ABSTRACT: The first earthdam using geotextile filters was built in 1970. Afterwards, several other dams were built using geotextiles, but many more using the conventional granular filter solution: designers believed that the level of reliability of standard geotextiles was not sufficient in comparison to the level of safety required by these works. From studies carried out in the last decade, a new geotextile filtration concept was therefore developed, resulting in a two-layer filtration product with optimized properties leading to safer conditions of use. Examples of several dams recently built with this improved filtration system are described in the paper.

1 INTRODUCTION

The first earthdam using geotextile filters instead of granular filters was built in Valcros (France) more than 30 years ago. The geotextile filters were installed both around the drainage trenches at the bottom of the dam and under the rip-rap layer on the upstream slope.

Afterwards, several other dams were built using geotextiles, but many more using the conventional granular filter solution, because designers estimated that the level of reliability of standard geotextiles was not sufficient in comparison to the level of safety required by these risky hydraulic works, such as dams and dykes, which require products with a high level of reliability to give the highest possible safety. One of the most common functions fulfilled by geotextiles inside these hydraulic works is filtration. Failure or malfunctioning of the filtration system, caused either by soil piping or by filter clogging, may have severe and always costly consequences. For such structures, users therefore require product with the highest possible level of confidence.

The filtration function, which involves intricate interaction mechanisms between soil particles and geotextile fibres, is certainly one of the most complex among all the functions fulfilled by geotextile products. A lot of studies and research have been carried out around the world to evaluate the behavior of geotextiles used for the filtration function, both in the laboratory and in the field, and to define design criteria.

From these published or unpublished studies, a new geotextile filtration concept was developed based on all the available information on this topic, including deep analysis of works after several years of use and sampling of products, theoretical modelling, laboratory and on site testing. The result is a specific filtration system with optimized properties leading to safer conditions of use: higher tolerance to soil heterogeneity, ease of installation, safe design guidelines. These improvements were judged of utmost importance by the designers of recent hydraulic projects requiring a high level of safety.

This paper describes first the background and the development of the optimized filtration concept. Then 4 recent dams in which this filtration system has been installed are described.

2 DEVELOPMENT OF AN IMPROVED FILTRATION CONCEPT

The development of this specific geotextile started from an analysis of several old sites in Europe and Asia submitted to different hydraulic conditions and soil characteristics. On these sites, needle-punched nonwoven have been installed for the last 5 to 30 years as filters either around drainage structures or as filters for internal erosion control on river banks, dams, and marine coasts. The main direction of product improvement was defined from the results of the analysis of these old works, both as regards the long-term filtration behavior of the geotextile (functional part), but also on its resistance to mechanical damage (during and after installation).

2.1 Observations on the Valcros dam

The Valcros earth-dam built in the South of France in 1970 is a major reference work: a geotextile filtration system was installed for the first time in a dam both around the toe drainage trenches (Figure 1) and under the rip-rap layer laid on the upstream dam slope (Figure 2).

The behavior of these geotextiles is fully documented because several excavations and investigations were carried out 6 years (Giroud et al. 1977) and 21 years after installation (Faure et al. 1996).

During the last investigation, cross sections of the geotextile samples were analyzed in a transmission microscope. Figure 3 shows an example of these cross-sections: the soil particles of the dam to be filtered (white spots) are stabilized by the first layers of filaments of the needle-punched nonwoven geo-textile (black dots). The particles cannot move because they are confined close to the interface, between the upstream soil and the downstream filaments of geotextile which apply a reaction force on them.

Inside this interface zone between the soil and the geotextile, it has been observed that there are fewer fine particles than in the

Figure 1. Valcros dam during construction in 1970. Installation of the geotextile filter around the drainage trenches.
natural soil itself: a highly permeable soil structure corresponding to a granular filter has been built. In spite of reversing flow, arching of particles between the filaments can be seen: the soil skeleton (the coarser soil particles in contact with one another) build bridges over the filament constrictions which maintain the equilibrium of the whole soil upstream. The finest particles of the soil in contact with the geotextile have been eroded and washed out of the geotextile by the flow.

The transition zone, where the particle stabilization occurs, corresponds to a small thickness of filaments, in this example less than 1 mm with the structural characteristics (filament size, porosity) of the nonwoven sampled.

Furthermore, the geotextile thickness downstream the transition zone can be considered as not useful for filtration purposes, but on the other hand decreases the geotextile water permeability and increases the risk of internal clogging.

2.2 Improvement of the short-term and long-term functional properties

From this example, which has been confirmed in other situations, some important points can be made to improve the functional performances of a geotextile filter:

- the geotextile is a catalyst for filtration: it helps to stabilize the coarser particles of the soil (the skeleton) which should not move, otherwise the soil particles are destabilized;
- this catalytic action is an interface phenomenon: only a minimum number of filament layers is necessary;
- this phenomenon is only possible if the geotextile filaments are in intimate contact with the soil surface: the geotextile should be flexible enough to conform to the soil roughness;
- the finest soil particles contained inside the arches at the interface must be washed in suspension through the geotextile: a very thick geotextile or a geotextile with very low opening sizes may block these particles and increase the risks of internal clogging.

These qualitative observations were expressed as optimum values of geotextile characteristics (Delmas et al. 2000):

- an optimum range of opening sizes has been defined firstly to be able to filter the majority of soils, and secondly to avoid the risk of clogging by the finest particles transported in suspension;
- the optimum thickness, which depends on the nonwoven structure, can be more generally expressed in term of an optimum number of constrictions. The number of constrictions “m” is found to be a more general parameter than the thickness, as it can be used for all nonwoven structures: it is a dimensionless parameter which includes in addition to the thickness the structural characteristics of the nonwoven ( fibre size and porosity). The relationship established by Giroud (1996) to calculate this number of constrictions “m” is very simple:

\[
m = \sqrt{(1 - n) \frac{t_{GT}}{d_f}}
\]

where \( t_{GT} \) = geotextile filter thickness (m); \( d_f \) = fiber diameter (m); and \( n \) = geotextile porosity (-):

\[
n = 1 - \frac{\mu_{GT}}{\rho_f \cdot t_{GT}}
\]

where \( \mu_{GT} \) = mass per unit area of the geotextile filter (kg/m²); and \( \rho_f \) = density of the fiber (kg/m³)

- an optimum range of number of constrictions has been defined to guarantee firstly the homogeneity of the filtration opening size of the geotextile, and secondly, the stabilization of the soil skeleton near the soil-geotextile interface to reduce the risk of internal clogging.

These rules can be described by the following complementary relationships:

1. \( 40 \mu m \leq O_{100} \leq 80 \mu m \),
2. \( 25 \leq m \leq 40 \);

where \( O_{100} \approx O_{0,w} \), the largest opening size of the geotextile measured according to ISO 12956; and “m” the number of constrictions.

2.3 Improvement of the characteristics for installation

A perfect filtration system may fail if it is damaged during installation: holes, tears or localized puncturing may be caused by rip-rap stones dropped on the geotextile or by the angular gravel of a drainage trench: characteristics for installation must be therefore designed to preserve the functional properties of the geotextile when it is being placed.

An analysis of several old hydraulic works in Europe and Asia (Mannsbart & Christopher 1997) has shown that the mechanical stresses applied on the geotextile during or after installation were sometimes very high, but this risk of damage was unfortunately not often taken into account in the past when the geotextile was specified or chosen. This situation is certainly due to the lack of design tools available to estimate installation damage.
Recently, several laboratories have undertaken experimental programs on real sites to evaluate the damage inflicted on geotextiles by dropped stones (Caquel et al. 1999; Chew et al. 1999). Even allowing for differences in test methodology, (use of real stones or concrete pyramids, drop of the stone directly on the geotextile or on a secondary layer, uniform fine subsoil or heterogeneous soil with gravel, horizontal or slope), the general results are comparable and complementary. In term of product improvement, they can be summarized as follow:

- the drop energy of the block is an important damaging parameter;
- the soil stiffness plays a major role in dissipating this energy by deforming;
- a secondary layer of smaller stones increases the stresses on the geotextile;
- the tensile strength is not a design parameter;
- the elongation at maximum strength is very important in case of soft soil: the geotextile must penetrate with the block into the soil without tearing; deformations measured on the geotextile were more than 50%.

On stiff soils or in case of heterogeneous soils mixed with stones, the resistance to localized damage (static or dynamic puncturing) is very important.

2.4 The optimized geotextile filtration system

In case of stiff or coarse soils, the resistance to puncturing of the geotextile must be adapted to the external stresses which depend on the method of installation and on the site conditions (drop height, shape and weight of the stones, secondary layer). An increase of these mechanical properties is commonly obtained by increasing the mass of the product. But an increase in the mass and the thickness of the geotextile means an increase in its number of constrictions. This may influence the functional properties of a geotextile filter which has been previously optimized: change of opening size, decrease in permeability, risk of internal clogging if \( m > 40 \).

To combine both functional and installation requirements, a new concept of two-layer needle-punched nonwoven filter has been developed (Figure 4):

- one functional layer with optimum filtration properties: (1) optimized range of opening sizes: 40 \( O_{100} \) 80 \( \mu m \); (2) optimum range of constrictions of the filter layer: 25 \( m \) 40; (3) higher permeability than homogeneous products; (4) the 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.

These characteristics give the geotextile:

- a higher tolerance towards in-situ soil heterogeneity;
- a higher safety level for the hydraulic works.

Finally, from a high level technical background, a new geotextile has been produced combining enhanced functional properties, safer behavior, and simplified use. This new range of products named “bidim F”, “F” as filtration, has been used for several years in many hydraulic applications, such as river and canal banks protection or coastal protection, and as internal erosion control in dams and dikes. The following section describes 4 different dams recently built with this filtration systems range of the latest generation.

3 EXAMPLES OF USE OF THE IMPROVED FILTRATION CONCEPT IN DAMS

3.1 Sidi M’Hamed Ben Taiba - Algeria

The National Algerian Dams Agency (ANB) decided on the construction of this large earthen dam for water supply and irrigation in the area of Ain Defla, about 150 km South-West of Alger. The Hydraulic Engineering Center of EDF is in charge of the execution studies and of the on-site control. The contractor COSIDER started the construction in 1998, and it should be finished in 2003.

The dam has a storage capacity of 75 million of \( m^3 \), and is 64 m high, corresponding to a total volume of embankment of about 2.5 million \( m^3 \). The geology of the subsoil is very complex, including fine materials and cracks.

The cross section of the dam is shown on figure 5. The main dam is built around a central clay core 64 m high, supported on both sides by two embankments made of stones and gravel \( (d_{50}=5/100 \ mm) \), and upstream rip-rap layers.

The toe of the upstream embankment is stabilized by a 22.5 m high cofferdam built with the same material, including a clayey upstream cutoff placed under rip-rap made of stones of about 500 kg maximum.

Figure 5: Cross section of the Sidi M’Hamed Ben Taiba dam.

Figure 6: Schematic cross section of the upstream cofferdam of the Sidi M’Hamed Ben Taiba Samira dam.
Table 1. Main characteristics of the geotextile filtration systems used.

<table>
<thead>
<tr>
<th>Protection layer (two-layer)</th>
<th>GT1</th>
<th>GT2</th>
<th>GT3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filtration opening size ISO 12956 μm</td>
<td>100</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Number of constructions Giroud, 1996</td>
<td>25-40</td>
<td>25-40</td>
<td>25-40</td>
</tr>
<tr>
<td>Velocity index ISO 11058 mm/s</td>
<td>85</td>
<td>60</td>
<td>45</td>
</tr>
<tr>
<td>Pyramid puncture resist. NF G38019 kN</td>
<td>0.9</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Elongation ISO 10319 %</td>
<td>80/70</td>
<td>85/85</td>
<td>85/85</td>
</tr>
</tbody>
</table>

The drainage system of the dam made of coarse gravels 20/80 mm consists of:
- a drainage blanket at the bottom of the downstream embankment;
- vertical drainage chimneys on each side of the clayey core;
- horizontal drainage trenches installed at two different levels inside the upstream main embankment.

Geotextile filtration systems have been installed around the clayey cutoff of the cofferdam (GT3, see Table 1), and around the horizontal trenches. These products were chosen for their long term filtration performance, and were designed according to the mechanical stresses to be applied on them.

These geotextile filtration systems were found to be a very pragmatic solution: in particular, they offer both an economical solution is this area and the insurance of homogeneous, constant and certified product characteristics.

3.2 Dzoumogné – Mayotte island

This earthen dam was built in 2000 by the contractor Colas Océan Indien for the Mayotte Territorial Collectivity for the storage of drinking water. The maximum storage capacity is 2.8 million m³, corresponding to a volume of embankment of about 250 000 m³, a total height of 24.5 m and a crest length of 300 m (Figure 7).

The drainage system consists of:
- a layer inclined 1v/1h downstream to intercept the stream lines inside the body of the dam;
- drainage trenches and blankets at the bottom to direct infiltrated water to a gutter at the upstream toe of the dam (Figure 9).

The drainage systems built with gravel are protected by a geotextile filtration system GT1 (Table 1). This mono-layer filtration system didn’t require an additional protection layer as the mechanical properties of the filtration layer alone are sufficient to withstand the installation stresses.

3.3 Samira – Niger

This homogeneous earthen dam was built between October 2000 and May 2001 by the contractor DTP Terrassements for the water supply of a gold mine. The storage capacity is about 4 million m³, corresponding to a volume of embankment of 370 000 m³, a total height of 18 m and a total length of 1000 m.

The drainage structures of this dam built with very fine lateritic soil require filtration systems of high performance combin-
(Figure 10 & 11) and the horizontal drainage blanket made of sand were designed by the MDM consultant with a geotextile filtration system GT1, which has the appropriate characteristics (Table 1).

The upstream slope is protected with a 30 cm thick rip-rap layer made of 200 mm maximum rock size. The filtration system laid between the rip-rap and the embankment is the two-layer GT2, the protection layer of which provides sufficient puncture resistance to prevent the damage of its filtration layer by the installation of the stones (Figure 12).

3.4 Montaubry - France

This old homogeneous earthdam with a masonry upstream slope (Figure 13 & 14) was built in the middle of the 19th century in the center of France to supply water to the “Centre” canal, connecting the Loire and the Saône rivers. The French waterways (VNF) decided to strengthen it. The Safege consulting office designed a downstream abutment made of 0/63 mm material, and a gravel drainage blanket protected by a GT2 two-layer filtration system (Figure 15). The Pelichet S.A. contractor started the construction in 2001 under the supervision of the DDE in Montceauls-Mines.

4 CONCLUSION

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.

This new filtration concept and the resulting two-layer geotextile filtration system were judged by several designers to provide the safety level required in dams, either to prevent internal soil erosion below the upstream rip-rap layer, or around the vertical and horizontal drainage systems inside the embankment, without risk of clogging.

5 REFERENCES


