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Flood protection through dyke reinforcement at the river "Elbe" in Germany

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ABSTRACT: Heavy and prolonged rain caused considerable damage to the infrastructure in June 2013 along the river Elbe region in Germany. Several flood protection dykes were damaged and caused over 12 billion Euros of economic losses throughout Germany. The purpose of dykes is to protect the towns/localities on the land side from being flooded. In order to maintain flood protection, the dykes must be renovated and reinforced. In many cases, the space on the Dam is narrow and there are buildings, monuments and protected trees along the dyke axis. Therefore, the renovation takes place often through a statically fully effective core seal (steel sheet pile wall) directly in the middle of dyke. In Germany, the remediation of the dykes through reinforcement with sheet pile wall is a reliable, efficient, permanent and therefore economical solution and, above all, a method with significantly lower environmental impact.

1 INTRODUCTION

1.1 *General preliminary remark*

River dykes serve to people to protect all over the world from floods. Damage caused by floods, climate change or simply aging can cause dykes to lose their protective function for human life, the environment, cultural assets and economic activity. Their maintenance is therefore a permanent challenge for competent authorities.

The measure described here serves to repair flood damage to a dyke in the middle reaches of the river Elbe. The Elbe is a European river. Coming from the Czech Republic, it flows through Germany and after about 1095 km (680 miles) it flows into the North Sea. It has a catchment area of approximately 150,000 km² (57,000 sq mi). This corresponds to about 40% of the Japanese territory.

The study described here does not represent a general solution for reinforcing a dyke. It must always be considered in the context of the local boundary conditions. However, it can be used as a method to find economical and sustainable dyke reinforcement.

1.2 *Normative references*

In Germany the standards of the German Institute for Standardisation (DIN) are used as the main basis for assessing river dykes. The technical standards and regulations of DIN 19712:2013-01 (Flood protection works) apply to the construction and repair of dykes.

Precisely, DIN 19712 contains specifications on:

– Planning criteria,
– Hydrological and hydraulic design bases,
– Requirements for flood protection installations (dykes, walls, mobile systems),
– Required evidence,
– Construction materials, construction execution, and quality assurance,
– Third-party construction,
– Construction work on existing flood protection works
– and operation and maintenance of flood protection works.

1.3 *Planning boundary conditions*

For the planning and redevelopment of dyke systems, a large number of boundary conditions and specifications must be taken into account. Last but not least, regional requirements of the responsible authorities must be observed. The boundary conditions described here can therefore only provide a small insight into the planning process.

The design of flood protection works is based on the design flood. This is determined by hydrological data and hydraulic models. For the example given here, a flood with a 100-year probability of recurrence is to be used.

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To this resulting design-basis water level (HQ100 water level), a freeboard of 1 m is to be added in order to make the dyke overflow-proof even in the event of wave run-up or extreme floods.

Another point is the dyke construction. In addition to the height of the dyke, the width of the crown and the slope inclination, this also includes the soil used to create the cubature. Due to the potential difference of the water head between the land and water side in the event of flooding, water may seep through the dike. Among other things, this geohydraulic load case must be taken into account when planning dyke systems: The cubature and the materials to be used must be coordinated.

Often, the inhomogeneous structure and the unqualified soil placement (insufficient compaction) especially in the case of existing dykes can lead to harmful rearrangements of fine grains in the dyke (inner soil erosion). In extreme cases, these can lead to the failure of flood protection works. Often existing plants have deficits in dyke height with regard to the design water levels. The resulting reinforcement of the dykes is accompanied by an increase in the dyke contact area. As a rule, the dyke contact area is extended towards the land side.

This leads to another essential aspect of planning - the availability of land. Thus, the possible construction time and permanent land use is influenced by, among other things, adjacent buildings and infrastructure facilities, agricultural uses and nature conservation law issues, and thus also the technical solution for reinforcing the dyke. These are often technical solutions, in the form of a structurally effective core seal (sheet piling), by which interventions in protected biotopes, existing tree populations, listed buildings or parallel roads (Figure 1) or railway lines can be reduced or avoided. Press-in methods are frequently used as insertion methods because of their reliability and the avoidance of vibration.

Figure 1. Dyke heightening parallel to a federal road.

2 COMPARISON OF VARIANTS FOR THE REINFORCEMENT OF A POLDER DYKE

2.1 *Causes*

The evaluation of flood damage over the past 15 years clearly shows the need for action. The weak-point analysis carried out on the dykes shows that the existing protective dykes do not meet today's requirements in terms of dyke geometry and construction, and therefore their stability is not guaranteed.

The following deficits were identified in the planning phase:

Although the existing dyke height is above the HQ100 water level in the entire planning section, the required freeboard of 1.00 m is not achieved along the entire section. As a result, there is a risk of overflowing during extreme floods.

The recommended dyke crest width according to DIN 19712 of at least 3.0 m with a dyke height ≥ of 2.0 m is largely not achieved. This endangers the stability in the event of flooding.

A land side surcharge filter which fulfils the function of a DIN-compliant filter berm is not existent. Due to permeable layers in the supporting body, it cannot be guaranteed that seepage water will leak out at the foot of the dyke in the event of flooding. If the seepage line above the foot emerges from the embankment on the land side, this endangers the stability of the embankment.

A paved path for dyke defence is only located on the dyke crest. This makes it difficult to access the foot of the dyke on the land side and to defend the dyke in the event of flooding.

The supporting body of the dyke has a highly inhomogeneous structure made of mainly locally extracted materials (alluvial loam, sand and gravel) with sometimes very low layer thickness. This can cause material to be discharged in the event of a flood, confirmed by observations of seepage points during the June 2013 flood. In extreme cases, it may lead to the failure of the flood protection system.

The landward slopes of the dyke are partly steeper than 1:3. The slope is 1:1.8 at some points. This endangers the stability in case of flooding and makes management more difficult.

The measure serves to eliminate flood damage and includes the repair of the existing dyke system in its current position. In addition, the dyke is to be prepared for polder use (damming on both sides).

2.2 *Presentation of the variants of the planned measure*

2.2.1 *Homogeneous dyke of impermeable soil (variant 1)*

For the construction of a homogeneous dyke (1-zone dyke), the existing dyke body is to be removed down to the top edge of the terrain. The supporting shell section of the new dyke is to be made of cohesive soil (has to be delivered).

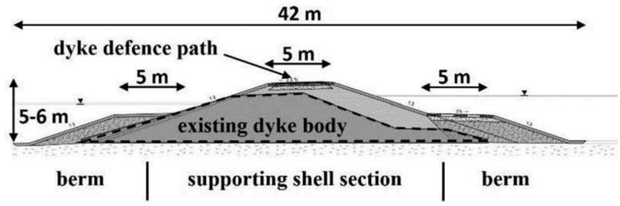

Figure 3. Variant 1.

From the non-cohesive existing material (approximately 50 %) a berm is to be profiled at the foot of the dyke on land and water side. This has two positive effects. The reduction of mass transports reduces the construction costs and furthermore the waterlogging of the actual supporting shell section will be counteracted by raising the terrain dyke (cf. Figure 3).

2.3 *2-zone dyke with mineral sealing core and supporting shell section on both sides (variant 2)*

As in variant 1, the existing dyke body is completely removed to the top edge of the terrain. Then a watertight core of cohesive material is built up in the area of the dyke top (cf. Figure 4).

A supporting shell section is built on this watertight body on the land and water side. It is estimated that about 50 % of the existing dyke material can be reused.

2.4 *Installation of a technical core seal (variant 3)*

For the installation of a technical core seal, a sealing element is installed in the existing dyke body. The raising of the dyke to the design height starts in the area of the water-side embankment shoulder towards the dyke land side made of non-cohesive material. Four sub-variants are considered for the creation of a core seal. The embedment depth of 7 m is the same for all sub-variants.

a) Sheet piling (variant 3a)
For this type of core sealing, a steel sheet pile wall is installed in the area of the planned water-side banisters, outside the dyke defence path (cf. Figure 5). In this way, subsidence-related damage to the dyke defence path caused by the sheet pile wall can be avoided.

Due to the more favourable load distribution (larger area), a flexible arrangement in the dike body is possible for variants 3b to 3d. From the point of view of construction technology, the construction on

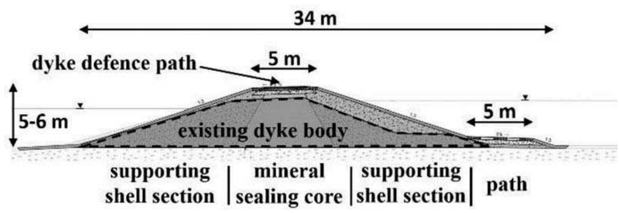

Figure 4. Variant 2.

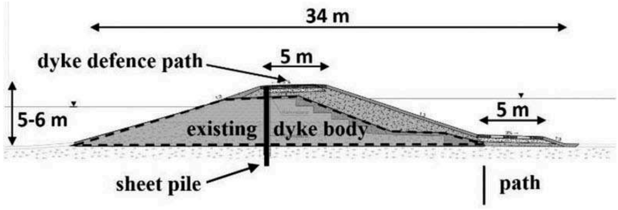

Figure 5. Variant 3a.

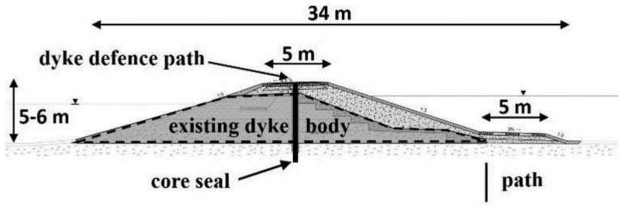

Figure 6. Variant 3b-3d.

the dyke axis (middle of the dyke crest) is advantageous (cf. Figure 6).

b) Slurry wall (variant 3b)
In the slurry wall method, a clamshell is used to excavate the existing soil along the planned dyke axis and replace it with sealing material (usually in-situ concrete).

c) Soil stabilisation (variant 3c)
For the production of the core seal, two methods are used for soil stabilisation, which essentially differ in the production process.

In the Mixed in Place process (MIP), a defined soil volume is prepared along the planned dyke axis with the aid of a single or triple screw with a predetermined quantity of binder suspension (cement) to form a homogeneous self-hardening mass in the wet mixing process and pressed back into the area from the bottom upwards. With the deep soil mixing process (DSM), the water-blocking soil-cement wall is produced by mixing soil and an injected cement suspension in one step.

d) Thin diaphragm wall (variant 3d)
For a thin diaphragm wall, a steel profile (vibrating beam) is vibrated into the substrate. The profile dis-places the existing soil and thus compacts the sur-rounding material. When the beams are pulled, a hollow space is created which is filled with sealing material. This procedure is continued one after the other along the axis of the dyke with an overlap, thus creating the sealing wall.

3 DERIVATION OF THE PREFERRED SOLUTION

3.1 *Variant analysis*

The first step was to derive the preferred solutions from the three basic variants. For this purpose, an evaluation matrix was created that allows a comparison (cf. Table 1). The consideration includes, for example,

Table 1. Variant analysis.

Evaluation Criteria	Variant 1 Homogeneous dyke of impermeable soil	Variant 2 2-zone dyke with mineral sealing core	Variant 3 Installation technical core seal
Permanent land use	identical, due to uniform cubature specifications		
Building time land use	1	1	3
Constructional expenditure	3	2	1-2
Availability technology	3	3	1-2
Construction time	1	1	3
Quality assurance (effort)	2	1	1-3
Durability	2	2	2-3
Control effort during floods	1	1	2
Nature conservation intervention	1	1	3
Flood protection during construction	1	1	3
Applicability in changing soil conditions	3	3	1-3
Construction costs (net)	2175 €/running meter 1	1345 €/running meter 2	875 - 1330 €/running meter 2-3
∑	18	17	22-30

Table 2. Variant analysis.

Evaluation Criteria	Variant 3a sheet piling	Variant 3b Slurry wall	Variant 3c Soil stabilisation	Variant 3d Thin diaphragm wall
Technology/Brief description	Installation of steel sheet piles in the area of the dyke crown	Trench construction and placement of hydraulically bound sealing material	Column-shaped loosening by means of a drill or cutter, addition of slurry to produce the sealing wall (MIP, DSM)	Cavity production with injection beam + filling during drawing with self-hardening suspension, application range sandy and gravelly subsoil
Standards	ZTV-W LB 214, DIN EN 10204, DIN EN 12063, DWA 512-1	DIN 4126, DIN EN 1538, EAB, DWA 512-1	DIN EN 14679, DWA 512-1, MIP: general technical approval (Z-34.26-200)	ZTV-W LB209, DIN EN 1538, DWA 512-1
Construction cost (net)	1330 €/running meter 1	1215 €/running meter 1	970 €/running meter 3	875 €/running meter 3
Quality assurance	3	1	1	1
Construction time	2	2	3	2
Durability	3	2	2	1
Building time land use	3	2	2	2
Waste disposal	3	1	2	2
Nature conservation intervention	3	1	1	1
Emissions	2	2	2	1
Flood protection during construction	given for all variants, as the execution is carried out from the existing dyke crown			
Suitability of the existing dyke body	3	3	1	1
Market availability/wide range of suppliers	3	2	1	1
∑	26	17	18	15

the construction method in terms of its availability and the associated costs (availability technology), the intervention in terms of the nature conservation agreement (nature conservation expert evaluation - impact), and the feasibility of implementation over the entire dyke section (applicability to changing ground conditions).

The criteria were drawn up depending on the local conditions and the requirements of the client and vary from measure to measure. The matrix serves as a summary of the boundary conditions and should allow an objective and comprehensible derivation of the preferred solution.

A scale of points from 1 (negative/disadvantages) to 5 (positive/advantages) has proved useful for the evaluation. In Tables 1 and 2, a scale of 1 to 3 points was used. Points were awarded for the individual criteria according to the scale.

Depending on the process used to manufacture the core seal, there is a range of variation for this variant. Irrespective of the type of core seal, variant 3 with the highest number of points is the preferred solution from the evaluation. For this reason, variants 1 & 2 are not considered in the further planning steps.

3.2 *Variant analysis core seal*

In the second step, the types of technical core seal described in Section 2.4 were considered in more detail. For this purpose, an evaluation matrix was drawn up analogous to the basic variants. The points awarded in Table 2 refer to the evaluation of the individual core sealing types among each other and are to be considered independently of Table 1.

Despite the highest price for this example, the production of a core sealing by means of a sheet pile wall (variant 3a) is the preferred solution with the highest target achievement from the evaluation.

4 DISCUSSION

In summary, it can be said that, in addition to the normative specifications, dyke repair depends on a large number of boundary conditions. Therefore, each planning is an individual process of consideration, and the overall view should result in the most economical method of rehabilitation.

The influence of the solution approach on the feasibility of dyke rehabilitation must already be taken into account in the planning stage. A complicated dyke construction with many cross-sectional elements makes the realization and quality control of the measure more difficult.

The local space conditions must also be taken into account. Often, only by reducing the number of interventions in protected biotopes can the nature conservation agreement be established (cf. Figure 8).

Even in urban areas with adjacent buildings, often only solutions with a statically effective core seal (sheet piling) can be considered. In this case, special solutions must be developed in accordance with the applicable standards (cf. Figure 7).

Changing subsoil conditions and conditions of the dykes make the rehabilitation as pure soil construction more difficult, because they have high demands on the soil to be used. A qualified soil that meets the geotechnical and geohydraulic requirements is often only available locally to a limited extent. Furthermore, it is associated with high costs.

In case of changing subsoil conditions, the installation of a sheet pile wall can be supported by

Figure 7. Confined space conditions during the reinforcement of a dyke.

Figure 8. Freeboard secured by sheet piling.

a combined drill-press system. In addition, that can be installed vibration-free and low-noise by pressing them into the ground, thus avoiding damage to adjacent installations.

Pure earth structures are more sensitive to weather conditions when they are constructed. Excessive moisture, prolonged periods of precipitation, dryness or frost can make it difficult to meet the installation criteria or lead to an interruption of construction activities. In sensitive areas (crossroads, areas with adjacent buildings and areas parallel to roads/railroads) it is important to reliably forecast the construction time, as interruptions due to construction-related impairments often have to be planned for the long term. Due to the high insensitivity to weather influences, the advantages here also lie in the restoration of existing dykes using sheet piling.

5 CONCLUSION

This paper introduced a case history of applying sheet pile walls to the reinforcement of the river dykes in Germany.

In conclusion, it can be said that dyke reinforcement by means of sheet piling is an established part of flood protection measures in Germany. The reasons for this are, among others, the flexible applicability, the reduction of environmental impacts, the constant high quality and reliable and proven technology. Furthermore, the method is an integral part of German standards and technical literature.

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