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# The use of geotextiles as filters in unsteady flow conditions

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ABSTRACT: The paper deals with the design of geotextile filters in unsteady flow conditions, typical of geotechnical applications in coastal and hydraulic structures such as canals, inland waterways, reservoirs. In these applications, boundary conditions (i.e. vertical stresses and interface continuity) and flow conditions can be very different and not always easy to predict. In particular, while in the applications of geotextiles as filters under flexible revetments the vertical effective stresses are low and the contact between the filter and the base soil may be not continuous, in submerged or submersible foundations of coastal structures vertical effective stresses are high and the geotextile filter is in close contact with the base soil. In the paper the influence of design parameters on the soil - filter interaction in unsteady flow condition is analyzed and some indications on the choice of the appropriate design criteria for such specific applications are provided.

## INTRODUCTION

For the applications of geotextiles as filters in simple steady flow conditions, several experimental and theoretical studies, also performed by the authors (Mazzucato et al. 1994, Moraci 1992), showed their reliability. In the present paper, the attention is focused to applications subjected to more severe flow conditions, as unsteady flow conditions, typical of geotechnical applications as filters in coastal and hydraulic structures such as canals, inland waterways, reservoirs. In such applications, geotextiles can be used as filters under flexible revetments, or as filter, separation and reinforcing layer in submerged or submersible foundations, offshore foundations, scour protections and pipeline protections.

In these applications boundary and flow conditions, that have a remarkable importance in soil-geotextile filter interaction (Cazzuffi et al. 1999), can be very different. In particular, in the applications of geotextiles as filters under flexible revetments the vertical effective stresses are low and the contact between the filter and base soil may be not continuous. On the contrary, in submerged or submersible foundation and in offshore foundations, vertical effective stresses are high and the filter is generally in close contact with the base soil. Fig.1 shows the range of vertical effective stresses and hydraulic gradients in the filter contact zone that generally occurs in these applications. Different design criteria were derived by using different laboratory methodologies. Some retention design rules for unsteady flow conditions are summarized in Table 1.

On the other hand, it's important to emphasize that experimental conditions typical of the various laboratory studies are often very different and not always are able to simulate adequately the actual behaviour on site. In particular, the main differences are as following:

- flow conditions (direction and value of the cyclic hydraulic gradient);
- grain size distribution and density of the soil;
- geotextile type;
- effective stress on the filter layer;
- type of contact (i.e., continuous or discontinuous);
- specimen size;
- type of apparatus;
- test duration;

filter criterion adopted.

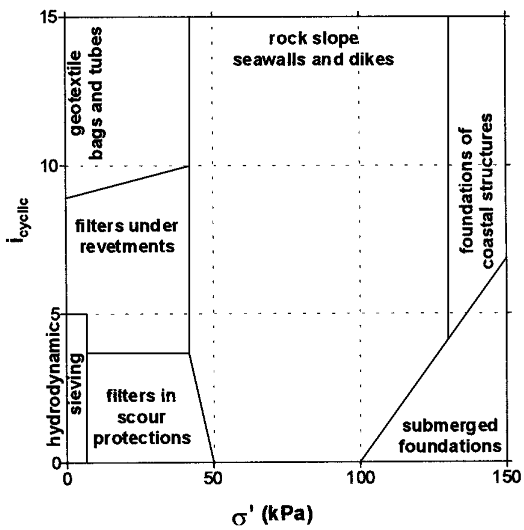


Figure 1. Unsteady flow: range of boundary conditions (Moraci & Tondello, 1996).

Table 1. Summary of some retention design criteria for unsteady flow-conditions.

| Author | Soil | Geotextile | Criterion |
|---|---|---|---|
| Ogink (1975) | sand | Woven and non-woven | $O_{98} < D_{85}$ (int. stable)<br>$O_{98} < D_{15}$ (int. unstab.) |
| Zitsher (1975) | sand | Woven | $EOS < D_{50}$ |
| Shober e Teindl (1979) | sand | Woven and non-woven | $D_{15} < 0_{90} < D_{85}$ |
| Heerten (1981, 1982) | sand | - | $D_W < D_{50}$ |
| C.F.G.G. (1986) | DR < 35%<br>DR > 65% | Woven and non-woven | $O_{95} < 0.5 \cdot D_{85}$<br>$O_{95} < 0.75 \cdot D_{85}$ |
| Mouw et al.(1986) | sand | - | $O_{95} / D_{85} \leq 2$ |
| Holtz et al. (1997) | | | $O_{95} \leq 0.5 \cdot D_{85}$ |

Therefore, presently general design criteria able to consider all the above mentioned parameters are not available for all the used of geotextiles as filters in unsteady flow conditions.

The parameters that must be considered in the design of geotextile filters in unsteady flow conditions are summarized in Table 2.

Hereafter, the influence of the various parameters on the retention criterion will be analyzed. On the other hand, permeability criterion will be not carefully studied, because for the high permeability, in comparison with the permeability of the base soil, and the small thickness of geotextile filters permeability criterion is generally satisfied.

Table 2. Design parameters for geotextile filters in unsteady flow conditions.

| Soil | Geotextile | Boundary Conditions |
|---|---|---|
| Type of soil | Pore size distribution and filtration opening size | Flow direction |
| Relative density | Permeability | Hydraulic Gradient |
| Grain size and distribution | Thickness, porosity and fibre diameter | Continuity of contact at the interface |
| Internal stability | Compressibility | Vertical effective stress at the interface |
| Permeability | Tensile stiffness and strength | Shear stress at the interface |
| Shear strength and deformability | Puncture strength and durability | |

## INFLUENCE OF DESIGN PARAMETERS ON THE SOIL-FILTER INTERACTION.

Concerning the retention criteria for unsteady flow conditions, it should be noted that all the Authors, with the only exception of Ogink (1975), referred to base soils both granular and internally stable.

For base soils internally unstable, there are not reliable design criteria at present time: therefore, in such circumstance, the only possible design approach is to use filtration tests able to reproduce actual site conditions.

With reference to granular base soil internally stable, the various retention criteria proposed by different Authors usually refer to the geotextile filtration opening size obtained by means of different methods, independently from the effective stress on the filter layer and also from the geotextile deformability. The filtration opening size can be determined using theoretical approach, based on geometrical models (Giroud 1996), or by means of experimental methods (dry sieving, hydrodynamic sieving, wet sieving).

Important differences are reported among the different experimental methods: for example, Bathia et al. (1995) founded that filtration opening size obtained by means of dry sieving are generally 20% greater than opening size obtained both by wet sieving or hydrodynamic sieving.

Filtration opening size, moreover, can vary due to vertical effective stress and due to tensile stress; the variations can be very different depending on the compressibility and stiffness of used geotextile.

For example the effects of vertical effective stress on filtration opening size are remarkable for nonwoven geotextiles as showed by the theoretical studies carried out by Giroud (1996). These studies are summarized in figure 2 where the dotted curves are referred to the ratio between the mass per unit area $\mu_{GT}$ and the fibre density $\rho_F$ by the fibre diameter $d_F$ ( ratio typical of the different nonwoven geotextiles), while the continuous curves are referred to the different values of porosity n.

For a specific nonwoven geotextile, a compressive stress increment implies a porosity reduction (path from A to B) and definitely a filtration opening size reduction.

Vice versa, for a specific woven geotextile, due to the intrinsic structure, a compressive stress variation is not associated to a filtration opening size variation.

Also, the influence of tensile stresses on the geotextile filtration opening size has been the object of several studies developed by different Authors (Fourie & Addis, 1996, Moo-Young & Ochola, 1999). These studies have showed that filtration opening size of woven geotextiles strongly depends on strain level; lower sensitive to strain effects are viceversa the nonwoven geotextiles as shows in figure 3 (Moo-Young & Ochola 1999).

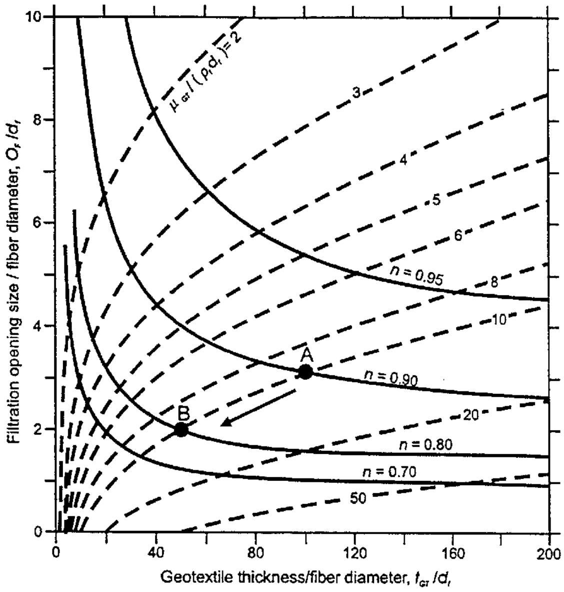


Figure 2. Effects of vertical effective stress on geotextile filtration opening size (Giroud, 1996).

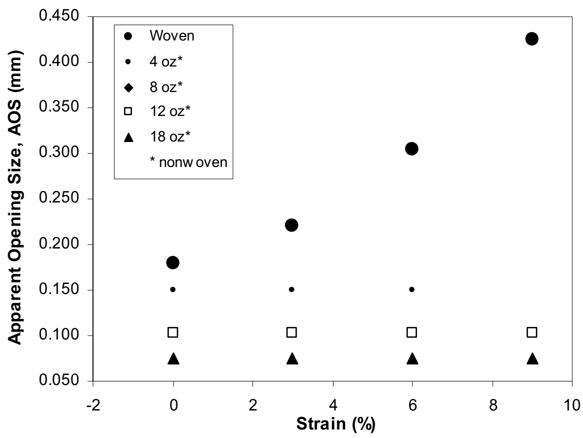


Figure 3. Effects of strain on geotextiles filtration opening size (Moo-Young &Ochola, 1999).

The influence of the hydraulic gradients and of the vertical effective stresses on filter stability was studied by the Authors using a new cyclic flow test apparatus capable to reproduce the stress and boundary conditions typical of real applications, with particular regard to bank protection (Cazzuffi et al.1999, Tondello 1997).

In previous papers (Moraci 1992, Mazzucato et al. 1994, Cazzuffi et al. 1999) the Authors showed the influence of vertical effective stress and gradients on the stability of the filter interface in steady and unsteady flow conditions.

In particular, in unsteady flow conditions it was emphasized that geotextiles with different stiffness have a different behaviour when loading conditions are varying (Fig. 4 and Fig. 5). Stiff geotextile, in fact, seems to be more sensitive to load variations (Fig.5). Moreover, the test results obtained clearly showed that the retention capability of geotextile filters (eroded soil mass) depends on the applied hydraulic gradient and on the vertical effective stress (Figure 6). It has also been shown that, if a geotextile is sand-tight, a stable soil-geotextile interface can reach instability, because of an increase in hydraulic gradient (path from A to C) or a decrease in vertical effective stress (path from A to B).

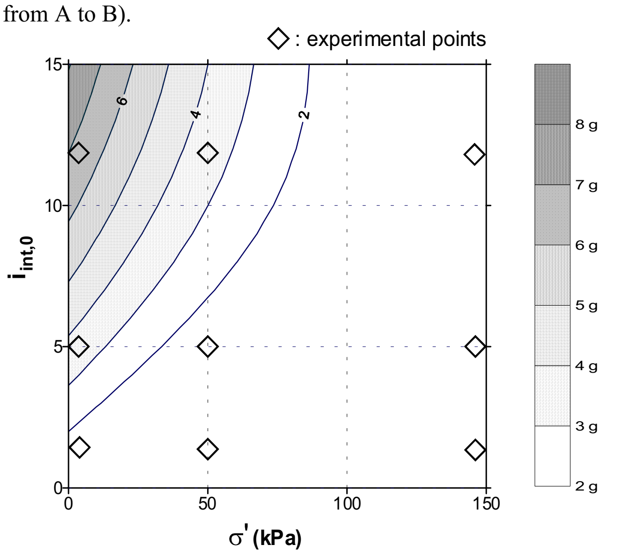


Figure 4. Passing soil mass measured in a filtration test carried out on a nonwoven needle-punched geotextile in contact with a fine sand (Cazzuffi et al. 1999).

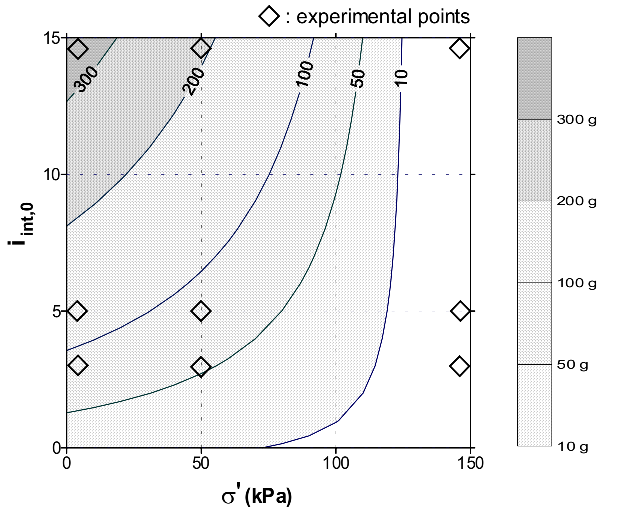


Figure 5. Passing soil mass measured in a filtration test carried out on a stiff woven geotextile in contact with a and fine sand (Cazzuffi et al.1999).

Another fundamental aspect is represented by the continuity of the contact between the base soil and the geotextile filter: this contact depends on the construction technology, on the density of the base soil and on the deformability of geotextile filter.

In particular, figure 7 shows the specific role played by the three above mentioned factors.

Figure 7 is in fact related to bank revetments with loose granular base soil in which the cover layer is placed directly in contact with geotextile filter: in such circumstances, the energy of the impact due to the cover layer placing may create remarkable deformations in the base soil, depending on the deformability of the geotextile filter.

For nonwoven needle-punched geotextiles (right side of figure 7), the deformability of the filter layer allows to follow the deformation induced by the cover layer placing, without generating important tensile stresses in the geotextile and also without a changing the value of the filtration opening size.

For woven geotextiles (left side of figure 7), important tensile stresses are induced in the filter layer, thus generating not negligible variation in the value of filtration opening size.

With special reference to the "flapping" phenomenon, laboratory tests performed by the Authors (Cazzuffi et al. 1999) showed for woven geotextiles a reduced capability to follow the deformation of the base soil, thus generating a greater area exhibiting no contact with the base soil, compared to the nonwoven needle-punched geotextiles behaviour.

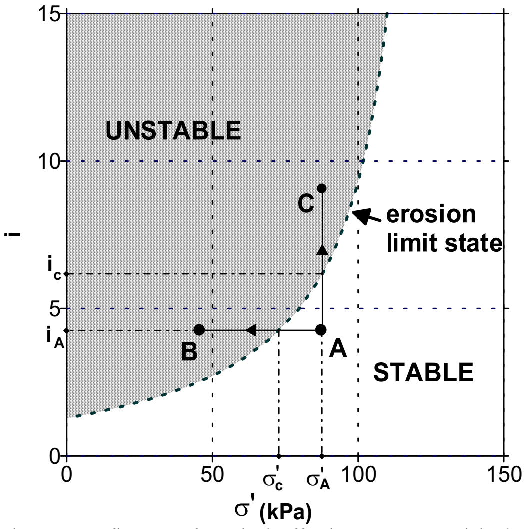


Figure 6. Influence of vertical effective stresses and hydraulic cyclic gradients on geotextiles filter stability (Cazzuffi et al., 1999).

In the case of bank revetments with dense granular base soils, the cover layer placing is usually inducing small deformations in the soil itself. Therefore, in those cases, both nonwoven and woven geotextiles may be used as filter layer, taking into account the good behaviour of both types in ensuring an "intimate" contact with the base soil.

In any case, also in order to avoid possible phenomena of localized detachment and to prevent piping, it's advisable to place after the geotextile a layer of sand, before the cover layer: this sand layer, as illustrated in figure 8, could distribute the stresses in the transition zone and could also ensure a continuous contact between base soil and geotextile filter.

## CONCLUSIONS

The following conclusions refer to the use of geotextile filters in unsteady flow conditions, only in the cases, where the base soil is represented by stable granular soils.

In such circumstances, two possible situations could be defined:continuous contact between the base soil and the geotextile filter;discontinuous contact between the base soil and the geotextile filter.

In the first situation (continuous contact), the different retention criteria proposed by the various Authors are applicable with a certain degree of confidence, provided that for the determination of the filtration opening size the same test method proposed by the specific Author should be adopted.

In these conditions it seems that also the less restrictive steady flow retention design criteria may be applied.

In the second case (discontinuous contact) flapping occurs. In the flapping zone the vertical effective stress becomes equal to zero so liquidization occurs and the particles of base soil become completely free to move. This occurrence can be related to the following factors: placement of geotextile, characteristics of underlying and overlaying layers, stiffness of geotextile, interaction between vertical effective stress and hydraulic gradients.

In such circumstances, typical of discontinuous contact, the different retention criteria proposed by the various Authors are

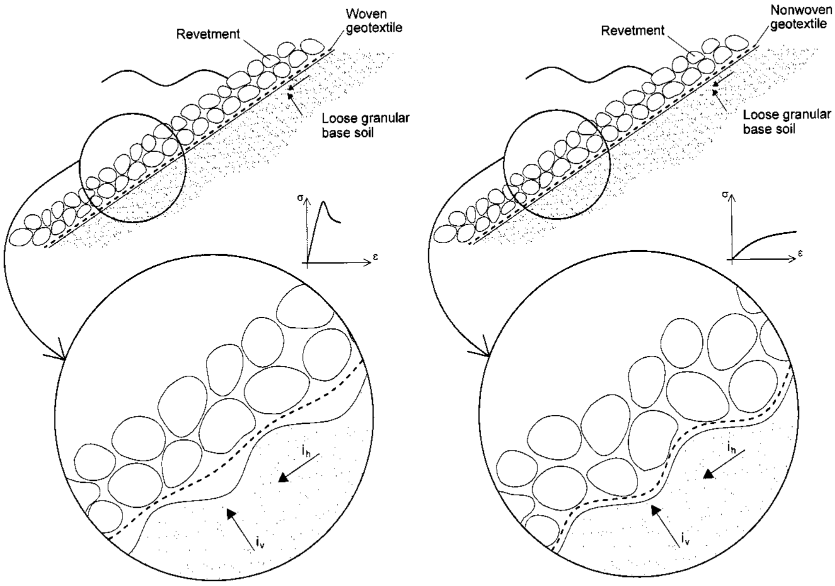


Figure 7. Schematic representation of different type of contact in bank revetments with loose granular base soil.

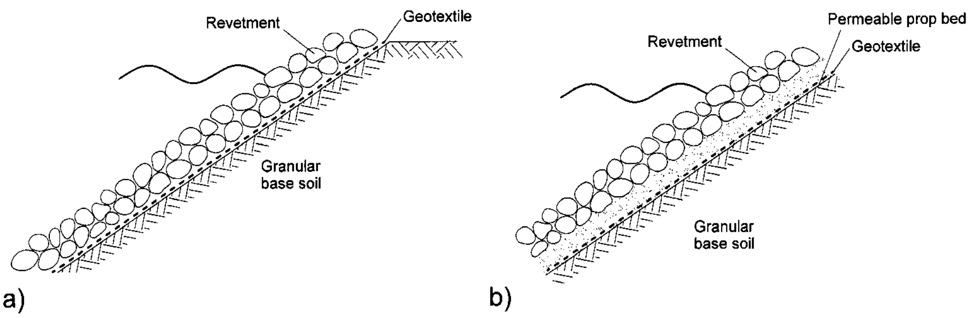


Figure 8 Different bank revetments schemes: a) not suggested, b) suggested.

not applicable, as already emphasized in some experimental studies (Cazzuffi et al. 1999): it is therefore suggested to adopt any solution that could contribute to avoid or limit the discontinuity on site. In the case of loose base soils, with irregular banks, it is believed that less stiff geotextiles have a better performance for good adaptability to the irregularities of base soil and also for maintaining the same filtration opening size, even in presence of deformations induced by the cover layer placing.

For loose base soils, it is always good practice to place a sand layer (figure 8) before the cover layer placement.

Finally, to take into account any possible variation of filtration opening size of nonwoven geotextile due to the effective vertical stresses applied on the interface geotextile filter - base soil, it should be advisable to make reference to the theoretical consideration proposed by Giroud (1996).

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