RECONSTRUCTION AND IMPROVEMENT OF DYKES BY USING LOCAL SOIL AND GEOSYNTHETICS

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ABSTRACT: During the past ten years, almost all large river basins in Germany have been afflicted by extreme floodings which caused devastating damages. Every single flood leads to the conclusion that an effective flood protection is urgently needed. Approx. 7,500 km river dykes forming the most important and effective elements of flood protection at our rivers have to be checked and adjusted to current protection aims. As funds are short and limited, technical solutions permitting the use of locally available soils for the construction of dykes are very attractive. Cost-effective and competitive solutions can be achieved by using geosynthetic clay liners and geosynthetic filters. It should be aimed for improved cross-sections of dykes with an effective sealing zone and a downstream filter zone with the possibility for the use as a dyke maintenance road. Examples from the river basins of Rhein, Donau, Oder and Elbe show the successful realization of corresponding conceptions for safe dykes.

1 INTRODUCTION

Dyke failures of comparatively "aged" old dykes characterize the damages caused by the floods at the German river basins of Donau, Oder and in 2002 at the Elbe River and its tributaries (see also Figures 1 and 2, more than 100 dyke failures alone along the Mulde River!).

Figure 1 More than 100 dyke failures and floodings in 2002

Comparing old railroads and road embankments it is also held for the old dykes that cross-section, construction material, design and sealing do often not correspond to the today's technical requirements. The bygone floods showed that especially in the case of older dykes the critical ultimate state of a water supersaturated dyke cross-section can result in a dyke failure. Dyke cross-sections which are already damaged by erosion, root penetration and burrowing animals have to be judged as damaged dykes and have thus to be improved. Results from soil investigations show that especially the efficiency of water exposed sealings of the "aged" dykes is not sufficient to withstand the loads to be expected. These dykes can be rehabilitated by means of technical measurements and can regain their ability to work as barrage construction also for long-term floods with flood peaks within the design flood water level.

Figure 2 Mulde River dyke failure in August 2002

2 BASIS INFORMATION - RIVER DYKE DESIGN

The design principles for the constructive design of a river dyke with a high protection efficiency in the load case flood are suggested in the Guidelines 210/1986 "River Dykes" published by the German Association for Water Resources and Land Improvement (DVWK) in the form of the Three-Zone-Dyke (Fig. 3). The characteristic features are:

- D = Impermeable water exposed side - sealing
- S = Permeable dyke core - supporting
- F = Very permeable air side - head-loss-free drain-off

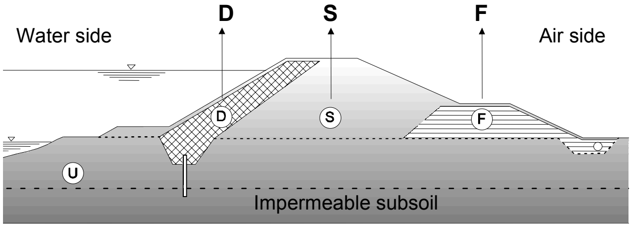

Figure 3 Three-Zones-Dyke cross-section (DVWK 1986)

To guarantee the efficiency of the dyke also under long term flood loads the mentioned components are of decisive importance. Especially in the case of older dykes these components have to be checked continuously as to their functionality.

For the construction of a modern Zone-Dyke it is recommended to install geosynthetic clay liners (GCL) as water exposed side sealing and geotextile filtration nonwovens to achieve safe filtration zones below the necessary dyke maintenance road on the lee-side of the dyke.

3 THREE-ZONES-DYKE - WATER SIDE SEALING

Special attention should be paid to the notes given for example in the DVWK-Guidelines 210, saying that compacted mineral clay liners (CCL) as sealing layers should be installed in thicknesses of d = 1 m to 1.50 m in order to be able to sufficiently withstand dehydration processes and cracking which can occur resulting from our climate.

The increase of the water permeability or the decrease of the sealing effectiveness of installed mineral compacted clay liners (CCL) have especially been observed and tested in the field of landfill technology. These results can and must be transmitted to dykes, if they should be "safe". The installation water content of a mineral sealing is just a short-term value. Thus, modified water contents and consequently modified permeability of the installed compacted clay liners have to be assumed. After dry periods have influenced the sealing a higher water permeability can be achieved, which especially has to be considered in the case of long term floods. Current experiences gained from river dykes and from landfill technology document that the permeability or the sealing efficiency of the fine-grained sealing zone have to consider partly saturated soil conditions. Long-term water contents of the mineral sealing zone can considerably deviate from the original installation water content. Dramatic changes of the permeability or loss of the sealing efficiency can occur (e.g. $k_f \leq 10^{-9}$ m/s to $k_f \leq 10^{-6}$ m/s) HEERTEN (1999). A reactivation of the sealing efficiency in the case of, for example, a water logging occurring during a flood, must not be expected. In the case of fine-grained sealing zones in partly saturated soil zones of the dykes a sealing efficiency which can be reached with a classic compacted clay liner placed under water under permanent water build-up must also not be expected.

In the case of actually available geosynthetic clay liners (GCL), corresponding losses of the sealing efficiency which were concurrently causative for the dyke failures at the Oder and the Elbe River are demonstrably not to be feared also after possible dry-wet-cycles, as perennial lysimeter test trials have shown by BLÜMEL (2002).

In terms of soil mechanics sufficiently dense, fine-grained soils ($k_f \leq 1{\cdot}10^{-9}$ m/s) or artificial sealing elements have to be installed as sealing zones in the dyke. According to ZTV-W LB 210 a laboratory value $k_f \leq 1{\cdot}10^{-9}$ m/s is required for the installation of a mineral sealing layer. This value has to be verified and must not exceed more than one decimal power at each testing sample (limiting value $k_f \leq 1{\cdot}10^{-8}$ m/s). Relating to the layer thickness according to DVWK 210 the installation of soil layers with a layer thickness of 1 m to 1.50 m with a permanent permeability coefficient $k_f \leq 1 \times 10^{-9}$ m/s is consequently recommended for the construction of a water exposed dyke sealing system.

Geosynthetic clay liners are suitable for the replacement or the improvement of conventional mineral clay or loam sealing at water exposed slopes. The sealing function is taken over by the bentonite powder with its high swelling capacity which is - in the ideal case - encapsulated erosion stable and needle-punched between two geotextiles (cover and carrier nonwoven). Geosynthetic clay liners can - in comparison with mineral sealing materials - achieve an equivalent sealing efficiency at considerably lower layer thickness (approximately 1 cm) because of the comparatively low permeability coefficient of the swollen bentonite.

It is possible to install a geosynthetic clay liner in winter at temperatures of up to -10 °C, if an immediate coverage of the soil of at least 60 cm can be guaranteed. In comparison with a mineral compacted clay or loam sealing the installation of a geosynthetic clay liner can be carried out simple, fast and with a minimum use of machines (installation by means of a spreader bar, Fig. 4).

Figure 4 Reconstruction of the Kinzig River dyke in 2001 - Installation of GCL Bentofix® B4000 (installation by means of a spreader bar)

The recommendations for the application of capping sealing systems at the bed and on the slope of waterways EAO (2002) published by the BAW describe the properties and requirements for compacted mineral sealing systems and geosynthetic clay liners (bentonite mats). Both sealing systems are assigned to those sealing systems of natural sealing materials.

According to EAO (2002) geosynthetic clay liners have a high deformability and adapt very good to the existing subground deformations or to those which come into being during the construction phase. A basic test according to the BAW criteria can be required for GCLs in analogy to geotextile filters. In this case the erosion stability required by EAO (2002) that means that a prevention of a washing-out of the bentonite out of the carrier and cover geotextiles by a carrying out of percolation tests with high gradients, turbulence tests according to RPG (1984) and flood tests carried out with very high velocities can be tested. The German Association for Geotechnics (DGGT e. V.) documents the state-of-the-art concerning the dimensioning, application and inspection in the Recommendations for the Application of Geosynthetic Clay Liners EAG-GTD (2002). These recommendations give minimum values as orientation guide for the selection of geosynthetic clay liners. The requirements for this soil sealing system follow the above mentioned ZTV-W LB 210 or MAO (2002).

Geosynthetic clay liners are superior to compacted mineral sealing systems also as to dry-wet-cycles and freeze-thaw-cycles. The possibly occurring effects of root penetration and/or rodent attacks must - as in the case of mineral sealing systems - also be considered. The risk of rooting of GCLs can be decreased significantly, if non-cohesive cover soils are used (Fig. 5). Beaver grids can provide protection efficiency against rodent attacks. Further advantages of geosynthetic clay liners as dyke sealing elements are:

- The susceptibility to settlements without reducing the sealing properties
- the constant quality standard also after installation
- good friction behaviour also at steeper slopes

Figure 5 Reconstruction of the Kinzig River dyke in 2001 - installation of non-cohesive cover soil from the river bed

For the stability analysis and the determination of the saturation lines in the case of flooding the structure of the subsoil in the dyke area must of course be considered. The dyke sealing should only go into the subsoil thus far as it is necessary to keep the stability of the dyke or for reduction of the seepage water, respectively. The use of a subsoil sealing system, as it is usually installed in embankment dams or dams, is not necessary for river dykes and is often undesired as the groundwater table between the land to the seaward side of the dyke and the land to the landward side of the dyke usually should not be separated. Further information is among others given in the DVWK-Guidelines 210/1986 "River Dykes" or in the German Standard DIN 19712 "River Dykes".

Based upon the extraordinary high level of experiences in landfill technology, already available mineral systems in dams and dykes are more and more improved by means of geosynthetic clay liners (GCL) or are totally replaced.

4 DYKE REHABILITATION PROJECTS WITH GEOSYNTHETIC CLAY LINERS

4.1 *Elbe River dykes in Saxony-Anhalt (2003)*

Since April 2003 different units of dyke rehabilitation projects at the Elbe River near Dessau have been tendered by the regional authority of flood protection and water management in Saxony-Anhalt for regaining adequate flood protection. Geosynthetic clay liners for the water-side as well as geotextile filter nonwovens for the lee-side and geogrids as reinforcing elements in case of less subsoil bearing capacity have been installed (Fig. 6 and 7).

Figure 6 Elbe River dyke near Bösewig in Saxony-Anhalt - rehabilitation cross-section

4.2 *Mulde River dykes (2002)*

The summer flood in the year 2002 caused more than 100 dyke failures at the Mulde River. In November 2002 sections of the Mulde River dykes to the north of Leipzig have been reconstructed within the framework of rehabilitation measures by means of a geosynthetic clay liner as dyke sealing system on the water exposed side. An installation of these layers during a frost period is no problem; however, the constructional accompanying measures, thus the covering of the GCL, could not be carried out in time because of the onset of winter. In February 2003 this region was again afflicted by a flood. At this time the rehabilitation works have not yet been finished and although the works at this dyke sealing project were still in progress the dyke where the already swollen GCLs have been installed without any soil coverage withstood this winter flood without any damages (Fig. 8). Thus, a sufficient protection against flood could be guaranteed even during the construction phase. After the winter flood has receded this project has been finished.

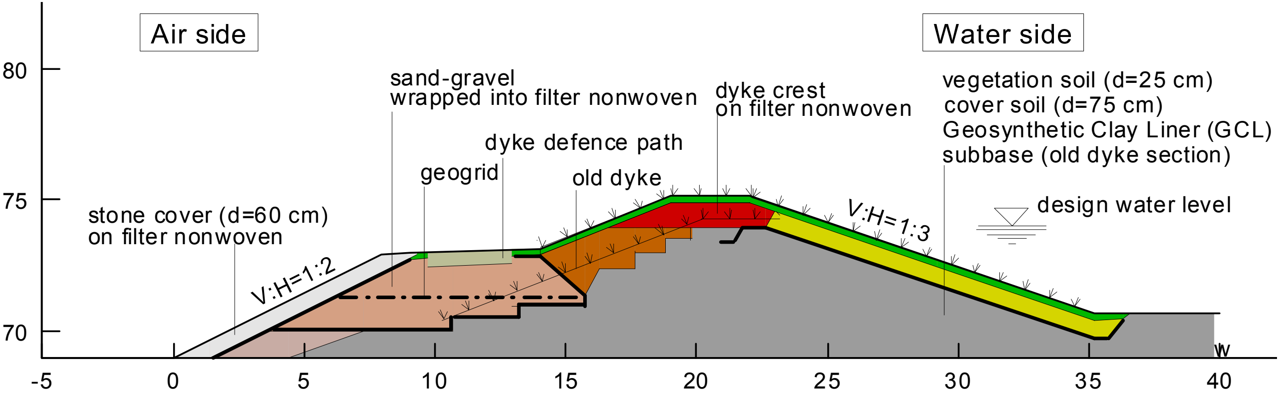

Figure 7 Elbe River dyke near Bösewig in Saxony-Anhalt - rehabilitation cross-section

Figure 8 Mulde River dyke already protected during the construction phase: Installation of GCL on the slope at the water exposed side 2002 (top); already swollen but intact GCL which has been folded back to be able to drive on the dyke crown after the flood in winter 2003 (below).

4.3 *Lippe River dyke (1994)*

The dykes in the mining sinkhole area on both sides of the Lippe River near Haltern-Lippramsdorf and Marl have annually been attacked by floods in the winter months. To protect the surrounding residential areas as well as the coal-mine nearby, the dykes have been made higher in 1994 on behalf of the Lippeverband. The northern and the southern dykes have been reconstructed in layers by means of locally available residues gained from the coal-mining (SAATHOFF & HEERTEN, 1996).

For stabilisation and ecological reasons (lixiviation of the residues) it became necessary to install a sealing system.

The use of clay or loam was evaluated as uneconomical and would have lead to extensive installation and control measures during the construction phase. Furthermore, the installation period would have been restricted to the dry months. For this reason a geosynthetic clay liner was installed in a laminar way as sealing element on the water exposed side of the dyke slope and covered with sand, gravel and topsoil (Fig. 9).

In the case of the southern dyke the installed residues gained from the coal-mining have been encapsulated by the geosynthetic clay liner, in the northern dyke a steel sheeting was installed which was connected with the geosynthetic clay liner.

The decisive factor for a solution with a geosynthetic clay liner was also the susceptibility to settlements for the rigid connection with the steel sheeting.

Figure 9 Installation of a GCL for use as dyke sealing system on both Lippe River sides near Haltern-Lippramsdorf and Marl (1994)

4.4 *Kinzig River Dykes (2000/2001)*

Even in the year 1987 the Gewässerdirektion of the southern Upper Rhine started to keep the Kinzig River dykes which are partially older than 100 years and 160 km long state-of-the-art. During floods in the years 1990 and 1991 critical dyke penetrations appeared. A considerable programme for the rehabilitation of the Kinzig River dykes has been conceived, the execution and purpose of which will guarantee a state-of-the-art construction in the years 2000 and 2001.

During this construction phase the dykes at the Kinzig River have in defined section been made higher on an average between 60 cm an 80 cm for more safety against overtopping during flood. In the case of an insufficient impermeability the river dykes have been provided with a dyke sealing system on the water exposed side consisting of an continuously installed, shear strength transmitting geosynthetic clay liner (SANTO, 2003).

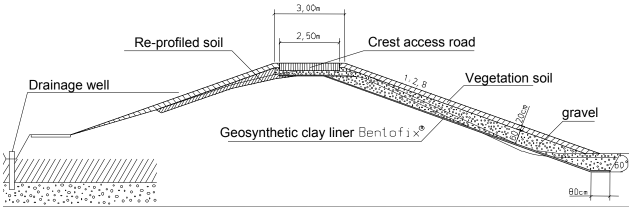

Figure 10 Cross-section of the Kinzig River dyke

For the left side of the Kinzig River near Weier (River-km 14+750 to 17+000) 36,000 m² of a geosynthetic clay liner have been installed. Due to the arising expenses for the transportation of the mineral sealing material a loam sealing would have been uneconomical from the Gewässerdirektion's point of view. The realisation of this project was carried out in consultation with the Bundesanstalt für Wasserbau in Karlsruhe (BAW):

The delivered GCLs have been subject to an external and internal quality control for the entire construction period. After the installation works which have been carried out every 100 m have finished a 60 cm thick compacted gravel-sand layer was installed at a slope inclination of V:H = 1:2.8. The soil has directly been taken from the washed up toe of the Kinzig. Thus, at the same time the important maintenance function at the Kinzig River could have been taken over. In order to achieve a rapid surface erosion protection by means of a sod each installation and rehabilitation section has been covered with subsoil and has been sowed.

4.5 *Oder River dykes Bad Freienwalde (2001)*

The summer flood in 1997 was an extraordinary event at the Oder River with a flood peak which remained on the same level for 14 days and where the highest recorded flood peaks have been exceeded. The flood caused considerable dyke failures which have been repaired within the framework of an immediate programme for the rehabilitation of dykes and the general plan "flood protection Oder River" which have been brought into being by the regional authority for environment in Brandenburg (LUA). In 1997 leachates occurred at the land exposed side of the dyke in the area of Bad Freienwalde (northern area of the Oderbruch) as well as slippings of the slopes. All actions which have been taken included among others the elevation and widening of the dyke crown, a levelling of the water and land exposed sides of the dyke slopes as well as the installation of mineral load filters. The detailed rehabilitation programme is presented in a paper published by TÖNNIS, GRIROD & PAPKE (2002). The existing dyke has been removed - starting from the dyke maintenance road up to the slope toe at the water exposed side of the bench - and been displaced and reinstalled at the water exposed side (Fig. 10).

The slopes have been built up again in inclinations of V:H = 1:3 and a geosynthetic clay liner has been installed as dyke sealing. This GCL has been covered with gravel sand and top soil. Due to the special geological situation of the dyke subsoil a vertical sealing wall where the GCL is connected was installed in a vertical FMI-wall at the water exposed side of the dyke toe area.

5 RAILWAY-RECONSTRUCTION AFTER FLOOD 2002 IN WEESENSTEIN IN MÜGLITZ-VALLEY

In consequence of the devastating floods in 2002 approximately 80% of the available infrastructure of the Müglitz-Valley near Dresden has been destroyed. Also the Weesenstein section of the Müglitz-Valley-Railway has been affected. Near Weesenstein the existing railway embankment and complete slope in direction to the Müglitz River flood have been eroded and destroyed by the flood water table and strong currents.

Within the framework of the reconstruction of this railway line the railway embankment was rebuilt as temporary reinforced earth construction by means of Delta-Green front grid elements for achieving a smooth front face (Fig. 12). Secugrid 120/40 R6 which is approved by the EBA (Federal Railway Administration) was chosen for use as reinforcing element. According to the calculations which were carried out, the geogrids have been installed in 10 layers in layer spacings of approximately 0.50 m and has been connected with the front element with a guaranteeing tensile strength. A crushed grain material (0/45 mm) has been used as fill material (Fig. 11).

The installed geogrids are stretched, monolithic polyester bars with welded junctions and a main tensile direction. A special advantage is the notably low creep strain behaviour of the stretched polyester as well as the non-existence of a production related construction elongation. Thus construction settlements or elongation, respectively, are drastically reduced which is an important requirement for rails and routes.

By means of this fast and cost-saving construction method the structure could be rebuilt within a few weeks and the normal railway service could be taken up again.

It is assumed, that this geogrid reinforced railway embankment will survive each flood impact in future.

Figure 11 Installation of geogrids as reinforcing as part of flood railway rehabilitation in Weesenstein (2002)

Figure 12 Facing of geogrid reinforced railway embankment

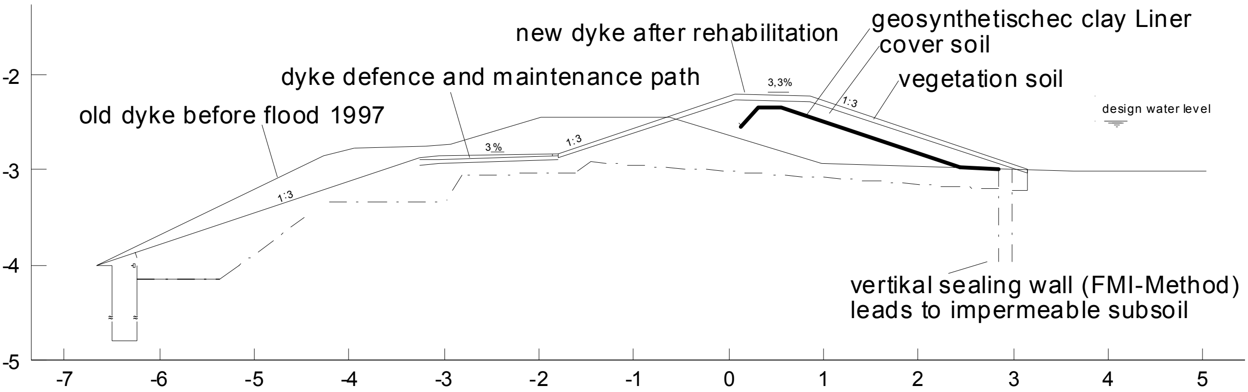

Figure 10 Cross-section of Oder River dyke in Bad Freienwalde (TÖNNIS et al. (2002))

6 CONCLUSION

In dyke construction geosynthetics are used as sealing system on the water exposed side, in the air exposed drainage and load body as well as for the increase of the stability against slip and slope failure mechanisms or for erosion protection measures. To guarantee the efficiency of a dyke under permanent flood loads the construction of an impermeable water side (impervious), a permeable dyke core (supporting) and a very permeable air side (head-loss-free drain-off) is of decisive importance.

Because geosynthetic clay liners (GCL) have already been installed as standard construction method in landfill technology, they have also been used more and more for about 10 years in hydraulic engineering for use as sealing of toes and slopes of artificial waterways (FLEISCHER & SCHREIER, 1998, 2001) or as water exposed surface sealing system at dams and dykes. As geosynthetic clay liners are part of the EAO 2002 published by BAW they can be considered as established hydraulic engineering solution.

Compared with mineral sealing systems geosynthetic clay liners can achieve an equal sealing effectiveness at considerably thinner layers (approximately 1 cm) because of the comparatively very low permeability coefficient of bentonite powder. As to dry-wet-cycles and freeze-thaw-cycles they are superior to the compacted mineral sealing systems and offer the following advantages because of the

- lower susceptibility to settlements without adverse effects of the sealing properties
- defined consistent quality standard in installed condition
- erosion stability and
- a good friction behaviour at steeper slopes.

Compared with a compacted mineral clay sealing system a lower excavated soil quantity, a faster and more flexible installation, a lower permeability and cheaper solution are decisive arguments for the obvious acceptability in the case of current projects. The increasing number of tenders considering a geosynthetic clay liner instead of a mineral clay liner affirms this.

Based on experiences with both - mineral and geosynthetic clay liners - the authors are taking the liberty of postulation, that the equivalency of compacted mineral clay liners have to be shown in analysis and not vice verse as it is usable at present.

Projects which have successfully been carried out with a geosynthetic clay liner for use as sealing element on the water exposed side at the river dykes of Lippe, Kinzig, Oder or Mulde support the mentioned arguments as reference projects.

Relating emergency dyke rehabilitation works the authors gained the experience, that installed, but not soil covered GCLs are taking the double-functionality of sealing and erosion control at the same time, although in condition of direct flood water exposure.

A consequent development of the impermeable coverings-against-attack-by-waves-construction method in waterway constructions are geosynthetic clay liners as compound products together with a sand mat as geotextile filter. This composite is especially developed for an underwater installation in one execution process.

The authors conclude, that modern construction methods with geosynthetics for improved and reinforced earth structures as dykes, dams, roads, railways embankment are providing cost-effective solutions with a highly increased safety and protection capability relating the flood load case.

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