Tests on geosynthetics used in waterways

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ABSTRACT: In waterways geosynthetics are incorporated in several parts, mainly filters, containment and impervious linings. Such geosynthetic elements have often to be installed under water. Therefore special installation procedures and equipment have to be chosen that may exert loads on the geotextile that isn't found in other applications. Furthermore, the geosynthetic elements are loaded not only by natural hydraulic actions, but also by ship induced currents and waves leading to turbulent and reversing flow with fluctuating gradients. Filter and containment fabric is often stressed by mechanical loads like armour movement or sediment transport that lead to abrasion. Such loads have to be taken into consideration when designing the geotextile. Often there is no empirical or theoretical design rule available, so performance tests are the only way to determine the appropriate product. When using geosynthetic clay liners in waterways, installed under water, the bentonite will swell prior to the installation of the armour, so it has to be tested if the bentonite will not be washed through the geotextile confinement and if the placement of the armour will not displace the bentonite.

1 APPLICATION OF GEOTEXTILES IN WATERWAYS

Waterways, i.e. rivers and canals allowing navigation with large vessels, often need erosion and scour protection. 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 in most cases is a permeable layer using riprap or concrete elements. Since these elements are larger than the subsoil grains, one has to pay special attention to the design of the filter in between the subsoil and the armour layer, which is increasingly often a geotextile filter. It's the advantage of geotextiles to provide the necessary filter function with only one thin layer which means significantly less effort compared to a granular filter.

The installation of the geotextile filter has to be done in most cases under water, therefore special equipment is needed. The simplest equipment is a spreader bar to carry the roll with the geotextile, but it is difficult to keep the geotextile in its position. The seam may 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. The geotextile is rolled out on the pontoon and the sheets are sewn together, so a continuous filter blanked with the width of the pontoon and 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 (Fig.1). Another placement system is to roll the sheets sewn together on a tube and unroll it under water.

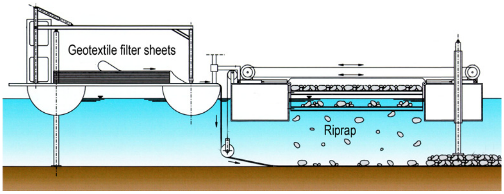

Fig 1: Under-water-placement of geotextile filter (System Colcrete-von-Essen)

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 difficulty 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.

For placing a filter despite higher flow velocities, geosynthetic containers can be used. Such solutions are realized predominantly to cover small areas, e.g. to form a scour protection around bridge piers or mooring dolphins. But also the use of geotextile bags as an exclusive revetment of a river has been executed (Heibaum et al. 2008) since it offers the potential for successful functioning low cost solutions, especially in developing countries.

In few cases, a geotextile clay liner was used as an impervious lining of a canal reach, replacing the traditional conditioned natural clay liner. Since placement has to be done in the wet, the problem arises that the bentonite starts swelling before the GCL is in its final position and before it is covered by any protection layer. It is obvious that such boundary conditions ask for extra care as to the GCL itself and the placing procedure.

2 LOADS DURING CONSTRUCTION AND SERVICE

The placement procedures exert certain loads on the geotextile fabric that differ significantly from other applications. When placing the geotextile with a spreader bar, improper handling, may result in high tensioning of one side of the sheet. The same holds for placement from a pontoon where the geotextile is sometimes misused as "anchor" if the pontoon is not positioned carefully. A certain tensile strength acts on the geotextile when it is stretched between the pontoon and the fixing bar on the bottom of the waterway and vessels are passing. But measurements showed only mild tensile stress (Abromeit 1996). Pinning the geotextile sheet on the top of a slope or fixing it in an anchor trench results in high tensile stress when the armour layer is dumped upon the filter sheet.

The placement of the armour layer is usually done by dumping riprap from a special pontoon that allows for a constant thickness of the armour layer. In shallow water, riprap is placed by an excavator. The impact of an armourstone hitting the geotextile creates a high local stress. Using GCL there is the additional problem that the impact of an armourstone may displace the bentonite leading to an increased hydraulic conductivity.

During service, geotextile filters in waterways are loaded by unsteady, turbulent, pulsating and reversing flow, created by natural hydraulic actions, but also by ship induced currents and waves. Such load is not covered by most of the design rules for geosynthetic filters that are developed for unidirectional flow only, and so are the conventional tests. Currents and waves agitate the armourstones. Since the stones are not completely fixed in their position but have a certain clearance to move or rock, they exert abrasive loading on the geotextile they are in contact with. Sediment and bedload transport causes abrasion of the fabric of geotextile containers that are used in scour protection measures without protection by an armour.

3 TESTS AND REQUIREMENTS

When a geotextile is used as a filter layer in a slope or bottom protection in German waterways, the standard requirements according to the classification procedure of the BAW apply (MAG 1993), which have been set up mainly on performance tests connected with empirical values. The European standard EN 13253 refers to a number of basic tests. But it became obvious that those tests are not sufficient for the proof of successful application of geotextiles in waterways. So, starting in the 1970s, additional performance tests were developed. These tests are mandatory for the use of geotextile filters in German waterways.

3.1 *Tensile strength and thickness*

For classification and to guarantee a certain general robustness, minimum values are required for tensile strength and thickness. Tensile strength is determined according to EN ISO 10319 and must exceed a value of 12 kN/m. This is an empirical value that has proven to be sufficient for nonwoven filter layers since due to the high straining capacity of nonwovens, the fabric responds on local stress maxima by increased strain that usually is far from the failure strain.

For the filter layer thickness a minimum value of 4.5 mm is required for sands and 6 mm for silty sands (problem soils). Thickness is determined according to EN ISO 9863. With increasing layer thickness the consequences of possible variations of mass per unit area on variations of opening size are reduced (which increases the erosion resistance). Also the sensitivity of a geotextile to large variations of grading curves of subsoil is less and hydrodynamic impacts (waves, turbulent currents) acting through the geotextile on the subsoil are damped. Thicker filter layers are able to drain water in its plane which is important for areas which are covered with large elements.

3.2 *Opening size and hydraulic conductivity*

The opening size (O_{90}, determined according to EN ISO 12956) is used in geotextile design as a characteristic parameter. Its magnitude is not invariable. It can be reduced due to surcharge or even be enlarged due to geotextile deformations or due to fibre shifting caused by dynamic impacts, dependent on type or on strength of a geotextile. It provides too few information concerning the hydraulic filtration stability of a geotextile Therefore it is used only to define changes due to abrasion (see below).

Hydraulic conductivity according to EN ISO 11058 of the virgin geotextile is needed to determine by comparison the effects of the impregnation of the geotextile by soil particles on its filtration behaviour

3.3 *Filtration stability*

Holtz et al. (1997) consider a filter design based on index tests (thickness, mass per unit area, opening size) not sufficient for erosion control and scour protection measures under severe conditions. Loads like reversing flow through the geotextile like e.g. in filters for revetments and similar systems are not covered by the usual design based on the opening size of geotextiles. In Germany performance tests (flow-through method or reversing turbulent flow method) according to the regulations RPG (1994) are mandatory for geotextile filter used in inland waterways.

The "reversing turbulent flow method" has been developed to prove the filter function even for fine grained but non cohesive soils. 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 often used also for sands.

The test imitates the turbulent and reversing flow parallel to and through the geotextile that is generated in banks and bottoms of waterways by passing ships or, in rivers, by flow and waves. It is usually performed with one out of four standard soils. The four standard grain size distributions represent the majority of the soils in situ. For special research, the soil in situ is used. This test is also used to check if the bentonite of a GCL is washed through the confining geotextile by hydrodynamic loading.

In the test setup, 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. This seems to be a large amount compared to 2500 g/m² given by Lafleur (1999). But the criterion is valid for turbulent bidirectional flow and has proved to be sufficiently strict, while the Lafleur criterion has been established for unidirectional flow.

To check the clogging resistance of a geotextile filter, 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 (1 to $8 \cdot 10^{-4}$ m/s for sands, $1 \cdot 10^{-7}$ m/s for silty sand).

3.4 *Resistance to dynamic perforation loads*

When armourstones are dumped upon the geotextile filter, the fabric should be strong enough to withstand that impact. The well known falling cone test or the CBR test do not represent this load. Therefore a special performance test is used to check the resistance of geotextiles to dynamic perforation loads. 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 (Fig.2). The standard tests are performed with a drop energy of 600 or 1200 Nm, depending on the stone size used for the revetment. That load represents the energy of the largest stone of the two most used riprap gradations falling from a height of 2 m through the air.

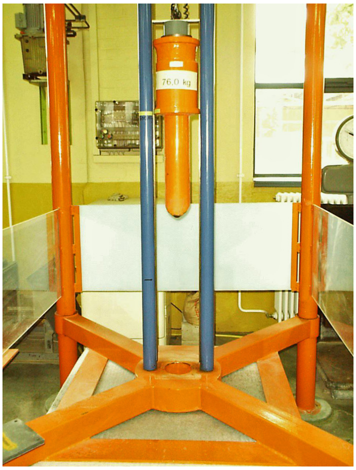

Fig.2: Drop test according to RPG (1994)

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 500 g/m² and a number of wovens survive this test.

The test facility is also used for testing GCL to determine the effect of bentonite displacement through the impact. A drop energy of ca. 300 Nm is used to simulate the impact of an armourstone falling through the water at limit sinking velocity. A stone falling through water accelerates only to a certain limit velocity depending primarily on its weight. After that test, hydraulic conductivity of the sample must remain below $5 \cdot 10^{-10}$ m/s.

3.5 *Abrasion resistance*

A major criterion of robustness of a geotextile is the resistance against abrasion. The well known "sliding block method" for geotextiles (ASTM Test Method D 4833 – 88: Abrasion Resistance of Geotextiles - Sand Paper/Sliding Block Method) 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 originally 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 to be 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 from sites 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 40000 revolutions each, changing direction every 5000 revolutions. If the samples are not degraded after the first 40000 revolutions (visual inspection) new stone chippings are filled in and the second phase is carried out. If the samples have not been destroyed after 80000 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 compared to the value required in the filter design.

Recently a test with similar objective was proposed by Huang et al. (2007). In a circular flow chamber, the geotextile is exposed to a flow with a certain particle concentration. Since no long-term experience is yet available and first tests were made with woven geotexctiles only, no comparison with the BAW test can be made.

4 CONCLUSION

For the application of geotextile filters in waterways, high quality fabric is needed to cope with the demands given. High reliability of the filter function is needed because only then the stability of a bank can be guaranteed. 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 installation process. Any correction or repair afterwards is hardly possible.

The experience gained over many years shows that only strong requirements concerning the geotextiles 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 or the bad execution.

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