters. Mineral filters of figure 6 show permeabilities of $4 \cdot 10^{-1}$ to $5 \cdot 10^{-2}$ cm/s, which are equal to those of mechanical bonded non-wovens ($k \sim 10^{-1}$ cm/s) and similar to those bonded thermically or chemically ($k \sim 10^{-2}$ cm/s).

The dimensionless parameters m and m* have to be considered if real filter thickness is calculated, because in these examples demonstrated fiber diameters are about 8 to 25 times smaller than the according equivalent grain-

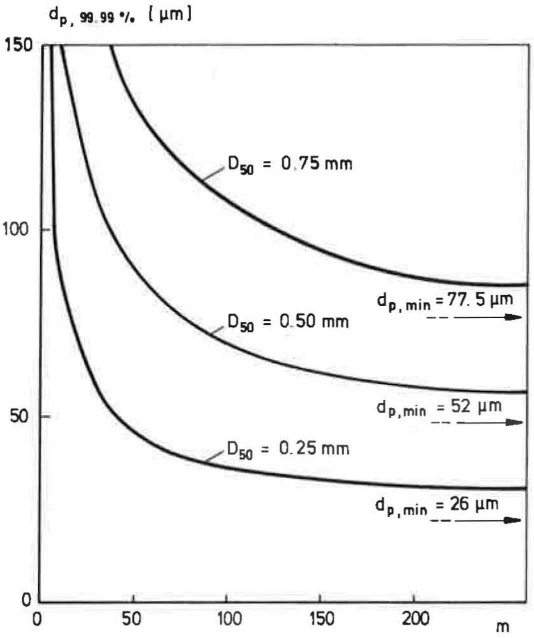

Fig. 6 Maximum pore-sizes of granular filters as function of filtration-length m

sizes and thus for the same dimensionless filtration-length, the granular filter has to be 8 to 25 times thicker than the equivalent filter fabric.

7 SUMMARY

As a first approach an objective comparison of different filter media has been tried in this paper. Based on new pore-measurements at granular filters and on the evaluation of the influence of filtration-length, the similarity of granular and fibrous filters in regard to their elements (grains and fibres) was demonstrated. Further research work has to be done, to complete the knowledge for example on the influence of compressibility, the influence of different manufacturing processes (type of fibres, type of bonding, influence of needle-punching, surface treatments, calendering etc.) and the influence of deformed geotextiles. All these influences have to be considered in filtration works. Geotextiles, being industrial products, are strongly influenced by these manufacturing processes, which in regard to a safe and economical filter design should be revealed in further studies.

8 REFERENCES

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