EXTRAORDINARY SOLUTIONS FOR HYDRAULIC APPLICATIONS WITH GEOSYNTHETIC CONCRETE MATTRESSES

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ABSTRACT

Flowing water or flood events have a high potential to cause scour and erosion, in such circumstances slopes, embankments and riverbeds are prone to failure. Similarly the risk of damage to important structures (e.g. bridges, dams, dykes etc.) increases with a rising number of flood eventslinked to changes in global climate. Geosynthetic concrete mattresses offer several possibilities to create a coherent revetment with a high resistance to mechanical impacts and hydraulic loads such as waves or high flow velocities.The intention of the following paper is to give an impression of the various aspects and application possibilities of geosynthetic concrete filled mattresses. The system is technically and economically compared with conventional solutions for different cases like bank protection of channels and rivers, covering of overflow sections, lining of power plant channels and for coastal applications.The general benefits of the system and the rapid and precise way of construction are explained by reference to already executed projects, scientific studies and the experience of almost50 years of product development.

Keywords: Geosynthetic concrete mattress, berth protection, erosion protection, overflow section

INTRODUCTION

Although concrete filled geotextile mattresses have beenused and installed worldwide formore than40 years, they still represent a construction element that is rather unknown until today.

A geosynthetic concrete mattress consists of two layers of a high-strength polyamide and/or polyethylene woven geotextile, internally connected by spacing binders or intermediate sections, which are connected together. The internal void space is filled in-situ with highly fluid fine aggregate concrete or mortar. The woven geotextile functions as a lost form-work for the fresh concrete during the filling process. By using different production techniques permeable as well as impermeable mattresses can be fabricated. For permeable mattresses, after hardening of the concrete, the woven geotextile also performs as a permanent geosynthetic filter layer in the predetermined filter point areas.

The installation of such mattresses can be readilycarried out in the dry or even in submerged conditions.

Due to the flexibility of the unfilled mattress, the system is able to adapt to complex geometric shapes without the need for time-consuming formwork. Factory-produced larger panels allow for a custom-made solution.

Scientific studies as well as practice have shown the high resistance of geosynthetic concrete filled mattresses exposed to increased hydraulic discharges.

When the internal space is filled with concrete, the woven layers perform as a flexible lost formwork. Because of the hydraulic permeability of this textile formwork, a small amount of the "cement milk" will drain out through the fabric (so called bleeding). Examination sand experiences (PROSERVE LTD) have shown, that due to this reduction of the water-cement ratio, the strength of the cured concrete is higher when compared to constructions with conventional formwork.

This method of production also offers the possibility to create mattresses with various shapes and with spacing binders of different lengths; thus the mattress thickness can be adjusted to project specific requirements. Moreover it is possible to produce permeable and impermeable mattresses.

Experience of such applications over many years clearly defined the need for four different, typical types of geosynthetic concrete filled mattresses:- The impermeable ***Standard*** mattress(Fig. 1) has a continuous, solid concrete cross-section with a thickness of 6 to 60 cm. It is therefore ideal for applications, which call for an erosion resistant sealing system.

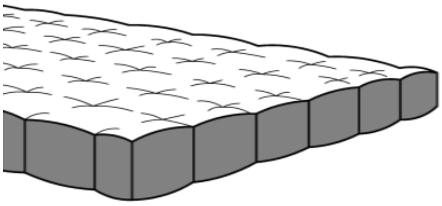

Fig. 1 Schematic section of a Standard mattress.

The ***Flex*** mattress (Fig. 2) looks like several connected cushions. It is permeable because of the regular arranged filter points and offers a certain flexibility regarding settlements due to the predetermined breaking zones which are located in between the cushions. It is mainly used to protect embankments from erosion.

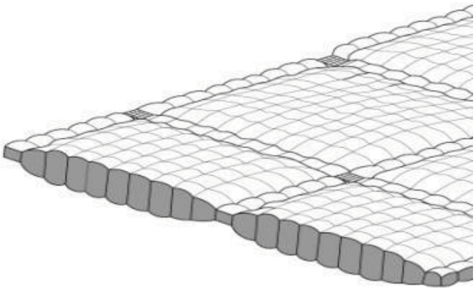

Fig. 2 Schematic section of a Flex mattress.

A higher drainage capacity can be generated by the ***Filterpoint*** mattress (Fig. 3). This type of mattress has an increased quantity of filter points, which are regularly distributed across the mattress surface. Because of its permeability (providing a reduction of hydrostatic pressure) and its relatively rough surface (which causes turbulences and is therefore creating energy dissipation)it is often used to cover overflow sections as an erosion resistant revetment system.

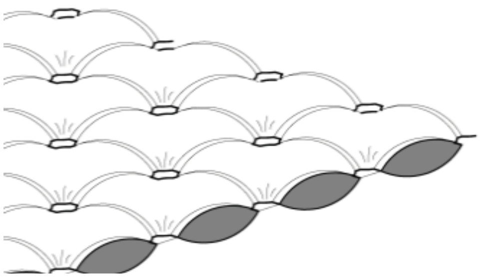

Fig. 3 Schematic section of a Filterpoint mattress.

The optimal solution to create a vegetative revetment is the ***Crib*** mattress (Fig. 4). It offers the highest permeability of all mattress types due to its large filter sections between the tubular concrete elements. It is predominantly used as erosion protection above the permanent water level. Often in combination with a vegetative cover layer. The filter sections can also be penetrated to plant willows, reed or other vegetation.

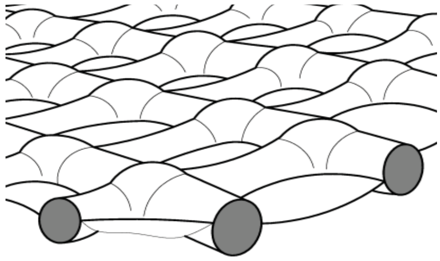

Fig. 4 Schematic section of a Crib mattress.

In general geosynthetic mattresses offer several benefits. The flexible fabric is able to adapt to small undulations of the subsoil and even challenging geometries. In contrast to common cast-in-place concrete constructions time-consuming formwork is no longer required. The problem of a complex arrangement of joints, like it is necessary when pre-cast elements are used, can be avoided by connecting the mattress panels with industrial zippers (see Fig. 4) or seams before the filling with concrete takes place.

Fig. 4 Industrial zipper connection after filling

The installation and the filling of geosynthetic concrete filled mattresses can be done in the dry or even submerged. Therefore filling pipes have to be inserted into the mattress via filling inlets. The concrete or mortar has to exhibit a sufficient (high) mobility in order to be able to spread uniformly inside the mattress. Moreover the filling material should not contain aggregates with a diameter larger than 8 mm. Otherwise the filling pipes may clog or the coarser aggregates might segregate during the filling process.

Geosynthetic concrete mattresses are usually delivered in rolls with standard dimensions or in the form of large (up to 800 m²) prefabricated panels.

Special sewing techniques (see Fig. 5) allow for the production of these customized project-specific panels.

Fig. 5 Factory-made sewing of a panel.

The following chapters will explain special applications for concrete mattresses in greater detail.

OVERFLOWSECTIONS

With regard to the possible risk in case of a failure, the prevention of erosion due to high discharges of overflow sections of earth dams is an issue of utmost importance.

Geosynthetic concrete filled mattresses offer the possibility to create a robust, joint free and coherent concrete revetment without additional formwork. They can be used for new constructions, dike reinforcements as well as for repair works.

The flexible textile has to be laid out precisely and be fixed temporarily on the dike crest. This can be done by steel bars, ropes or with the help of hemstitches which can be attached at the mattress in advance. If permeable types of geosynthetic mattresses are installed, it is suggested to put a geotextile layer (woven or non-woven) beneath. This will reduce the risk of mechanical damage of the fabric during installation and filling and enhance the mechanical filter stability of the filterpoints. Furthermore it is suggested to put the whole construction on top of a mineral leveling course. In (Tschernutter and Schuell 2010a) and (Tschernutter and Schuell 2010b), this gravel layer is recommended to have a thickness of at least 200mm.

Subsequently the filling of the mattress can be started. As in all other applications of geosynthetic mattresses, the filling concrete is the most critical parameter for a successful installation. It has to offer a high capacity of flow and aggregate diameter should be limited to a of maximum 8mm.

The construction process of an overflow section is shown in Figs.6 to8.

The use of a geosynthetic mattress as surface erosion control offers several advantages in comparison to conventional systems like ripraps made of loose gravel, asphalt revetments, precast concrete elements, etc.. These advantages rely in technical aspects, constructive and economical reasons.

From a technical point of view geosynthetic concrete mattresses used as erosion protection combine many benefits of different conventional alternatives. The revetment has due to the concrete core an extremely high resistance against the mechanical impacts of high discharges (abrasion, shear forces, impacts of driftwood). The integrated permeable filter points facilitate the reduction of hydro static pressures within the dike body.

Fig. 6 Installation – preparing under layer.

Fig. 7 Installation – laying out mattress.

Fig. 8 Installation – filling mattress.

Because of the systems coherence, the stability is not endangered by the failure or the displacement of single elements. Gravity and shear loads due to the overflowing water are transferred to the substructure by friction forces, an adequate anchor trench on top of the dike and a toe construction at its bottom. According to (Tschernutter and Schuell 2010a)and (Tschernutter and Schuell 2010b) the flow of leakage water below the mattress can be neglected.

A constructive and logistic advantage is the comparatively low demand of material. In some cases a 20cm geosynthetic concrete mattress was able to replace a boulder riprap with a thickness of 0.6m. As a consequence the amount of delivered material and thus the logistic effort could be substantially reduced.

Studies at the Technical University Vienna (Tschernutterand Schuell 2010a) and (Tschernutterand Schuell 2010b) have shown the high resistance of this type of revetment. For this investigation a physical model (scale 1:4, shown in Fig. 9) was built and exposed to specific hydraulic discharges up to 2 [m³/(s*m)] (natural scale; compare: for conventional systems specific discharges of less than 1 [m³/(s*m)] are recommended by literature). The results highlighted the suitability of this system for such or for similar applications, if basic construction guidelines are taken into account.

Fig. 9 Physical model test at the TU Vienna.

To give an idea of the economical benefits some projects that are comparable regarding size, slope inclination and specific hydraulic discharge were analyzed. The mentioned projects were located in Austria. This research was conducted by the help of (Quaißer, 2005), (LfU BW, 2004) and gained experiences during the execution of previous projects. Figure 10 shows, that geosynthetic concrete mattresses are most cost-effective when compared with other solutions.

Beyond the fast installation process, (more than 1000 [m²/d]), the possibility to create steeper slopes and the resistance against higher specific hydraulic discharges support and highlight this aspect.

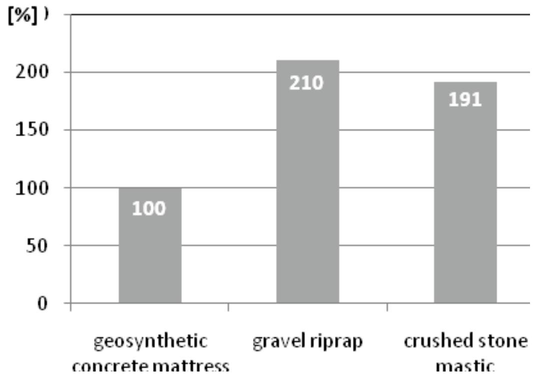

Fig. 10 Estimated costs per square meter in relation to construction with geosynthetic concrete mattress.

In some projects, the concrete mattress was afterwards covered by coarse gravel or by a vegetative layer, to achieve a pleasant integration into the landscape. This is illustrated in Figs. 11 and 12 from a project in Austria; (pictures taken 2008 and 2010). In the case of a flood event, this sacrificial cover layer will be eroded, but the revetment below will remain and therefore also the dike body.

Fig. 11 Overflow section during installation of mattress (2008).

Fig. 12 Overflow section (see Fig. 10) two years after mattress installation (2010).

CHANNEL AND RESERVOIR SEALING

As mentioned above geosynthetic concrete mattresses can also be produced without filter sections (type *Standard*). After filling with concrete those mattresses have a continuous, solid cross-section which can be regarded as impermeable as a conventional concrete sealing slab. Geosynthetic concrete mattresses are accepted and recommended as sealing system according to the guidelines of the German Association for Water, Wastewater and Waste (DWA 2012).

The field of possible applications includes the sealing of channels as well as reservoirs and basins. The sealing effectiveness can be increased by the mattress thickness. The edges and joints of the 5 m wide widths can be constituted as weak points. Therefore, depending on the requirements, different construction solutions have been developed. (Figs. 13 to 15)

The factory made prefabrication (mentioned previously) of large panels (up to 800 m², limited by the possibility of transport and manageability on site) can avoid the existence of too many joints. The precondition for this is of course the knowledge of the exact geometry in advance. Furthermore a modified sewing technique is necessary to perform a tight connection.

The use of industrial zippers (Fig. 4) enables the connection of several panels on site without additional site efforts and also provides a full thickness slab at the joint location.

The connection of a geosynthetic concrete mattress as sealing system with existing structures or penetrations requires individual solutions.

Fig. 13 Irrigation channel with a geosynthetic concrete mattress as sealing system.

The permeability of a sealing system made of a geosynthetic concrete layer strongly depends on the quality and mixture of the used filling concrete. Based on a water-cement ratio that is usually between 0.4 and 0.5, and taking into account a high assurance (due to joints, irregularities of concrete mixture and installation) an averaged permeability of not less than $1x10^{-11}$ [m/s] can be achieved.

Fig. 14 Storm water basin with a geosynthetic concrete mattress as a sealing system.

Geosynthetic concrete mattresses are preferably installed to create a robust sealing system that does not require an additional protection layer. When the concrete has cured and the subsoil is stable and capable of bearing, the surface can be passed over directly with small vehicles. This fact is the more beneficially for the construction of sedimentation basins, which have to be vacated regularly. The risk of damages due to the work of buckets or dredgers is considerably lower compared to alternative systems.

One of the most important advantages of geosynthetic concrete mattresses as sealing system is the possibility of a submerged installation. In this manner maintenance works of power-plant intake channel or irrigation channels can be carried out without lowering the water level. The power plant operation is not affected.

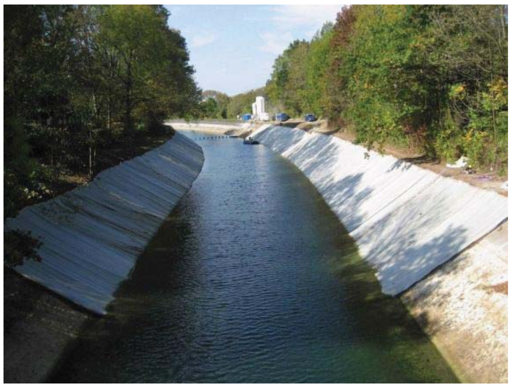

Fig. 15 Sealing of a power plant intake channel with the *Standard* mattress.

EROSION PROTECTION: RIVERS AND RESERVOIRS

In a similar manner erosion protection of river beds and embankments can be achieved. In contrast to channel sealing applications, the usage of permeable mattresses is suggested in such cases.

Thus hydrostatic pressure, which may cause uplift, can be reduced and the interaction of groundwater and free water level is not disconnected.

Flow velocities can be determined as decisive loads for the most applications. But not uncommon, for example for navigable waterways, a considerable wave impact has to be taken into account, too.

Permeable geosynthetic concrete mattresses are also used to prevent erosion due to surface water at storm water basins (see Fig. 16).

They are often applied to prevent erosion of in- or outlet areas, where difficult geometries and limited space describe critical boundaries.

Furthermore erosion protection with geosynthetic concrete mattresses is an adequate solution for only temporary water-bearing rivers in arid regions, where suitable building materials are rare or downstream of hydro power plants.

Fig. 16 Storm water basin: slopes covered with a geosynthetic concrete mattress (type *Crib*) 19 years after installation.

BERTH PROTECTION

The use of geosynthetic concrete mattresses to protect harbour beds against propeller and jet induced scour is an application of growing interest. The unfilled panels are precisely installed and temporarily fixed with the help of divers and subsequently filled with flowable concrete. Some building contractors have already developed a considerable degree of experience and technique regarding the submerged installation of this type of erosion protection.

Since it is possible to produce mattresses with a thickness of up to 0.6m, geosynthetic concrete mattresses represent a viable alternative to withstand the forces occurring due to maneuvering ships.

Design methods have been developed (Römisch 1993) and (Römisch 1994).The design approach according to Römisch estimates an equivalent grain size, which counteracts the propeller thrust. The equivalent grain size can be increased by the dimensions (thickness and expanse) of the used mattress.

However, there is still a need for research left. But the system has been approved by practice and its excellent performance on projects to date.

The submerged installation of geosynthetic concrete mattresses in port facilities always requires a large degree of experience and the operation of divers.

EROSION PROTECTION IN COASTAL AREAS

In addition to the mentioned applications in harbours and berths, geosynthetic concrete mattresses can also be applied very skillfully around foundations in coastal areas, as a protective layer for temporary or permanent dam or dike constructions or to strengthen existing structures.

In some projects, geosynthetic concrete mattresses were used to form the transition between a solid, sheet pile surrounded, grouted riprap and the soft and sandy seashore. In this context, the connection of the mattress and the sheet pile was executed with the help of prefabricated loops and steel bars, which were linked to the sheet pile. After filling of the mattress the existing space between the mat and the sheet pile wall was filled with tremy concrete. Figures 17 and 18 show such a solution for a project at the German North Sea Coast.

Fig. 17 Connection with sheet pile (unfilled mattress)

Fig. 18 Connection with sheet pile, transition to sandy seashore (filled mattress)

This kind of erosion protection may conceivably be used to prevent scours around offshore foundations. However there are no experiences with that kind of application, yet.

SPECIAL SOLUTIONS

The opportunity to produce and to assemble elements with differentshapes and geometries offers additional application possibilities for geosynthetic concrete mattresses.

A geosynthetic concrete mattress may for example be used as an additional load for negative buoyancy of inverted siphons (Fig. 19). For this purpose a customized panel is prepared in advance. On site it is wrapped around the pipeline and is fixed by the help of industrial zippers. The pipeline is now completely coveredby the double formwork fabric. Subsequent the concrete can be poured via the filling inlets. After curing of the concrete, the complete construction can be put in position. The concrete mattress cover has not only the function to avoid uplift, but also to serve as a protective layer.

Fig. 19 Concrete mattress as negative buoyancy for an inverted siphon.

A further smart application is the use of geosynthetic concrete filled formworksfor grout bags. Small or large units of special fabric formworks are used to fill up scour holes and gaps between foundations and the subsoilor to seal leakages in sections, which are difficult to access.

This solution is currently intended to be applied inprojects where the bottom of a weir structure is eroded. The access is difficult, because a lowering of the water level is not possible, and thus the repair has to take place during operation. The suggested solution is to install a prefabricated grout bag in position below the damaged structure, fix it and fill it with concrete until the flexible fabric has adapted to the present geometry around and above the leakage. Figs. 20 to 22 show a scheme of the proposed solution also illustrating theinstallation procedure.

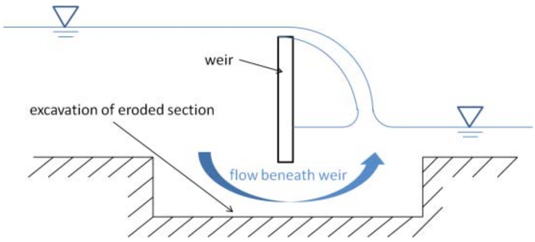

Fig. 20 Current situation, flow beneath weir, due to erosion

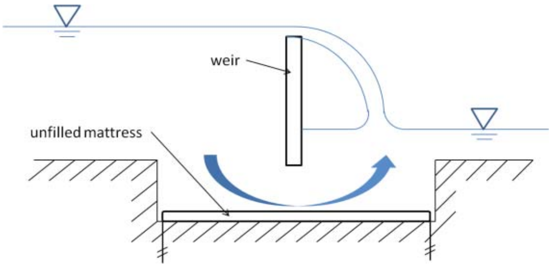

Fig. 21 Installation and fixation of grout bag

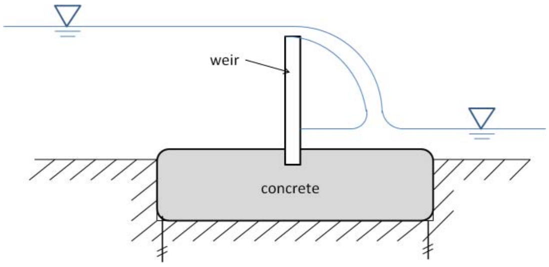

Fig. 22 Grout bag filled with concrete until it adapts to the weir structure; flow beneath weir stopped;

CONCLUSIONS

Geosynthetic concrete mattresses are a time- and cost-saving, highly resistant and contemporary solution not only for conventional applications according to Pilarczyks (Pilarczyk 2000) design approaches (flow resistance and wave attack), but even for problems of different origins, especially when smart an costum-made solutions are required.

The flexible, synthetic formwork allows a high degree of adaption to challenging geometries. The success of a project is highly depending on the concrete's quality and a proper execution.

REFERENCES

DWA (German Association for Water, Wastewater and Waste) (2012). Dichtungssysteme im Wasserbau - Teil 1: Erdbauwerke, Hennef, Germany

Landesamt für Umweltschutz Baden-Württemberg(2004) - Oberirdische Gewässer, Gewässerökologie 90: Überströmbare Dämme und Dammscharten. Karlsruhe : LfU Baden-Württemberg, 2004LfU BW.

Pilarczyk K.W. (2000). Rijkswaterstaat, Delft, Netherlands: Geosynthetics and Geosystems in Hydraulic and Coastal Engineering. Rotterdam, Brookfield : A.A. Balkema.

PROSERVE LTD. Micro concrete mix design.http://www.proserveltd.co.uk/pdfs/B65-Micro-Concrete-Mix-Design.pdf. Warwickshire, U.K.

Queißer J. (2006). Mitteilungen des Instituts für Wasser und Gewässerentwicklung - Bereich Wasserwirtschaft und Kulturtechnik - der Universität Karlsruhe (TH) - Heft 233: Entwicklung landschaftsverträglicher Bauweisen für überströmbare Dämme. Karlsruhe : Universitätsverlag Karlsruhe, 2006.

Römisch K. (1993). Propellerstrahlinduzierte Erosionserscheinungen in Häfen. HANSA – Schiffahrt – Schiffbau – Hafen – 130. Jahrgang. 1993 Nr. 8. Hamburg, Germany: 62 – 68.

Römisch K. (1994). Propellerstrahlinduzierte Erosionserscheinungen. . HANSA – Schiffahrt – Schiffbau – Hafen – 131. Jahrgang. 1994 Nr. 9. Hamburg, Germany: 231 – 234.

Tschernutter P., Schuell M.(2010a).Overtopping Sections of Dams – Report on the Incomat® FP C 60.148/20 Mat Tests, Technical University of Vienna, Instituteof Hydraulic Engineering and Water Resources Management, Austria.

Tschernutter P., Schuell M. (2010b). Overtopping Sections of Dams – Report on the Incomat® Crib 10.200 Mat Tests, Technical University of Vienna, Institute of Hydraulic Engineering and Water Resources Management, Austria.