Paper 111 - Technical-biological Bank Protection on Waterways with high Traffic Frequency – First Experience Gained from a Test Stretch at the River Rhine with regard to Bank Stability

FLEISCHER, P.; SOYEAUX, R.
Bundesanstalt für Wasserbau (BAW; Federal Waterways Engineering and Research Institute), Karlsruhe, Germany

Email (1st author): petra.fleischer@baw.de

ABSTRACT: A field test on the River Rhine near Worms, in which various bank protection measures with vegetation are being tested under waterway conditions, was started as part of the research project in 2011. The first results from the technical point of view will be presented in the following article.

1 INTRODUCTION

In order to prevent erosion and to avoid instability due to navigation-induced hydraulic loads or flooding in the long term, the banks of inland waterways are usually protected with technical revetments such as riprap. Since the EU Water Framework Directive (WFD) came into effect in 2000, ecological aspects have become more and more important for new constructions, development and maintenance measures along German federal waterways. Thus, close-to-nature technical-biological bank protection measures should be applied more frequently as a new type and as an alternative to conventional riprap revetments. This new type should meet technical and ecological requirements simultaneously. However, so far only little experience has been gained for their use along waterways with high traffic frequency. Optionally, experience of bioengineering at small unnavigable rivers can be transferred to other cases. For this reason, no standards exist.

2 RESEARCH AND DEVELOPMENT PROJECT

Therefore, in 2004, the German Federal Waterways Engineering and Research Institute (BAW) and the German Federal Institute of Hydrology (BfG) started the joint research and development project "Technical-biological Bank Protection on Waterways", thus bringing together the knowledge and the standpoints of engineers and biologists. Since then, several studies on the applicability of bank protection measures with, or in combination with, plants have been carried out, as well as on the quantification of their hydraulic load-bearing capacity and on their ecological effectiveness, but also on the conditions of installation, required maintenance and the costs. The aim is to develop application recommendations and dimensioning standards for their use along inland waterways. For this purpose, theoretical analyses and laboratory and model tests are being executed and the additional experience gained from first practical applications on waterways is being examined. A field test on the River Rhine near Worms, in which various bank protection measures with vegetation are being tested under waterway conditions, was started as part of the research project in 2011. The first technical results will be presented in the following article. For information on the first ecological assessments, please refer to Paper 110 by Schilling, Kleinwächter and Liebenstein (Schilling et al., 2013).

3 ENSURING THE STABILITY OF THE BANKS

3.1 Ship-induced bank load

The banks of inland waterways, most of which are sloped, are exposed to hydraulic load from shipping and, in river stretches, also from high water discharge and large fluctuations in water levels. When discussing ship-induced load, a distinction must be made between "normal motion" of the ship (travelling in a stretch of waterway) and "manoeuvring" (e.g. casting off or mooring at lock approach areas, berths, and the like). "Normal motion" – the major cause of load at the banks of waterways – is displacement motion in a confined waterway, which causes local and temporary changes to the water surface and the flow of water around the ship as a result of the interaction of ship and waterway. Here, a distinction is made between primary and secondary waves. A primary wave is defined as the sequence consisting of bow wave (including bow swell) ahead of the ship, water level drawdown alongside the ship and the stern wave aft of the ship (Figures 1 and 2). The associated flows (return flow and slope supply flow) may be superimposed on the natural flow of the river. At the bow and stern of the ship, regular short-period waves are created simultaneously: the secondary waves. The magnitude of ship-induced bank load is mainly determined by the cross section ratio (cross section of waterway to submerged cross section of ship), the ship speed through water and the distance of the ship from the banks.

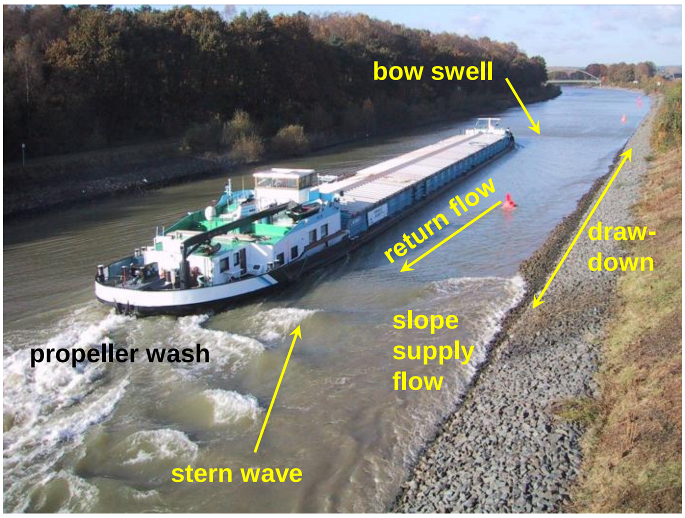

Figure 1: Types of ship-induced load

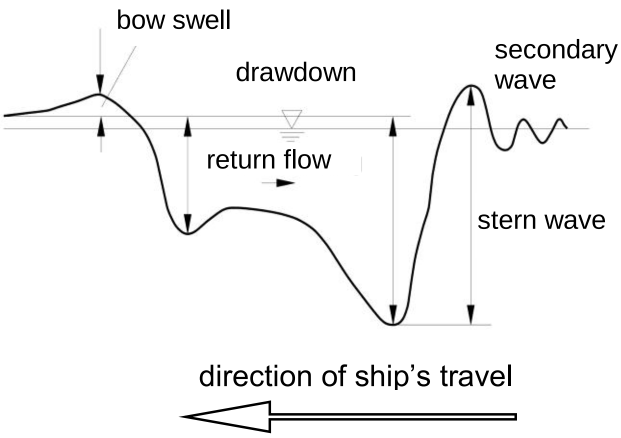

Figure 2: Diagram of the changes in water level at the banks

3.2 Verifications of bank stability

Technical-biological bank protection measures, that is, protection measures that consist only of vegetation or of a combination of vegetation and technical components, must be designed to ensure both bank protection and good ecological conditions in the bank zone in line with the requirements of the WFD. For technical purposes, this means that the overall stability of the bank slope, the local stability against sliding failure of a soil layer close to the surface and against hydrodynamic soil displacement, as well as against surface erosion, must be guaranteed according to the requirements for stability.

In all design calculations, the overall stability of the bank slope, including the bank protection measures, must always be verified according to DIN 1054 / EC 7. The use of vegetation for bank protection can only increase the overall stability in the long term if it has developed sufficiently deep and strong roots in the subsoil.

With regard to the local stability in terms of the sliding of a soil layer close to the surface and hydrodynamic soil displacement, the particular effects of water level drawdown on the bank slope caused by passing vessels must be allowed for. When the pore space in the soil adjacent to the waterway is fully saturated with water, a change in water level in the waterway would lead to a direct change of pressure in the pore water. As has been proven in field trials, however, the pore water in the relevant slope area contains microscopically small gas bubbles, which have a decisive effect on the physical behaviour of water (Köhler, 1989). Because of the higher compressibility of the gas/water mixture, the pore water pressure reactions are significantly delayed. The maximum excess pore water pressure that occurs in the soil immediately after the water level drawdown disappears completely over a period of time if a further drawdown situation does not follow immediately. The magnitude of the excess pore water pressure depends not only on the magnitude of the water level drawdown and the drawdown speed, but also, to a significant extent, on the permeability of the in-situ soil (Holfelder, Kayser, 2006). As a result of the excess pore water pressure, the effective tensions in the soil and, thus, the friction forces may be reduced so significantly that a bank slope may slide along a fracture plane parallel to the bank slope at the critical depth, at which the shear resistance of the soil is the least as a result of the excess pore water pressure, or hydrodynamic soil displacement may occur. Non-cohesive, fine-grained soils in the slope area, with low permeability, are especially critical. Therefore, bank slopes that are as flat as possible are particularly apt for this purpose.

One way to increase the effective tensions in the soil is to place a surcharge over the entire area, for example, by means of rip-rap revetment with vegetation or gabions with vegetation. Vegetation as the sole method of bank protection, for example, willow brush mattresses, can only stabilise the slope in the long term in the sense of providing additional cohesion in the soil if it has a sufficiently deep, dense and branching root system in the soil, or by means of sufficiently deep individual roots, as in soil-mechanical nailing. This must be achieved by means of additional constructional measures in the early phase, such as the anchoring necessary to secure the plants, comparable to soil-nailing in the form of a close network of wooden stakes reaching deep into the subsoil.

The verifications regarding sliding failure of a soil layer close to the surface and hydrodynamic soil displacement are only required for bank protection measures using vegetation when the bank protection measures are submerged for certain periods and are at the same time exposed to hydraulic load from shipping, for example, as on rivers with large fluctuations in water level, such as the River Rhine. As research is still continuing in this matter, however, it is not yet possible to make reliable quantitative statements as to how stability with respect to sliding failure in a layer of soil close to the surface and to hydrodynamic soil displacement can reliably be ensured by the roots of vegetation alone (Eisenmann, Fleischer, 2012). Studies regarding the quantification of root formation in terms of time, and of the correlation between the density of the root systems and the cohesion of the soil where these roots have penetrated, are currently being carried out using the example of various types of willow. Results to that effect are also expected from the field test on the River Rhine (see Point 4).

Stern and secondary waves, return flow and slope supply flow caused by shipping, and natural flow, as, for example, during high water discharge, may cause surface erosion in the bank zone as a result of the drag of the water if the in-situ soil is not sufficiently resistant to erosion. Plants may offer protection from surface erosion by covering the area of soil with the sections of the plant above ground that are firmly anchored in the soil by their roots, as well as by the roots that are close to the surface. At the same time, the plant sections above the ground can reduce hydraulic load by increasing the roughness at the bank (Rauch, 2006) although, locally, this may lead to turbulence effects, for example at larger willow plants. Additional protection from surface erosion may be required in the initial phase, for example, in the form of a biologically degradable filter fleece.

For the assessment of bank protection measures composed of vegetation in terms of protection from surface erosion, we can refer to the experience gained on smaller bodies of running water without shipping. Here, empirical threshold values already exist for permissible flow velocities or shear stress for a variety of construction methods using vegetation (Hacker, Johannsen, 2012).

4 FIELD TEST AT THE RIVER RHINE

4.1 Objectives and Planning

With the aim of testing technical-biological protection measures under natural conditions a 1-km-long test stretch on the right bank of the River Rhine (km 440.600 - km 441.600) opposite the city of Worms was realised in 2011. This selected stretch of river is subject to high traffic: about 120 ships travel here daily; furthermore, it is also subject to high water level fluctuation. Thus, the goal of this field test is to gain practical experience on the load-bearing capacity of various technical-biological bank protection measures on high-traffic waterways and to assess their technical and ecological effectiveness.

The first design plan, developed in 2010 within the scope of the research project by BAW Karlsruhe and BfG Koblenz, was coordinated with the WSA (Waterways and Shipping Office) Mannheim (project management) and the WSD (Waterways and Shipping Directorate) Südwest Mainz and submitted to the BMVBS (Federal Ministry of Transport, Building and Urban Development). Based on this, technically detailed planning was carried out by two consulting firms that specialise in technical-biological questions. They were also responsible for the supervision of the construction. For the pre-cultivation of plant material (reed gabions, vegetation mats, and individual plants), a specialist nursery was commissioned ten months prior to construction. The installation of the new technical-biological bank protection measures took place between September and December 2011. Technical and ecological assessment of the bank protection measures, based on comprehensive and detailed monitoring, was launched in 2012 and will take place at first over a period of five years.

4.2 Boundary conditions

The boundary conditions were comprehensively examined by the BAW and BfG and documented in an internal report (BAW, BfG, 2010). It is especially remarkable that the water level fluctuates enormously, i.e. about 6 m between the equivalent low water level (ELWL) and the highest navigable water level (HNWL) – Fig. 3.

The distance of the navigation channel to the bank increases: from 23 m to 140 m at km 441.600 (slip-off slope). Therefore, the ship-induced hydraulic load is highest at km 440.600 (undercut slope) and decreases in the direction of flow. Based on calculations according to GBB 2010 (BAW, 2011), maximum stern waves of 0.40 m (km 441.600) to 1.00 m (km 440.600) are to be expected. On 15 January 2011, during a high water event combined with partial flooding of the adjacent terrain, flow velocities of more than 2 m/s were measured.

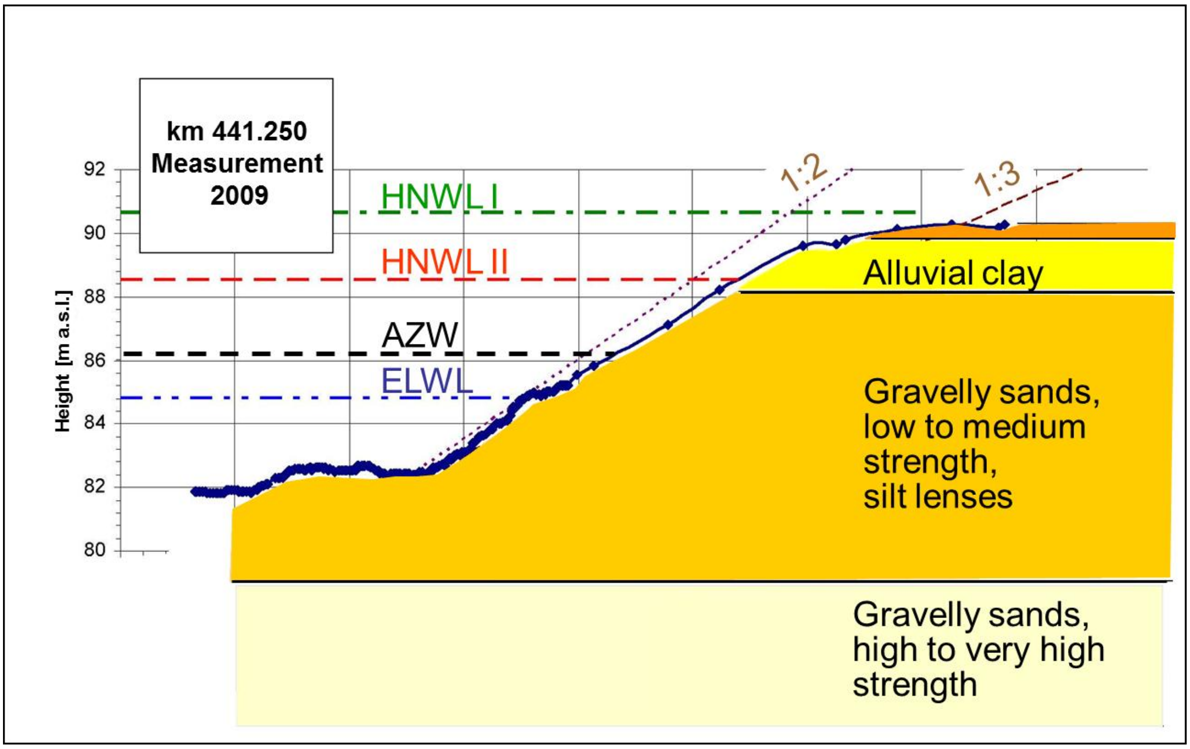

Figure 3: Cross section of bank with soil layers and relevant water levels

Before the construction measures, the inclination of the slopes was usually between 1:2 and 1:3. The original bank protection measure was riprap made from $LMB_{5/40}$ armour stones (layer thickness approx. 60 cm to 90 cm). Underneath, a mixture of armour stones and soil can be found down to a depth of 60 cm. At certain points, old pavement still serves as a bank protection measure. Investigations of the subsoil in the area of the slope showed that below a 1.50 m to 2.50 m thick layer of alluvial clay the soil consists largely of gravelly sands (see Fig. 3).

Prior to the construction measures, the overall stability of the bank with and without riprap above mean water level was determined for various load cases. The overall stability was sufficient even without the new protection measures.

4.3 Technical-biological bank protection measures and implementation

The 1-km-long test stretch was divided up into nine test fields (TFs). In five sections, the riprap was removed above AZW (AZW ≈ Ausbauzentralwasserstand: a mid-range water level about 20 cm below mean water level). In TF 2, 3, 5 and 7, the riprap was replaced by new technical-biological protection measures; in TF 9, the bank remained mostly unprotected. In four sections (TF 1, 4, 6, 8), the riprap remained to protect the bank but was improved with biological measures. On the underwater slope (below AZW), the riprap was retained in all sections. The nine alternative protection measures were based on previously gained knowledge. They were arranged according to the ship-induced hydraulic loading, which, due to the varying distance between channel and bank, decreases in the direction of flow.

Table 1 gives an overview of the 9 test fields and their new protection measures. Detailed descriptions can be found in the internal report (BAW, BfG, WSA-MA, 2012). All measures were installed from September to December 2011. A land-based construction method was chosen. Meteorological and hydrological conditions were good. During the construction phase, the water levels of the Rhine were low, so that the measures could mostly be installed under dry conditions. The construction works were not interrupted or delayed.

Tabelle 1: Overview of the new bank protection measures (TF = test field) (BAW, BfG, WSA-MA, 2012)

TF	km	New technical-biological protection measures
1	440.630 - 440.800	Riprap with willow log branch cuttings, living fascines, brush and hedge layers, stone wall with shallow water zone, dead wood trunks with roots
2	440.820 - 440.860	Willow brush mattresses, installed diagonally to the direction of flow (after removal of riprap)
3	440.880 - 440.950	Willow brush mattresses, installed transversally (after removal of riprap) – Fig. 5
4	440.950 - 441.000	Riprap with gravel fill, groups of individual stones, dead wood fascines – Fig. 7
5	441.000 - 441.110	Reed gabions and stone mattresses on granular filter, vegetation mats and hedge layers (after removal of riprap) – Fig. 4
6	441.125 - 441.200	Riprap with top soil alginate blend, hydroseeding and individual plants
7	441.200 - 441.375	Pre-cultivated vegetation mats on different filter mats (sheep wool fleece, geotextile, coir mat), dead wood fascines, vegetation rolls above hydroseeding (after removal of riprap) – Fig. 6
8	441.375 - 441.475	Riprap and pavement with reeds, elevation of existing stone wall
9	441.475 - 441.600	Limited erosion and succession, wooden groyne (tree trunks arranged in a fan shape and buried in the slope), stakes on edge of slope (after removal of riprap)

For the technical-biological bank protection measures, which were installed after the removal of the riprap, prefabricated elements such as reed gabions (TF 5; Fig. 4), stone mattresses (TF 5) and vegetation mats (TF 7; Fig. 6) were used as well as willow brush mattresses (TF 2 and 3; Fig. 5), which were made from local willow branches. The vegetation mats were pre-cultivated during one growth season.

If construction methods involve living plants, the bank is only gradually stabilised, with increasing plant and root growth. Thus, the initial phase is the most critical one. At the beginning the plants have no roots, and, therefore, must be adequately fixed to the bank with stakes, cross-bars and bracing wire. The stakes must be driven into the ground and must reach a sufficient depth to absorb the tensile stress that results from uplift or currents and waves. Hydraulic load may occur immediately after, and sometimes during, the installation work.

The filter stability of the bank may also cause problems in the initial phase. Thus, reed gabions and stone mattresses were installed over a granular filter (TF 5). Different filter mats (TF 7) – sheep wool fleeces, coir mats, geotextile fleeces – were installed under the vegetation mats, however, none of them could meet all the demands – filter stability, strength, permeability to roots and biodegradability. Experience will show which products are suitable. If willow branch cuttings are installed as closely together as possible, no additional filter will be necessary.

For the ecological improvement of the riprap revetment, materials such as log branch cuttings, brush and hedge layers as well as living fascines (TF 1) and methods such as hydroseeding on alginate (TF 6) were used. Moreover, the bank structure was enhanced through dead wood fascines and individual stones – Fig. 7 (TF 4). In these three fields, riprap is still the main protection measure, whereas additional elements were only installed for ecological reasons. Testing these measures is important for waterway sections which are subject to high hydraulic load and still require a riprap revetment. The assessment of these three improvement measures will focus on the ecological effectiveness.

In TF 9, the test field with the lowest hydraulic loads, the riprap was removed above AZW and not replaced by any new measure. On the underwater slope (below AZW), the riprap was retained. Changes in the bank due to hydraulic load and flooding will be observed. Erosion will be allowed. A wooden groyne (tree trunks arranged in a fan shape and buried in the slope) should guarantee a safe transition to the existing revetment behind the end of the test stretch. The maintenance path is to be protected by willow cuttings.

4.4 Monitoring program

Comprehensive monitoring was planned in order to analyse the results and subsequently apply them to other waterways. Its objective is to assess the implemented technical-biological bank protection measures regarding

- technical effectiveness to guarantee bank stability
- ecological effectiveness
- maintenance required.

The following parameters will be measured, analysed and documented:

- bank geometry, bank stability
- hydraulic load on the banks

- excessive pore water pressure in the soil of the bank
- meteorological influences and impact from Rhine water levels
- vegetation and fauna
- ecology
- maintenance measures
- damage and rehabilitation measures.

Figure 4: Reed gabions during installation on a granular filter (TF 5)

Figure 5: Willow brush mattresses immediately after installation (TF 3)

Figure 6: Vegetation mats on filter fleece and woven coir fabric over hydroseeding immediately after installation (TF 7)

Figure 7: Riprap with gravel fill, groups of individual stones, dead wood fascines (TF 4)

The monitoring was already started in 2009/2010 with, amongst others, the assessment of biological indicators. In the first year of the completion of the test stretch (2012), the focus lay on the experiences which were made during construction and on the critical initial phase of the technical-biological bank protection measures when they are only kept in place by their fixations. The progress of the roots and the vitality of the plants were observed and assessed. Were the attachment measures sufficient? What effect did hydraulic loads and periods of submergence have immediately after installation? Do the different measures offer sufficient protection against surface erosion and provide slope stability, even in their initial phase? If applicable, for what reasons did rehabilitation measures have to be carried out?

From the technical aspect, in order to assess the condition of the bank protection measures and the stability of the banks, inspections have been carried out at regular intervals and especially after specific high-water events, since January 2012. In this context, the most important events have been recorded photographically. Twenty-eight cross sections were defined, which will be geodetically surveyed annually for purposes of comparison. The hydraulic bank load resulting from navigation was recorded in June 2012 during a three-day measurement campaign with water levels in the area of the new bank protection measures. In addition, excess pore water pressure in the soil was measured three times while ships were passing.

4.5 First results from the geotechnical point of view

As only the measures that were newly installed in the Test Fields 2, 3, 5 and 7 after removal of the riprap revetment are primarily intended for bank protection purposes (see Table 1), the first experience and results for these construction types, and additionally for Test Field 9 which does not bear any new slope protection measure, will be discussed below.

Figure 8: TF 5, lower bank zone on 06.06.2012 (looking upstream)

Figure 9: TF 5 in late July 2012, after having been submerged for six weeks (looking down-stream) - loss of vitality

The bank protection measures with vegetation, which had been installed in optimal hydrological and meteorological conditions, were subjected to some very unfavourable conditions in their first year. These included several high water events (highest water level approx. 1 m below the upper edge of the bank) directly after completion of the construction work, long and, for a short period of time, very severe frost without a protective snow covering and, in some cases, long periods of low water levels, which occurred mainly in the early growth season from the beginning of February to the middle of April. Other high water events occurred in the summer months in which the lower embankment slope was under water between water levels of AZW - 0.5 m and AZW + 1.0 m for six weeks without a break [AZW = Ausbauzentralwasserstand: equivalent to approx. 20 cm below Mean Water Level]. In each case, the submerged zone during these higher water levels was affected by buoyant force, natural flow and hydraulic load from shipping. In the measurements of the hydraulic load on the banks, wave heights of a maximum of 80 cm at water levels at about AZW were recorded in the year 2009, and wave heights of up to 30 cm at water levels of 2.5 m above AZW in the year 2012. As it was only possible to include a limited number of vessels in the measurements, larger wave heights may, in theory, have occurred. The zone between AZW - 0.5 m and AZW + 1.0 m was exposed to the greatest hydraulic load – as a result of constant wave action at mid-range water levels and the longest and highest submergence during high water. The flow velocities measured close to the bank (5 m from the bank) during the higher water levels in 2012 (approx. 88.30 m above sea level; see Figure 3) ranged between 0.3 m/s and 1.1 m/s.

Using the measurements from Test Field 3 during three different high water events, it was possible to prove that water level drawdown during the passage of a ship caused excess pore water pressure in the in-situ soil below the brush mattresses. This means that, in the case of submergence, the bank protection measures are, in principle, subject to load that may cause not only surface erosion, but also sliding of the bank slope and hydrodynamic soil displacement. The excess pore water pressure values that have been measured so far are, however, low (max. 0.6 kN/m2), as the sandy-gravelly soil is fairly permeable, and only low drawdown values (maximum: 26 cm) have been recorded so far. In theory, however, larger drawdown values are possible; this would lead to higher values for the excess pore water pressure. Further measurements will therefore be carried out in the coming years.

The vegetation that had been planted was in the critical early phase of growth in the first year after completion of the construction measures, during which it first had to develop sufficient roots in order to form a stable connection with the subsoil. In general, it can be ascertained that the bank protection measures which, besides vegetation, also included technical elements, such as the reed gabions and stone mattresses in Test Field 5, were more stable from the start than the bank protection measures consisting only of vegetation because of their greater dead weight, and they were thus able to develop well overall. Here, additional anchoring was not required. The area of contact with the subsoil required for the growth of roots was present from the beginning. Overall, the reed gabions developed favourably on the incline of 1:2.5 of the bank slope. However, the relatively long and uninterrupted period of submergence (approximately six weeks) was detrimental to the vitality of the vegetation in the lower bank zone. Figure 8 shows the state of this zone (marked with "1") before it was submerged, and Figure 9, immediately afterwards. In the long term, however, the vegetation was able to recover, and its protective function was thus not impaired.

In the bank protection measures consisting merely of vegetation (e.g. willow brush mattress or vegetation mat), which have no significant dead weight under buoyant force, the importance of the anchoring methods (cross-bars, stakes, bracing wires) became very clear. The stones that were still in places in the subsoil had the effect that the planned anchoring depth for the stakes could not be achieved everywhere, with the result that these became detached from their position during submergence, as a result of buoyant force and wave load, and had to be renewed.

Figure 10: Willow brush mattresses in TF 3 (July 2012)

Figure 11: Excavation of roots in TF 3 (20.11.2012)

The willow brush mattresses (mainly consisting of purple willow and white willow, Test Fields 2 and 3) have, in general, developed well on the 1:3 incline of the bank slope (Figure 10 compared with Figure 5). By October 2012, shoot lengths of up to 2.5 m had been reached. Despite repeated submergence, only limited soil displacement was noted. At the downstream end of Test Field 3, the willow roots were dug free in November 2012 in order to assess root development here. The roots were uncovered in two places at different depths over an area of 1.0 x 0.5 m in each case (Figure 11). This revealed a relatively dense root system, with root lengths of up to about 60 cm, which had already developed after the first growth season. On the basis of this root formation, a clear increase can be assumed in the shear strength of the soil close to the surface. Furthermore, in the zone where willow branches were installed, a layer of finely intertwined roots, a few centimetres thick, has formed, which increasingly provides better protection from surface erosion. Further excavations are planned in the next few years, also in the other test fields.

The vegetation mats with pre-cultivated plants of the bank and reed zone (slope inclination 1:3) installed on various types of filter mat (sheep wool fleece, synthetic fleece, woven coir fabric) were not able to develop well in the zones that were submerged repeatedly and, in some cases, for long periods of time. The point-by-point (stakes) and linear (cross-bars) anchoring methods were not capable of permanently guaranteeing contact between the vegetation mats and the soil over an entire area when exposed to load from buoyant force and wave action. The load causes the vegetation mats to rise and fall between the anchors, with the result that the pre-cultivated individual plants cannot take root in the subsoil, or the fine roots are torn out again. Stakes that have become loose or have been displaced must be renewed repeatedly. Figure 12 shows the lower slope zone in Test Field 7, which was subject to considerably stronger hydraulic load up to about 1 m above the AZW. In comparison with the well developed growth in the bank zone just above this, investigation here revealed a destroyed vegetation mat, largely devoid of growth, while the filter mat underneath was partly exposed. The sheep wool fleece that had been used in some places had been almost completely dispersed in just a few months, which meant that these areas no longer had any protection against erosion. Soil erosion that has already taken place can be clearly seen in Figure 12 through the position of the cross-bars. To ensure the stability of the slope, it has already been necessary to secure the lower slope zone with armour stones in some places.

Figure 12: The vegetation mats in the lower slope zone, subject to heavy load (30.05.2013) – TF 7

Figure 13: TF 9 without slope protection (14.12.2011)

Figure 14: TF 9 without slope protection (22.02.2012)

Test Field 9, which remained without bank protection measures after removal of the riprap revetment above the AZW, demonstrates that – given the current hydraulic load and the total lack of bank protection – erosion and sliding of the slope will occur, as expected, with in-creasing frequency (Figures 13 and 14). Whether the hinterland at this section of bank, with its limited dynamic activity, is adequately protected by the willow stem cuttings, and their root systems, that were planted in two rows at the transition between the slope and the level ground will be demonstrated by the future development.

5 SUMMARY AND OUTLOOK

The purpose of the field trials at the River Rhine was to test various technical-biological bank protection measures in situ under the conditions of a waterway with large fluctuations in the water level and with heavy navigational traffic. Extensive experience regarding the installation of the various measures and their development in the critical early phase has already been gained, of which it was possible to present only a small extract in this article. Detailed reports with further results may be viewed at the thematic portal: "http://ufersicherung.baw.de/en/index.html".

The majority of the technical-biological bank protection measures developed well in the first year after completion and provide adequate bank protection. In some test fields improvements were necessary – for example, renewal of the anchorings that had become loose as a result of submergence. Only in one test field (Test Field 7) has it already been necessary to carry out local repair measures (covering of the lower slope zone with armour stones), as the vegetation mats there had been severely damaged by submergence and ship-induced load.

This monitoring work will be continued as before. Besides the increasing growth of the plants, and particularly of the roots, that will continue to be studied intensively for its relevance to the stability of the banks, one of the aims of the monitoring of vegetation and fauna is to assess the effectiveness of the measures with regard to ecological improvement of the bank. The final assessment of the various measures, as far as possible, cannot be carried out before 2016 at the earliest, after several growth seasons.

Based on the analyses and assessments of the test stretch at the River Rhine and other test areas, valuable conclusions are expected to be drawn on how technical-biological bank protection measures can be implemented on large rivers, and on waterways in general. Starting from experience gained on test stretches, and using also results from laboratory and model tests as well as theoretical analyses carried out at the BAW, recommendations for future projects will be developed.

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