Danger of flooding - New safety measures in dike construction by using geosynthetics

Risques d'inondation - de nouvelles mesures de sécurité pour la construction de digues grâce à la mise en œuvre de produits géosynthétiques

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ABSTRACT

The risk of dyke failure is mainly given in cases of critical water saturation (due to non effective sealing or drainage zone) and dyke crest overtopping (due to undervalued crest height, settlements or higher design water levels than expected). Safe cross-sections according to state of the art are characterized by the successful use of geosynthetic clay liners as alternative dike sealing element. After several years of service as sealing element at dikes in Germany, geosynthetic clay liners (GCLs) have been exhumed and examined. The results of these in-service GCL analyses confirm the effectiveness. As an alternative to conventional construction designs for dike crest overflow, an enhanced geosynthetic application of soil reinforcement is taken into account. Different construction methods for the design of overflow dikes are presented. Some of the presented constructions were tested within a research project at Institute of Hydraulic and Water Resources Engineering of the Technische Universitaet Muenchen. The results of these tests are briefly summarised.

RÉSUMÉ

Le risque de ruptures de digues est surtout important dans les cas de saturation critique en eau (causée par un étanchement ou une zone de drainage inefficaces) et de déversements sur le haut de la digue (suite à une mauvaise évaluation de la hauteur des vagues, un tassement ou des niveaux d'eau supérieurs à ceux prévus). Les sections sûres selon les règles techniques reconnues se caractérisent par l'utilisation réussie de bandes d'étanchéité géosynthétiques en tant qu'éléments d'étanchement de digues alternatifs. Après de nombreuses années, pendant lesquelles les bandes d'étanchéité géosynthétiques (GCL) ont servi d'éléments d'étanchement de digues en Allemagne, elles ont été déterrées et analysées. Les résultats de ces analyses de GCL usagées confirment leur efficacité. En tant qu'alternative aux concepts de construction de digues conventionnels pour les déversements sur les hauts de digues, une application de renforcements de sol plus étendue des géosynthétiques est prise en considération. Différentes méthodes de construction sont présentées pour le développement des digues à déversements. Certains des concepts présentés ont été testés au sein d'un projet de recherche à l'Institut de Sciences Hydrauliques et Aquatiques de l'Université Technique de Munich en Allemagne. Les résultats de ces essais ont été résumés brièvement.

Keywords : dike, geosynthetic clay liner, overflow, geogrid

1 INTRODUCTION

Historical flooding along rivers in Germany has led to the significant incorporation of geosynthetics in dike construction.

The use of geocomposite drainage materials for soil stability and erosion prevention between the core of a dike and its air-exposed side and the installation of geosynthetic clay liners (GCLs) as a sealing barrier along the dike’s water-exposed side have become established methods of construction.

The effectiveness and strength of geosynthetic performance in dike construction has been examined at various research institutions and documented.

Erosion from within embankments and sudden breaches to the surface of dikes can be prevented with knowledge and implementation of geosynthetics. Thus, these technologies provide not just structural defenses but more time for evaluating risk and providing emergency response to populated areas that are threatened by rising water levels.

2 DIKE SEALING WITH GEOSYNTHETIC CLAY LINERS

2.1 *General*

Towards the end of the 1980s, a new class of needle-punched GCLs was developed for geotechnical containment applications. The needle-punch manufacturing technique allowed bentonite clay to be sandwiched between geotextiles. This created an industrially produced alternative barrier to conventional construction techniques made of thick layers of compacted clay.

In addition to environmental protection applications, needle-punched GCLs were used successfully in structural waterproofing installations, such as for buildings; and, this led to more investigation of uses for GCLs in hydraulic engineering (DGGT 2002). Needle-punched GCLs found considerable recognition for dike improvement (Figure 1), where they helped realize an economic sealing solution (Heerten 2002 and 2006). The uniform layer of bentonite clay between the cover and supporting geotextiles created a mineral sealing layer with high long-term shear strength (DGGT 2002).

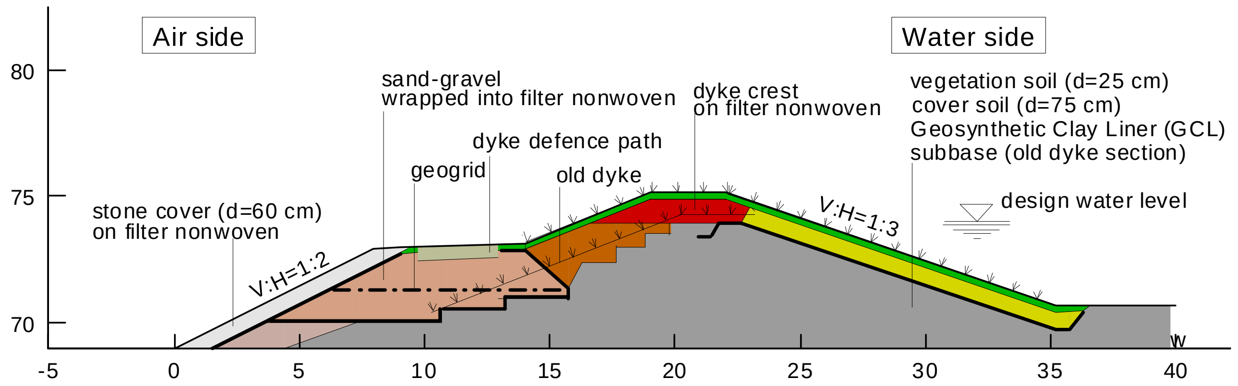

Figure 1. Typical cross-section of a rehabilitated dike on the Elbe River near Bösewig, Saxony-Anhalt (Heerten 2008)

From the aftermath of the Elbe River floods of 2002 through the end of 2007, approximately 160 flood protection projects were carried out in Germany and used approximately 2.4 million m² of filter fabric, 330,000 m² of geogrids, and 770,000 m² of GCLs for dike sealing (Heerten 2008).

2.2 *GCls - Exhumed Material*

Taking into account climatic influences, a protective cover layer of 80 cm is generally recommended for barriers made of cohesive soils and geosynthetic clay liners (DWA 2005). The functional advantages of using GCLs include installing a thinner barrier layer without sacrificing barrier performance, consistency in the barrier layer thickness, and good friction behavior. However, one must consider the possible effects of root penetrations and/or rodent attack, just as one would with conventional compacted earth barriers. These effects are controlled through a dike's cross-sectional geometry, use of non-cohesive soils, cover layers that deter or do not attract burrowing animals (Figure 2) or through additional, technical measures.


Figure 2. Rehabilitation of dike slope along the Kinzig River (2001): covering of the GCL Bentofix with gravel as an "animal deterring" cover layer (right)

At dikes on the Elbe River (Dessau, Saxony-Anhalt), Lippe River (Haltern-Lippramsdorf, Northrhine-Westphalia), and on the Kinzig River (Rhine area, Offenburg, Baden-Württemberg) sections of GCL installations were exhumed for technical analysis after four-, six- and 12-year service windows and investigated by the Federal Waterway Engineering and Research Institute (BAW) in Karlsruhe. Gained results are partly documented in Fleischer et al. (2007).

The laboratory investigations sought to uncover possible variations in material properties that occurred during the GCLs' multi-year burial. Compared to newly manufactured products, researchers found no significant quality differences and the samples were certified as such. The analyzed GCLs had retained full functionality up to 12 years. The investigated "high performance product" GCL (with only 1 cm of a high-value bentonite layer) fulfilled all expectations. The exhumed samples showed permeability values of $k = 2.5 \times 10^{-11}$ m/s to 8×10^{-11} m/s, hydraulic conductivity values that corresponded to pre-installation permeability tests. Figure 3 shows the installation of the needle-punched GCL as dike sealing element at the Lippe River dike in 1994. A couple of years later the Kinzig River dike rehabilitation was realized in 2001 (Figure 2). In both cases the recently exhumed GCLs show full efficiency after several years in service.


Figure 3. Lippe River dike rehabilitation (1994): installation of Bentofix GCL as a sealing layer

3 OVERFLOW PROTECTION SYSTEMS

Normal flood embankments along rivers are not designed for overflow loads, except special designed overflow sections. Overflow areas are very rare, nevertheless the reactivation of flood retention volume is one of the main aims of the German national water management law. The technical code for flood protection dikes along rivers (DIN 19712, 1997) excludes the protection of the landside embankment from technical standard structures because of high costs and poor experience with such structures. Thus, overflow loads mostly lead to a very rapid and complete failure of the dike body forming a dike breach with lengths from few meters to several hundreds of meters. A huge part of the damages that occurred due to dike breaches during the flood incidents 1999, 2002 and 2005 in Germany could have been avoided by focusing the application of overflow protection structures. Hereby the fact should be kept in mind that overtopping or overflow is the most likely reason for dike failure. Additionally, flood protection measures in order to avoid overtopping bear a high risk for the flood task forces.

One major issue objecting to overflow dike structures are the high costs. This aspect can be met by using designs applying geosynthetics. Model tests showed that special protected dikes using geosynthetics can withstand overflow heights up to 0,30 m and more (Haselsteiner et al. 2008). These measures lead to a retardation of the flooding of the hinterland located behind the dike and additionally a complete failure is avoided. Both effects result in a reduction of flood damages and in gaining more time for taking other flood protection measures. Although a lot examination work on the field of this topic had been carried out centuries ago (CIRIA 1987) no design specification or standards were created. Nevertheless, in comparison to commonly used overflow protection measures such as riprap or just flat embankment inclinations geosynthetic overflow structures are an effective and efficient solution. Hereby, LFU BW (2004) admits that basically this kind of structures can withstand higher loads and have steeper embankment inclinations than other structures what put emphasis on the efficiency and bearing capacity. Possible combinations of geosynthetic overflow structures with soil-geosynthetic interaction approaches are:

(I) Surface erosion control (with geosynthetic-reinforced grass cover)

(II) Transition zone protection of dike and vegetation layer (in the event of lost grass cover)

(III) Integrated erosion protection (security of the dike's core/cross-section)

By Method (I), the vegetation layer is reinforced by the use of three-dimensional erosion control mats. As vegetation is established, the roots wrap themselves in the synthetic undirected netting and lock themselves into place, thereby stabilizing the surface against erosive forces. This method does not involve much expense since it mainly requires simple time for the establishment of vegetation. Pilot installations in Great Britain in 1987 confirmed the effectiveness of reinforced grass covers on dam overflow embankments. They showed good functionality for the three-dimensional erosion control systems (CIRIA 1987).

At the laboratory of the Technical University of Munich's Hydraulic Engineering and Water Supply Research Institute a series of model tests were carried out in the years of 2006/07. Bavaria's State Department of the Environment (LfU) provided the professional backing for the project. Two of the examined constructions that performed best are representing Method (II) and Method (III). The test rig was located in a concrete U-profile discharge section of 2.5 m width and 2.5 m height. Therefore the tests were carried out in full scale. The test rig channel was about 20 m long. The models were loaded by specific discharge values from 0.050 m³/s·m up to 0.300 m³/s·m what lead to overflow heights of 0.10 m to 0.35 m (Haselsteiner et al. 2008).

Applying a composite product of a geotextile and a geogrid, the system shown in Figure 4 and 6 performed well. Underneath the surface protection layer gravel was spread and compacted. The transition zone from sand body to gravel layer was filtered by a geotextile filter. To provide homogeneous overflow conditions a steel kerb was placed on the crest. One advantage of this kind of protection system for practical use is the simple way of application. After the refurbishment of dikes, the geosynthetic layer can easily be placed on the finished landside slope. The top soil layer can be placed on the top of it afterwards. If the grass cover is lost, a reinforced overflow slope remains. So with only a slightly higher expenditure, a stronger protection system is achieved.

Method (III) is certainly the most secure and most technical approach to dike construction. A breach failure such as with a traditional, unreinforced dike can happen without warning. Soil improvement through the installation of geotetxiles or preferably with geogrid reinforcement in a wrap-around construction draws upon geotechnical measures used commonly in road construction, in reinforced steep slopes, and geotechnical structures inclined 45° to 90°. In dikes with comparatively more less slope angles, this method of construction can handle hydraulic loads for slope angles of approximately 33° (or, 1:1.5). This system using wrap-around has the advantages that a certain part of the energy dissipation takes place on the slope similar to stepped spillways (cascades). Among the investigated systems Method (III) is considered to have most bearing capacity (Figure 5 and 7).

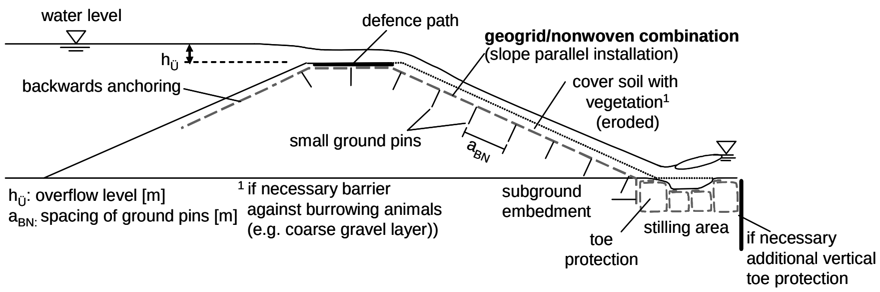

Figure 4. Overflow defense Method II, embankments with geogrid-geocomposite system and soil nails (Haselsteiner et al. 2008)

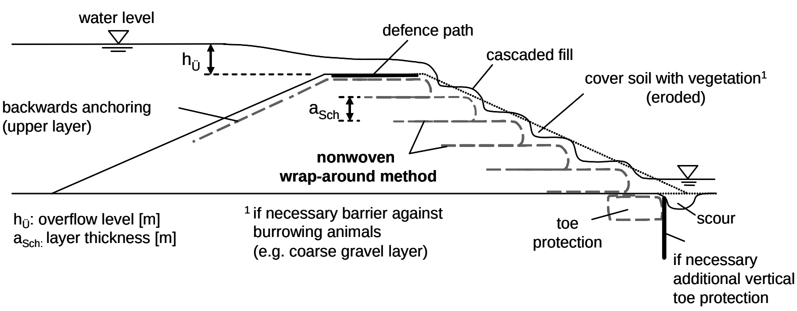

Figure 5. Integrated overflow defense Method (III) with geocomposites and wrap-around method (Haselsteiner et al. 2008)

Figure 6. Method (II) – Overflow with embankment stabilization system using geogrids and geocomposites (nails up), slope 1:n = 1:2.5, q = 300 l/(s·m) (Haselsteiner 2008)

Figure 7. Method (III) – Overflow with integrated defense design using geocomposite envelopes, slope 1:n = 1:1.5, 1 = 130 l/(s·m) (Haselsteiner 2008)

4 SUMMARY

For the design of dikes, the use of Geosynthetic Clay Liners (GCLs) as a barrier on the water side has become established in current practice. Evidence from exhumations of in-service installations dating back more than 12 years show how GCLs maintain full functionality over time.

Integrated into flood defenses, geosynthetic technologies provide structural strength against floods and more time for emergency responders to react and to notify and evacuate at-risk residents.

An example of a dike improved with geosynthetics is shown in cross-section in Figure 8. This project was realized after the Oder River's flood in Poland (1997). After a dike was breached, its reconstruction demonstrated ideal aspects for a long-term standard of safety and defense against overflow threats. The dike was strengthened through the placement of a GCL on the water side, an integrated erosion control design at the dike's core using the geocomposite wrap-around method, and a defensive drainage system on the toe of the air-exposed side. Breach behavior such as in a dike with a conventional construction (using only earth materials) may then be considered out of the question.

In the future, economic considerations will certainly play a larger role in the design and construction of river dikes, not just in terms of the stability of retention areas behind dikes in flood zones but with consideration for the need to minimize risk to areas with a heightened potential for damage and catastrophe.

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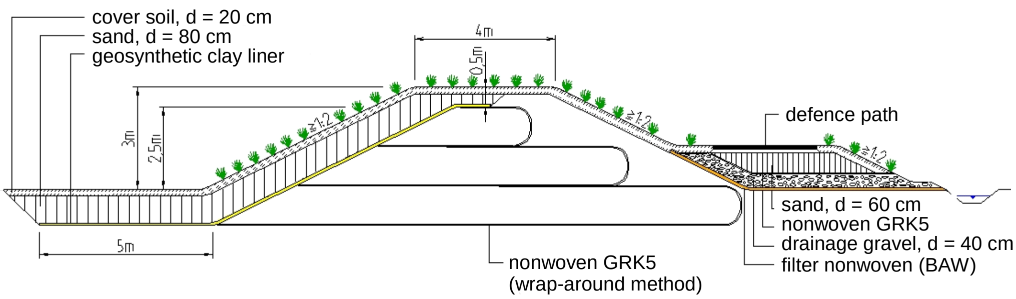

Figure 8. Cross-section of a rehabilitated dike along Poland's Oder River