Examples of river bank and coastal protection by a new two-layer filtration system

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ABSTRACT: The severe hydraulic conditions that are met on hydraulic constructions for river or marine protection require appropriate structures against external and internal erosion. The hydraulic energy is broken up and dissipated inside the external revetment (rip-rap, gabions or concrete slabs), while the risk of internal erosion due to the outflow from the bank is controlled by the filtration layer. This filtration layer is commonly made with geotextiles. They must be designed to stabilise the underlying soil formations and at the same time resist damage when the external revetment structure is installed. There are many possible combinations, but the use of a two-layer composite filtration system, which combines in the same product a filtration layer and a protection layer, offers higher stability of the hydraulic constructions and a greater ease of installation, specially in difficult conditions of installation.

1 INTRODUCTION

Hydraulic structures such as reservoirs, dams, river banks and coastlines are subjected to severe hydrodynamic stresses. Where exposed these embankments need to be stabilised by appropriate protection systems. These comprise two distinct parts, which fulfil different functions.

The outer part must absorb and deflect the hydraulic energy of the waves. This part generally includes aggregates or prefabricated concrete elements, the mass of which is proportional to the hydraulic energy they have to dissipate. On the coast, rip-rap used for such structures may exceed several tonnes.

The layer below these blocks, which is in direct contact with the natural ground formation, has a completely different function. It must prevent the soil from being eroded by water flowing out of it in rhythm with the tides. This function is referred to as filtration. Granular filters consisting of layers of aggregates of outwardly increasing grain size have frequently been used for this function up to now. They work well provided they are properly designed and, more importantly, properly built, as it is essential to ensure precise grain size ratios and minimum thickness between the various layers.

Geotextiles are reliable, economic alternatives to these multiple-layer granular filters. As they are manufactured products, they are often subjected to strict quality control procedures of the ISO 9001/9002 standards, and are accompanied by a guarantee of quality such as those delivered by the ASQUAL organisation in France. They are simpler to use, quicker to install and can also replace several layers of a granular filter by themselves.

Nevertheless, the use of standard geotextile may have some limitations due to bad long term filtration performance or difficult installation. That is why a specific filtration system has recently been developed for internal erosion control applications only. After a short review of the general design principle, this paper describes, from several old or more recent case histories, the benefits of using an optimised two-layer filtration system.

2 FUNCTIONAL DESIGN OF FILTRATION SYSTEMS

Any geotextile used in a structure has a well-defined function, which means that a number of very specific characteristics have to be carefully determined. These are conventionally grouped into three categories according to role, as shown in figure 1.

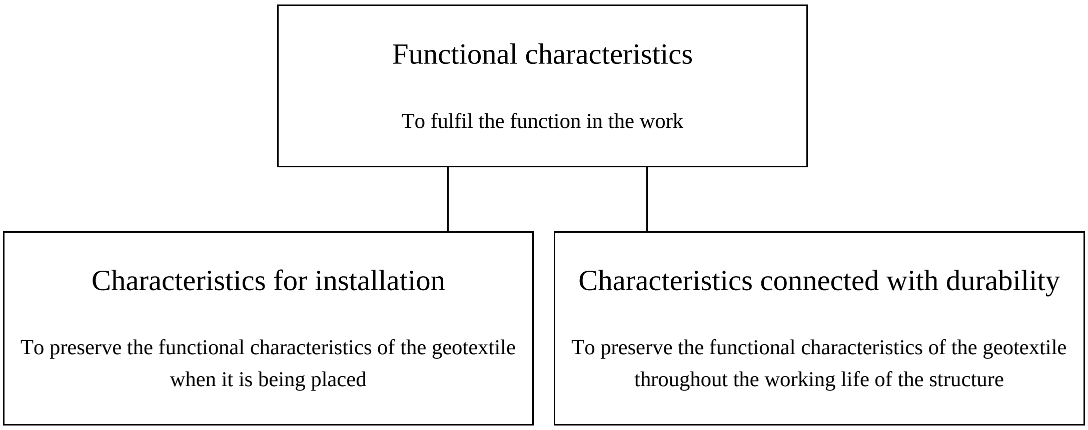

Figure 1. General procedure for designing geotextiles : the role of the 3 groups of characteristics

The function of a geotextile in bank protection is to provide filtration : its role is to stabilise the surface structure of the soil to avoid internal erosion while at the same time allowing water to circulate freely at all times. The functional characteristics that need to be determined in order to fulfil this role are: filtration opening size, number of constrictions, flexibility and permeability. Delmas et al. (2000) have justified the reasons of these characteristics.

However, correct design of the geotextile is no guarantee in itself of an effective filtration system. As emphasised by J.P. Giroud (1997):

- poor installation may prevent even the best filter from working,
- a geotextile filter must withstand stresses that are likely to damage it.

Indeed, the functional characteristics of a geotextile must not be lost during the works phase or in the long term. The actual placing operation is vitally important, especially for bank protection, as the geotextile itself must be properly laid on the ground and damage avoided when the outer structure is placed; this often consists of sharp rocks that generate a high level of energy.

These two aspects will be examined in detail by considering several actual examples.

3 GEOTEXTILE ALONE : AN INEFFECTIVE SOLUTION

The first geotextile used to protect the upstream facing of an earth dam was installed in the Valcros dam in the south of France in 1970. Several structures were tried on successive pilot sections as the dam was being built, including one with the geotextile alone sewn together and fixed to the ground with metal pins, and one with the same geotextile covered by small rocks 250 mm across (Fig. 2). The results of these tests are described in detail in Giroud et al. (1977). They show that the section of embankment covered with geotextile alone had changed shape after a few months' service, with a step-like structure forming in the area affected by waves (Fig. 3). The rise and fall of the geotextile under the effect of the waves progressively eroded the underlying ground, which was then no longer stabilised. This test area was subsequently rebuilt with rip-rap.

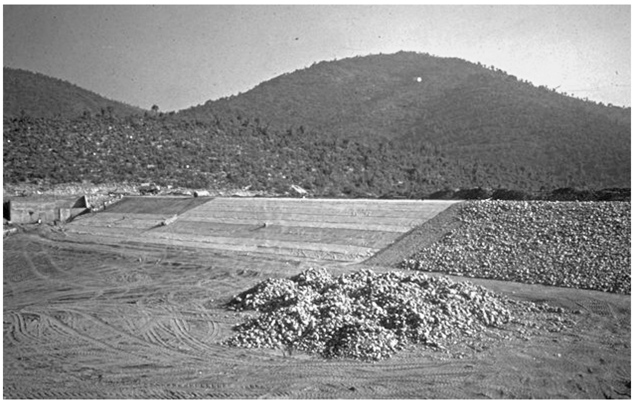

Figure 2. Valcros : installation of the geotextile and of the rip-rap protection structure on the upstream face of the dam.

Figure 3. Valcros : Step-like deterioration of the upstream facing under the "geotextile only" test zone.

A filter layer consisting of geotextile alone is therefore ineffective in protecting a bank. The geotextile must always be covered with a "heavy" outer layer to dissipate wave energy and ensure that its profile follows the ground, as only perfect contact between the filter system and the ground will create a self-filtering granular structure that is stable and lasting. The role of this layer is also to protect the geotextile against ultraviolet radiation, as any geotextile exposed to light will deteriorate in time.

4 GEOTEXTILE FILTER AND OUTER RIP-RAP LAYER

Monitoring of Valcros dam since it was built and the excellent condition of samples of the needle-punched nonwoven geotextile of continuous filaments taken from the site after 22 years' service clearly reveal the effectiveness of the geotextile + rip-rap solution (Faure et al. 1996). It is true that this type of structure is now widely used for both river bank and coastal protection schemes.

4.1 *Risks of damaging geotextile during placing*

The geotextile filtration systems in this type of structure are subjected to high mechanical stresses when the outer rip-rap layer is being placed. Analyses of several sites in Europe and Asia by Delft Hydraulics laboratory have shown that these stresses are severe (Mannsbart, Christopher 1997).

The marks left for example on the filter geotextile protecting the sandy beach at Lacanau (France) show that deformation has exceeded 50% in places (Fig. 4-5). With an higher level of elongation at maximum force (measured on a 20 cm wide strip), this needle-punched nonwoven geotextile has not torn, and the filter structure has therefore remained continuous.

Figure 4. Lacanau : reverse imprint of a rock placed on the geotextile.

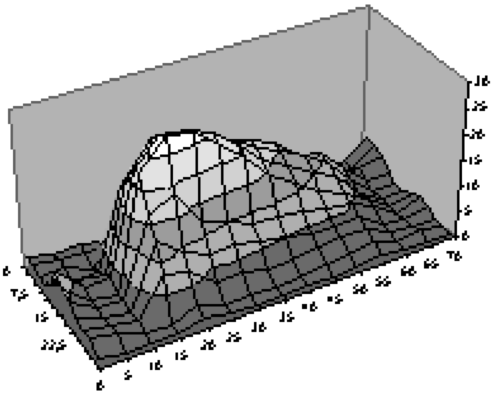

Figure 5. Lacanau : analysis of geotextile deformation.

4.2 *Possible protection of the geotextile against damage by rip-rap*

In addition to a minimum elongation value before failure, other features of the geotextile are important in withstanding damage during placing, and in particular its resistance to static puncturing. Indeed, in certain situations the rip-rap in contact with the geotextile may have been obtained from crushed hard rocks and have sharp edges.

4.2.1 *The secondary layer is not a protection layer*

The risk of puncturing is particularly serious when the outer structure comprises two layers of stones: an outer primary layer consisting of large rocks that are intended to remain stable when exposed to the often severe hydraulic conditions along the seaboard, placed on a secondary layer consisting of smaller rocks. The latter, which are often crushed and angular, sink into the geotextile and the ground when the large rocks are placed on them, creating a "hammer and punch" effect. One conclusion of the extensive study carried out by Chew et al. (1999) to evaluate the damage of different geotextiles submitted to stone drops confirms that the stresses on the geotextile are much higher with a secondary layer than without secondary layer.

4.2.2 *Protection with a layer of fine soil*

Using a layer of fine material is certainly effective in protecting the geotextile but the fine particles may be eroded by the waves and destabilise the rocks that it supports, causing the blocks to move and risking abrasion or tearing of the geotextile. Therefore, if the filtration criteria to stabilise the fine soil by the upper stone layer are not reached, the protection by a layer of fine soil must be prohibited.

If a granular protection layer is absolutely required, the filter stability rule between the protection layer and the stones of the revetment must be fulfilled. This solution was for example chosen for the coastal defence works at Newtownards in Northern Ireland, where a 30 cm conforming layer of coarse gravel with some cobble sized material was introduced between the geotextile filtration system and the layer of small secondary rocks having an average mass of 125 kg (Fig. 6). The primary layer was built with 1-2 ton rocks. In these conditions, a geotextile resistance to pyramid-die puncturing of 3 kN (NF G 38019) was sufficient.

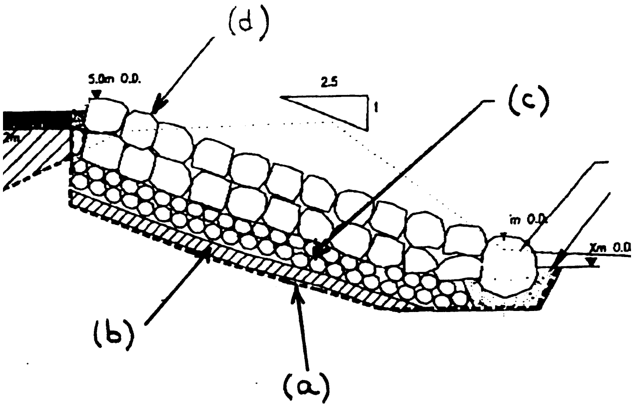

Figure 6. Newtownards – cross-section : (a) two-layer needle-punched nonwoven filtration system; (b) gravel intermediate layer; (c) secondary layer of 125 kg rip-rap; (d) primary layer of ½ ton rip-rap.

4.2.3 *Protection with another geotextile*

Another technique involves using two superimposed geotextiles. The first is designed to meet the functional requirements of filtration. It is covered by a second that is intended purely to protect it. This solution was used, for example, to protect the banks of reservoirs along the side of Sainte-Croix lake at Les Salles-sur-Verdon in France (Degoutte 1987). To prevent the fine soil in the embankment from being eroded by waves and water flowing from the reservoir into the lake, the geotextile filtration layer had small filtration opening size. This was covered by a thick geotextile protection layer able to withstand damage by the outer layer of 500 kg rip-rap placed by mechanical shovel (Fig. 7). Test sections that were later uncovered demonstrated the need for and the efficiency of this double geotextile structure. The technique also proved to be economically attractive in relation to a protective layer of small gravel.

Figure 7. Salles-sur-Verdon : rip-rap laid on the geotextiles for protection (black) and for filtration (grey).

This solution has nevertheless an important technical limiting factor with respect to the superimposition of two geotextiles : the stability of the structure on the slope. The friction angle between two geotextiles is indeed often small, and the entire structure may slide at the interface between the two geotextiles. This solution can therefore only be used on gentle slopes, and in any case, the stability of the structure must be checked.

4.2.4 *An innovation : the two-layer filtration system with integrated protection*

A new geotextile filtration system has been developed to improve the level of confidence required in case of critical hydraulic works, such as dams, dikes and reservoirs, in which malfunctioning of the filter may have severe and costly consequences. From a technical background based on the producer’s long experience from old sites, but also from the most recent research on geotextile filter behavior, providing both theoretical analysis and experimental validation, enhanced filtration properties have been defined, improving both functional characteristics and resistance to mechanical damage.

The improvement of the filtration function has been achieved by adjusting the maximum opening size and the thickness of the filter within an optimum range of variation. The optimum thickness, which depends on the nonwoven structure, can be more generally expressed in term of an optimum number of constrictions.

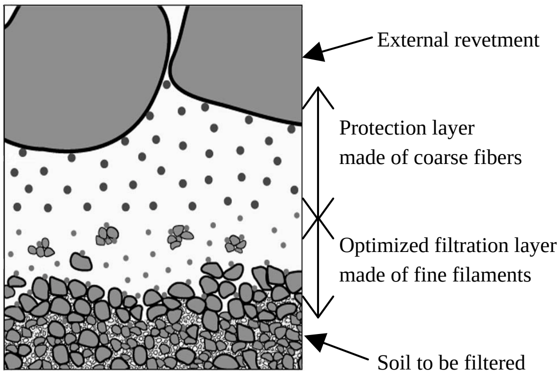

Figure 8. Concept of the two-layer geotextile filtration system

On the other hand, high installation stresses require sufficient mechanical properties, i.e. minimum elongation and minimum resistance to static and dynamic puncturing. This last characteristic is usually met by increasing the thickness of the nonwoven, which may cause problems if this modifies the optimization of several functional characteristics of the geotextile filter, i.e. opening size, number of constrictions, permeability.

To combine both functional and installation requirements, a new concept of two-layer needle-punched nonwoven filter has been developed (Fig. 8). This composite filtration system of completely innovative design, comprises a functional filtration layer made of thin continuous filaments to ensure that the ground is perfectly stabilised, and a needle-punched nonwoven protection layer of larger filaments that does not affect the filtering properties of the functional layer. The characteristics of each layer are :

- A functional layer with optimum filtration properties: (1) optimised range of opening sizes: $40 \leq O_{100} \leq 80$ µm; (2) optimum range of constrictions of the filter layer : $25 \leq m \leq 40$; (3) higher permeability than single layer geotextiles; (4) the usual flexibility of needle-punched nonwoven;
- A second protection layer, adjustable to the site conditions, which increases the mechanical properties of the geotextile to protect the functional layer against stresses due to the installation of the stones, and without interaction on the functional characteristics of the filtration layer.

This system has been successfully used in several hydraulic constructions to solve problems of stability and installation.

5 EXAMPLE OF USE OF THE TWO-LAYER FILTRATION SYSTEM

5.1 *Two-layer with rip-rap layer*

5.1.1 *Biarritz coast protection*

A secondary layer of small rocks may nevertheless be essential to build the external revetment for various reasons: need for protection against ultraviolet radiation, width of available area, impossibility of positioning several layers of primary rocks, etc.

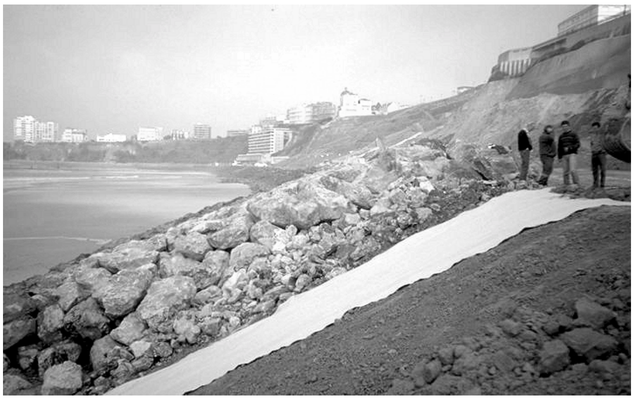

Figure 9. Biarritz - Côte de Basques : Two-layer geotextile filtration system covered by two layers of secondary

This type of structure was designed along the Basque Coast at Biarritz, France, for the stabilisation of the base of the cliff. The marls in the area are attacked by the waves, causing the strata to separate. The cliff often collapses and the sea is seriously eroding the land. The designed structure included (Fig. 9):

- a two-layer filtration system,
- covered by a secondary layer of small rocks (50-150 kg)
- and a primary layer of 3-6 t rocks.

The small rocks were dumped from the top of the cliff, and the large ones placed by hydraulic shovel with a drop height between 0.5 to 1 m. Because of the rough way in which the rocks were placed, it was necessary to place a two-layer composite filtration system made of needle-punched nonwoven of continuous filaments with a resistance to pyramid-die puncturing of 4 kN according to standard NF G 38019 and elongation of over 80% according to standard EN ISO 10319. Because of this combination of characteristics, the geotextile was not damaged.

Without a secondary layer, additional tests on this site showed that it was possible to increase the drop height of the primary stones from less than 1 m to about 4 m, without damaging the composite filtration system.

5.1.2 *Valras-Plage sea breakwaters*

The use of a two-layer composite filtration system also avoids :

- the risks of inverting the two geotextiles on the job site
- the risks of slope instability,

but also facilitates and reduces the cost of placing two different geotextiles, particularly in difficult conditions, such as under water or when there are currents.

These advantages were undeniable for the contractor for building 5 offshore breakwaters at Valras-Plage in the south of France in comparison with a solution involving two different geotextiles. The core of the breakwater was to be covered by a functional filtration geotextile, which was itself to be covered by another protective geotextile in order to withstand the forces created when placing the 2 - 5 t rip-rap layer (Fig. 10). The filtration system chosen was F 70. This two-layer system made it much easier to construct the breakwaters in difficult conditions in the sea.

Figure 10. Valras-Plage : placing of rockfill on the filtration system (rolled in the front of the job zone due to the very small working area).

5.1.3 *Pembrey coastal protection*

A two-layer filtration system of the same type was used along the seafront at Pembrey Coastal Park in Swansea, South Wales (UK). However, at this site, although the geotextile is in contact with rocks of identical mass to those at Valras-Plage, the method used was less aggressive. The rocks were first placed vertically to build a wall, and the filtration system was then applied against it (Fig. 11). The double-layer system therefore included the same optimised filtration layer, while the resistance of the protection layer to pyramid-die puncturing could be reduced to 2 kN (NF G 38019).

It may be noted that another geosynthetic (reinforcement composite) was used at the base of the embankment. This was not for filtration purposes but to reinforce the foundation. In this case, the geotextile needs to have greater tensile resistance to differential settlement.

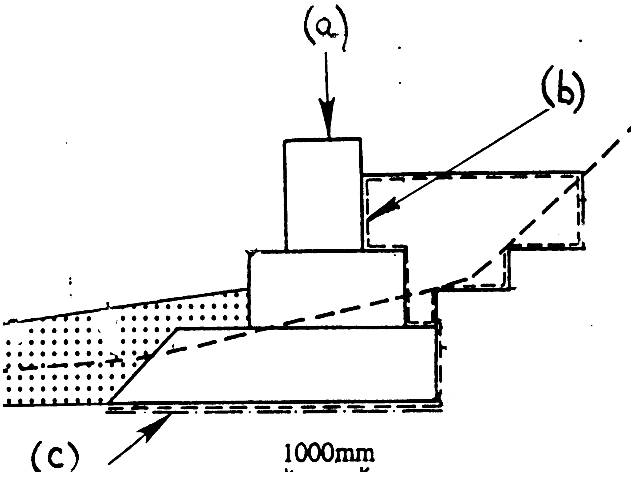

Figure 11. Pembrey cross-section : (a) rip-rap wall; ((b) geotextile for filtration; (c) geotextile for reinforcement

5.2 *Two-layer system with outer gabion structure*

Other external structures may replace rip-rap when hydraulic conditions allow. This is the case with gabions used to protect the banks of rivers or canals. Gabions and the stones they contain are less aggressive with regard to geotextile filtration systems.

This bank protection technique was used to rehabilitate the wide-gauge Dunkirk-Valenciennes canal along the banks of the Escaut at Haulchin in northern France (Fig. 12). The 910 m outer gabion structure consists of a Reno mattress placed on the bed of the redesigned canal, and two gabion cages. The bottom side of the mattress and the vertical part of the gabions in contact with the fill were lined with a double-layer filtration system identical to that of the Pembrey project.

As the lower part of the bank is under water, the mattress was fabricated first of all in the dry on the bank and then positioned at the bottom of the canal, using a lifting apparatus.

Figure 12. Valenciennes : Two-layer filtration system in contact with gabions along the Trith canal.

5.3 *Installation underwater*

Placing methods have to be adapted when work is being carried out under water. In particular, it is essential to take care in positioning the filtration system properly on the bed, and to make sure that it is continuous. No patch of ground must be left uncovered.

One way is to overlap the separate lengths of geotextile. In this case, it is preferable to ballast them so that they can be positioned more easily under water, especially if there is any current. In the case of the Meghna Bridge project, 25 km from Dhaka in Bangladesh, metal bars were sewn right across the lengths of geotextile at 5 m intervals. A special platform was built on the bank to help in carrying out this work. One end of the geotextile is then drawn by a barge on to the water (Fig. 13), while the other end is held on the bank. The geotextile then sinks slowly to the bottom and the rip-rap is poured from another barge. Divers check that the geotextile is correctly placed on the bottom.

A similar method was used to repair the banks of the river Hérault at Pézenas, in France. However, as there was less bank to cover, the ballasted strips were positioned by a long-armed shovel and diver (Fig. 14).

Another alternative is to sew the various lengths together. It is then simply a question of deploying the sheet using barges, as was done for the extension of runway no. 1 at Marignane airport, Marseille, France, which is built on the shores of the Etang de Berre. The stitching is strong enough to ensure that the filtration structure is continuous (RGRA, 2000).

Figure 13. Dhaka : installation of the ballasted filtration geotextile

Figure 14. Hérault river : installation of the ballasted two-layer filtration system by a diver.

6 ANOTHER ALTERNATIVE: THE OUTER STRUCTURE COMBINED WITH THE FILTRATION SYSTEM

In the absence of rip-rap, or when the structure has an awkward shape, complete bank protection systems can be used, combining the geotextile filtration structure and the outer protection in a single product. The latter generally consists of concrete slabs or blocks fixed on the geotextile. This technique was to stabilise part of the new port at Ravena, on the Adriatic coast of Italy. The filtration structure consists of a needle-punched nonwoven geotextile of continuous filaments meeting the ground filtration criteria, on to which reinforcement cables were knitted to support concrete blocks. This composite and its installation are described in Sarti et al. (2000).

7 CONCLUSION

The geotextile filtration technique offers numerous advantages in terms of adaptability, giving geotextile manufacturers considerable potential to innovate and adapt to local site constraints.

For example, a two-layer filtration system combining an optimised filtration layer and a protection layer adjusted to the external mechanical stresses gives the geotextile:

- An enhanced polyvalence towards the majority of the soils to be filtered;
- A higher tolerance towards in-situ soil heterogeneity;
- A higher safety level for the hydraulic works : long-term-filtration behaviour and stability of the structure;
- Ease of installation : one composite product instead of 2 different layers, specially under difficult installation conditions.

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