PLACEMENT PROCEDURES AND TESTS FOR GEOSYNTHETIC FILTERS IN WATERWAYS

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Abstract: For more than 30 years geosynthetic filters have been well established. Some time after the first applications in dams and in road construction, geotextiles were installed as filters in bank and bottom protection structures of waterways. For such applications, special requirements had to be established, especially when the geotextile filter has to be placed under water.

While at the coast (and in very wide rivers) the placement of geotextile filter fabric as part of a fascine mattress (willow mat) has a long tradition, the equipment to install a filter in rivers and canals had to be designed without earlier examples. It started with a simple spreader bar to install just a single panel with a width of ca. 5 m. Today geotextile filters are placed "continuously" with a width of 30 m or more by sewing together the manufactured panels prior to placing it under water, which is done either by preparing the filter mat on a pontoon and guiding it around a bar close to the bottom or by rolling it up over water and unrolling it on the bottom under water. Such techniques have been improved during the last two decades to very fast and effective methods.

It goes without saying that the placement procedures described above exert certain loads on the geotextile fabric that differ significantly from other applications. So special tests have been developed that take into consideration placement stresses, impact load caused by armour stones dumped on the fabric, abrasion effects by rocking armour stones and bedload transport. Furthermore, additional tests have been established to take into account hydraulic impact loads, turbulent and reversing flow through the geotextile, pore water pressure pulsations and other effects. With such tests combined with appropriate placement equipment, a long-time successful performance of geotextile filters in waterways can be expected.

Keywords: geotextile filter, erosion control, installation, testing.

INTRODUCTION

The application of geosynthetics in hydraulic structures "began with a first use of a woven plastic filter cloth in 1958", as it is claimed on the web-site of a manufacturer. The first well documented application of geotextile filter in a hydraulic structure the installation of geotextile filters instead of granular filters in Valcross Dam (France) more than 30 years ago (Artières / Tcherniavsky 2002). In the beginning, the conventional granular filter solution was preferred, considered to provide a higher level of safety. Failure or malfunctioning of the filtration system may have severe consequences. Meanwhile geotextile filters are well established. They require as granular filters careful installation and reliable design. For geotextile filters in severe hydraulic conditions, empirical design equations are not sufficient, so often additional performance tests are needed.

All the early applications were related to placement in the dry. In this way, all works and the final position of the geotextile could be controlled perfectly. Even today most of the geotextiles are installed that way. For the use of geotextiles in waterways, difficulties arose when it was not possible to dewater the area the geotextile was to be laid. The geotextile sheet will float, either due to the material itself that is used, e.g. polypropylene with a unit weight less than water, or due to air bubbles trapped within the fabric. So special methods and devices have been developed for the installation of geosynthetic filters under water. During installation in the wet, the geotextile fabric undergoes special load situations that are rather different to other applications. Therefore special tests have been developed that take into consideration placement stresses, impact caused by armour stones dumped on the fabric, abrasion due to rocking armour stones or bedload and sediment transport. Furthermore, tests have been established to take into account the special hydraulic loads related to waterways.

APPLICATIONS IN COASTAL WATERWAYS

In estuaries and coastal waterways ship induced loads caused by screw race and bow thrusters are – except in harbours – always only a part of the hydraulic load acting on bank and bottom protection incorporating geotextiles. Currents and wave actions are often dominant, so there is no significant difference to general coastal protection works.

To protect large areas, mattresses are a traditional shelter against erosion. The oldest form is the fascine mattress (also called willow mat). To form a mattress, willow bundles ("fascines") with a diameter of 10 to 40 cm are fixed crosswise to form a large grid. In the beginning only fascine grids and brushwood layers were combined to a mattress, being only a poor filter. Only coarse soil could be retained efficiently. Winnowing or more generally, erosion may be slowed down due to the damping of the hydraulic load, but it will not be stopped.

The important step forward was made when fascines and geotextiles were combined to a fascine mattress. Such mattresses usually comprise a base woven geotextile with the willow bundles tied on it. The fascines ensure the spreading of the geotextile and the floating of the mattress during the transport to the point of installation. The geotextile provides the necessary tensile strength to withstand the enormous stress during the transport through waves and currents (Figure 1). The geotextile acts also as a filter. Because a woven filter might not function well under severe hydraulic loads, today a geocomposite of woven and nonwoven fabric is used. This way, high strength and perfect filter design can be combined.

Figure 1: Pulling a fascine mattress to the installation site

The placement procedure has not changed much, but today modern equipment is used that allows for more precise installation. After the prefabrication of the mattress on land, it is pulled by a vessel to the desired position. Often it is the stone dumping vessel that will dump a first layer of armourstones on the mattress to keep it on the ground. In the final position, another vessel or a pontoon support the installation. One end of the mattress is drowned by floating the steel tube to which the mattress is attached (Figure 2). Thereafter armour material is dumped successively upon until the whole mattress is provisionally fixed on the ground. The steel tube is recovered and the armour layer is completed to the desired thickness.

To protect limited areas against scouring, where a fascine mattress cannot be applied, traditionally single large fascines have been installed. Originally large willow bundles have been tied together with a core of rubble or riprap (Figure 3) to provide sufficient weight to resist the current. As the mattresses, the large fascines will not be able to act as a filter. Winnowing will only decrease but not stop. Therefore today often geosynthetic containers are used instead of these elements. They can be prepared with the same size and weight as fascines, but with a geosynthetic casing that is designed as a filter. The only demand as to the fill material is sufficient permeability to allow the water to drain. An outstanding example is the stabilisation of probably the largest scour ever at the German coast (Heibaum 1999). 1m³ geocontainers were used to build a filter layer on the slopes of the scour hole as deep as 25 m below the sea bottom in front of a storm-surge barrier. In the upper part the slope was as steep as 1:1, so it was impossible to place a fascine mattress. During the works, the flow velocity of the tidal currents was as high as 2.5 m/s.

Figure 2: Fascine mattress attached to the sinker tube

Often it is not possible to handle the containers with special care. Therefore the installation procedure has to be chosen carefully, to avoid that the demand of sufficient strength would be cost decisive. Single geosynthetic containers are mostly placed by an hydraulic excavator. For elements up to 1.5 m³ clam shells with soft edges are appropriate while for lager elements special buckets are used. The placement of numerous containers won't be done element by element. In estuaries and in the sea, a stone dumping vessel will be appropriate, but a conveyor belt type should be used to minimize the abrasive forces acting on the cloth. If only a push-type is available, a sand layer under the containers is necessary to reduce the abrasion impact. Rough weather conditions may complicate the installation. Often it will be necessary not only to anchor the vessel at least twofold, but support exact positioning by an additional push tow perpendicular to the vessel.

Figure 3: Preparing a large Fascine with riparap core

APPLICATIONS IN NAVIGATION CANALS

In canals, where the banks are usually built with a steepness of 1V:3H to save ground, a revetment is needed to provide sufficient stability under hydraulic loads like waves, back-current and water level drawdown. Also the increasing use of bow thrusters in the limited cross section of a canal means high impact on the bank protection. Therefore a bank protection with a hard armour is needed, which can be executed permeable or impermeable. If a permeable armour is used like riprap or concrete elements, one has to pay special attention to the design of the filter in between the subsoil and the armour layer. The filter may be a granular filter or a geotextile filter. If choosing granular filter, for the installation under water only narrowly graded grain size distributions can be used, since otherwise there will be segregation of the filter material while falling through the water. The coarse material will reach the bottom first and the fines will be on top - just the opposite to what is desirable. If narrowly graded material is used, a larger number of layers with increasing grain diameters is needed. It's the advantage of geotextiles to provide the necessary filter function with only one thin layer which means significantly less effort compared to the granular filter. Nevertheless there are other problems to cope with during installation.

The filter sheet will float in the water and will not sink into the desired position on the bank and bottom of the waterway by its own weight. Even when the filter is made from polyester, a material with a density higher than water, the fabric floats due to the air bubbles trapped in between the fibres. Polypropylene, the raw material used for the majority of geotextile filter sheets, will float anyway due to the low density. The filter sheet cannot be drowned like a fascine mattress by just dropping armourstones upon because it would fold and wrinkle without the fascines to keep it spread out. So the correct placement of a geotextile filter below the water level asks for special equipment.

The simplest equipment to place a single roll would be a spreader bar, but if only a such a bar is used, the geotextile cannot be kept in its position. The seam will turn up and the necessary overlap of the sheets cannot be guaranteed. Therefore the installation of a geotextile filter cloth should be done from a pontoon, that reaches over the width of the area to be covered. In German canals with a width of the water surface of ca. 53 m and a depth of 4 m, usually one bank and half of the bottom are covered at a time while the second half of the canal remains free for the passage of vessels. The geotextile is rolled out on the pontoon and the sheets are sewn together, so a continuous filter blanked stretching form the middle of the canal to the bank above the water and over the length of the whole lot is created. The blanket is pulled over the edge of the pontoon and guided vertically down around a steel tube to be kept on the ground (Figure 4). Placement from a pontoon has been performed in countries, where no equipment as described above was available, but then a successful installation is hardly possible. At least one has to accept numerous wrinkles. Another placement system is to roll a number of sheets sewn together on a tube and unroll it under water (Figure 5). For all systems it is a must that the geotextile is kept on the ground by stones dumped immediately after placement of the filter. Usually the stone dumping unit is positioned in close contact or very close to the geotextile pontoon as shown on Figure 4.


Figure 4: Geotextile installation pontoon and stone dumping unit

To cover smaller areas, an equipment as described above might be too large. In such cases, a spreader bar is the only solution. But a hydraulic equipment (e.g. a modified excavator) should be used to control the bar in all directions. A spreader bar just hanging on chains from a crane does not allow for satisfying installation. To avoid floating of the geotextile, in former times much effort was undertaken. For example steel bars or steel chains have been attached to the fabric, such complicating the placement. With the development of the so called "sandmat", a general improvement has been made. Sand mats usually have a sand fill of 6 to 9 kg/m² kept in between to layers of needle punched nonwovens. The two nonwoven layers with the sand in between are needle punched again to reach a good shear resistance and to keep the sand fill in place during the placement procedure and on slopes under working loads. Also wovens are used and sewing instead of needle punching. Sewing is done in one direction only, so a row of tubes is created. In that tubes the sand may migrate in certain load situations. With hydraulic spreader bars, the sandmat can be installed to a depth of ca. 5 m. For placement in larger depth up to ca. 20 m, special equipment is needed.


Figure 5: Geotextile installation by unrolling

RIVER APPLICATIONS

Application of geotextile filters in rivers is on one hand easier than in canals, because banks that have to be protected are much flatter than in canals. On the other hand one complication is added: the flow velocity of the river. Depending on the flow velocity, the installation of a geotextile filter cloth is rather difficult or even impossible. Neither a grain filter nor a geotextile filter can be placed when the flow velocity is too high. Often the current is too strong even for placing fascine mattresses (in wide rivers) or sandmats as described above. A sandmat with the maximum fill weight available today of ca. 9 kg/m² increases the resistance of the geotextile filter against a flow velocity of up to 1 m/s. The sheets have to be installed as tiles in the direction of flow or sewn together.

An alternative are prefabricated mats with concrete elements cast directly on a geosynthetic fabric. They are of limited length and width and have to be installed with special cranes. Such mats will withstand the flow to a certain velocity but they are of limited size and are usually placed in low depth only.

For placing a filter despite higher flow velocities, elements are needed that combine the required filter capacity with sufficient weight to resist the hydraulic load: Geosynthetic containers can meet these requirements, as described in the paragraph on coastal applications. With an appropriate size and fill, geosynthetic containers may be placed even with high flow velocities. Model tests in a flume with stacked geocontainers (3 layers to a height of 1.8 m) proved stability up to an overtopping flow velocity of approximately 4 m/s and a mean velocity of 1.5 to 2 m/s (Pilarczyk & Zeidler 1996). Such solutions are realized predominantly to cover small areas, e.g. to form a scour protection around bridge piers or mooring dolphins. A successful first application also for bank protection measures reaching over several kilometres is presented in another contribution to this conference (Heibaum et al. 2008)

TESTS RELATED TO THE APPLICATION IN WATERWAYS

General

The placement procedures described above exert certain loads on the geotextile fabric that differ significantly from other applications. So special tests have been developed that take into consideration placement stresses, impact load caused by armour stones dumped on the fabric, abrasion effects by rocking armour stones and bedload transport. Furthermore, geotextile filters in waterways are loaded by unsteady, turbulent, pulsating and reversing flow. Most of the design rules for geosynthetic filters are developed for unidirectional flow only, and so are the conventional tests. Additionally, the development of excess pore water pressure in the subsoil due to the fast change in the hydraulic head complicates the proper filter design (Köhler 1993). So specific tests have been established to take into account these special hydraulic loads.

Basic tests are conducted to verify the suitability of geotextiles for their intended purpose. These test comprise

- mass per unit area (EN ISO 9864)
- thickness (EN ISO 9863)
- hydraulic conductivity (EN ISO 11058)
- tensile strength (EN ISO 10319)
- opening size (EN ISO 12956)

To take into account of the special hydraulic loads mentioned above, special tests have been developed in Germany (RPG 1994):

- mechanical filtration stability
- hydraulic filtration stability

To check the mechanical resistance to loads that apply during installation and service of geotextiles in waterways, two additional test are performed:

- resistance to dynamic perforation loads
- abrasion resistance

The basic tests are well known and established. The European standard EN 13253 refers to these test. But it became obvious that those tests are not sufficient for the proof of successful application in waterways. So starting in the 1970s the above mentioned performance tests were developed. These tests are mandatory for the use of geotextile filters in German waterways.

Mechanical filtration stability (reversing turbulent flow method)

The reversing turbulent flow method has been developed to prove the filter function even for fine grained but non cohesive soils (as fine as coarse silt). For sands the flow-through-method, similar to the hydrodynamic sieving method, to determine the opening size was used successfully, but in this test the gradient in the soil sample was to low to agitate the grains of finer soils. Meanwhile the turbulent flow test is used also for sands.

The test imitates the turbulent and reversing flow through the geotextile and the adjacent soil that is generated in banks and bottoms of waterways by passing ships. It is usually performed with one out of four standard soils. These four standard grain size distributions represent the majority of the soils in situ. For special research, the soil in situ is used.

In the test setup (Figure 6), a geotextile sample (181,5 cm²) is put in a bucket with a wire mesh bottom, covered by the test soil and loaded by a metal plate to achieve a uniform load of 2 kPa at the interface of soil and fabric. The bucket is drowned in a basin till the soil – geotextile interface. In the basin below the bucket, a propeller is turning at 260 rpm, creating a turbulent flow at the interface of soil and fabric with a velocity of ca. 0,8 m/s and a pulsation of ca. 17 Hz, which has been measured in the bank protection during the passage of vessels.

The sample undergoes five loading phases each lasting 30 min to a total of 150 min. After each loading phase the quantity of soil passing through the geotextile filter is determined. Geotextiles are deemed to act as stable filters if the quantity of soil passing through the filter during the final test phase and the quantity passing during the test as a whole does not exceed the maximum permitted amount of 30 g during the last phase and 300 g in total.

Hydraulic filtration stability

To check the clogging resistance of a geotextile filter, only for unidirectional flow reliable approaches are available (e.g. Holtz et al. 1997). In case of turbulent reversing flow, tests are recommended. Therefore after the test regarding the mechanical filtration stability, the remaining hydraulic conductivity of the sample is tested. All soil above the geotextile is removed, but clogged soil particles remain inside the fabric. The conductivity of the soil-impregnated sample may not fall below certain limit values (MAG 1993).


Figure 6: Reversing turbulent flow tester

Abrasion resistance

A major criterion of robustness of a geotextile is the resistance against abrasion. Since geosynthetics as used in geotechnical and hydraulic engineering today have developed from general industrial textiles, the testing of these geotextiles evolved from testing general textiles. Among these tests, the "sliding block method" for geotextiles is well known (ASTM Test Method D 4833 – 88: Abrasion Resistance of Geotextiles -Sand Paper/Sliding Block Method). But this test takes not into account the contact of soil and geotextile. The soil particles do not behave like a rigid surface, but roll, tumble, rock or draw off. Therefore the interaction of soil and geotextile is not represented by such a test.

To represent better the conditions in situ, a test was established to take into account the abrasive load induced by the hydraulic processes on the bank and bottom of waterways. The "rotating drum test" was developed for geotextile filter layers under riprap. The single armourstone always has some space that allows rocking movements under hydraulic loads which can abrade the fabric. This test proved also suitable to check the resistance against abrasion of geotextiles that are not protected by an armour and loaded by sediment and bedload transport. Recovered samples proved the similarity to fabric that was tested in that device.

In this test, a mixture of stone chippings and water passes over geotextile samples installed in a rotating drum. The standard test comprises two abrasion phases at 16 rpm of 40,000 revolutions each, changing direction every 5000 revolutions. If the samples are not degraded after the first 40,000 revolutions (visual inspection) new stone chippings are filled in and the second phase is carried out. If the samples have not been destroyed after 80,000 revolutions, samples are taken and their tensile strength is tested. A geotextile is considered resistant to abrasion loads if 75 % of the required tensile strength are kept after execution of the test. Since some fabric still shows significant tensile strength even though there is no filter function due to holes in the fabric, the remaining opening size is checked additionally. It has to be proved that the filtration capacity has not changed in an unacceptable manner, i.e. the opening size should not increase more than 0,01 mm to the value required in the filter design.

Resistance to dynamic perforation loads

This test is used to check the resistance of geotextiles to dynamic perforation loads (impacts). Such load is exerted to the geotextile when armourstones are dumped upon. To simulate this load, a drop hammer with a tip of defined geometry is dropped onto a geotextile sample placed on a test soil (medium dense sand) with a defined drop energy. The standard tests are performed with a drop energy of 600 or 1200 Nm, depending on the stone size used for the revetment. Perforations (holes) and any visible changes indicating a reduction of the filter function and strength, e.g. damage to the weft and warp threads, displacement of threads, are regarded as damage. Even though it looks like a very hard test, the majority of nonwovens with a unit weight larger than 600 g/m² and a number of wovens survive this test.

SUMMARY

The use of geotextile filters in waterways needs high quality fabric to cope with the demands given:

- High reliability of the filter function because only then the stability of a bank can be guaranteed. Bank stability is essential for the safety of navigation.
- Long term durability is needed – bank and bottom protection are designed for a lifetime of ca. 80 years.
- Sufficient robustness must be provided to allow the geotextile to survive the process of installing the filter and the amour layer. Any correction or repair afterwards is hardly possible.
- Precise installation is mandatory and asks for special equipment with high reliability for the placement under water. Usually the water is so murky that a diver can't see anything.

The experience gained over many years shows that it is possible to deliver perfect protection works in waterways incorporating geotextiles. But it was shown as well that only strong requirements concerning geotextile and equipment will guarantee that quality. Especially in the beginning, some manufacturers considered these requirements exaggerated. But today there are a large number of products and installation methods that meet these requirements. It doesn't pay to lower the standard to save some money, since the amount spent for the geotextile is often very small compared to the total costs of a structure. So premium fabric should be used, that passed the tests reported here, to avoid any risk. Any rehabilitation afterwards will create multiple costs and would disparage the geotextile even though the guilt is with the wrong design. Sophisticated equipment should be used to assure optimum installation and to avoid that the geotextile is blamed for improper installation.

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