THE REHABILITATION OF LEVEES WITH LARGE TREES BY EQUIVALENT STATIC SYSTEMS

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ABSTRACT

Levees are structures for flood protection and, therefore, their stability, serviceability and durability always prevail over other potential secondary "uses". But, levees are also a part of the environment and frequently covered by large trees. The effect of this vegetation type on and at levees is controversially discussed among civil and geotechnical engineers on the one hand and landscape architects and ecologists on the other hand.

Whilst the engineers focus on stability issues and define a tree with its roots as an unreliable weak spot, the opponent party frequently holds the opinion that a tree with its roots is stabilizing the embankment and, additionally, contributes benefits such as providing habitats and forming the landscape.

In the course of levee rehabilitation projects the handling of large trees is investigated in form of different alternatives embracing the span of complete demolition to complete conservation. According to the corresponding technical codes and guidelines in Germany, DIN 19712 and DWA-M 507/1+2, a strict handling is mandatory but the conservation of trees is allowed and feasible if the stability, serviceability and durability are guaranteed. For this reason, frequently "robust" construction methods such as steel sheet piles are applied. Corresponding case studies from Germany are presented and the specific fundamentals of the design approach explained.

1. INTRODUCTION

Flood incidents during the last decades showed the vulnerability of flood protection structures in Germany. Since 1993 severe floods occurred almost every five years, the latest one in 2013 caused billions damage.

The flooding occurred because of overtopping but also because of breaching. Especially levees are prone to breaching. Breaches occurred also within levee sections where large trees were located on or close to the levee. And always after such breaches did occur the discussion starts again whether trees are the cause for breaching and whether trees on and close to levees should generally still be allowed.

Frequently large trees come up as a consequence of a lack of maintenance. Many of Germany's flood protection structures show woody vegetation which is not conforming to up-to-date regulations (compare Figure 1). The regulations are clear and quite strict for levees, favoring a calculable stability of an earthen engineering structure instead of trusting the stabilizing influence of tree roots in soil which acts only positive against geostatic sliding processes. But, many case studies show that a complete removal of trees on levees is not required as soon as the stability, serviceability and durability are guaranteed by, e. g., the placement of equivalent static systems such as steel pile walls. For this case the trees may remain on and nearby a levee revealing all the positive aspects in regard to environment and landscaping.

Of course, the application of equivalent static systems are sometimes more expensive than classical levee rehabilitation methods but reflect a reliable way to combine flood safety and all the secondary uses and claims of third parties. For the time being, the conservation of existing trees is always a serious matter in many projects and the application of equivalent static systems is always one of the considered alternatives in a preliminary design phase. The controversial discussion regarding trees on earthen dams has to be led throughout the complete project phases involving all the stakeholders not only in order to find a common understanding of the subject but also to found the project on a reliable legal fundament in respect of the national and European laws.

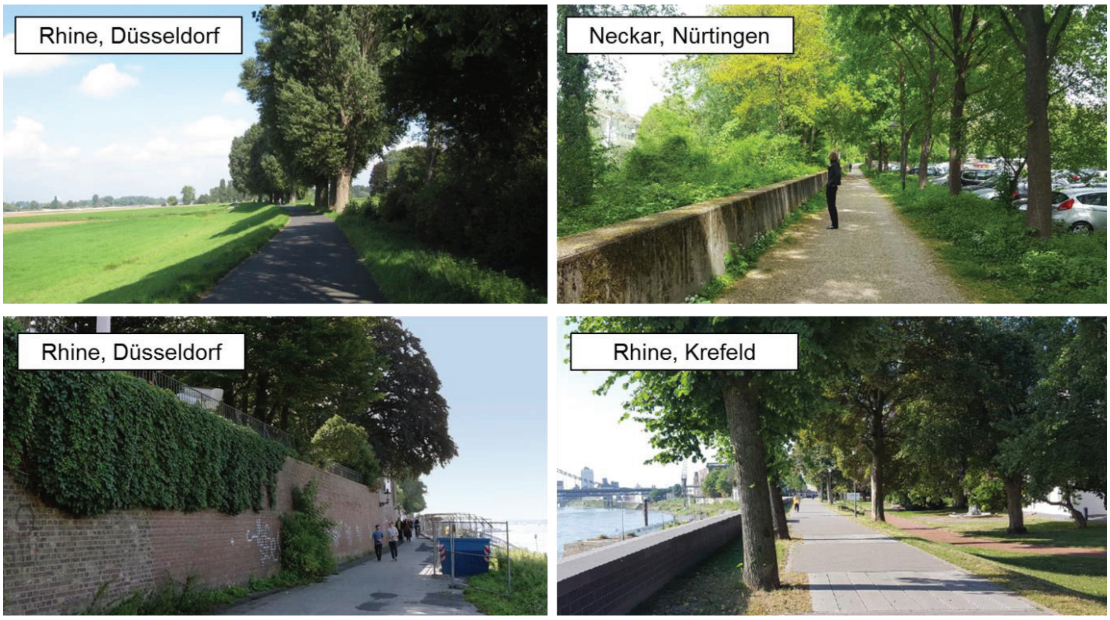


Figure 1 : Selected case studies showing large trees on and nearby levees and flood protection walls in Germany.

2. DESIGN BASICS AND CODES FOR LEVEES AND TREES

Levees are technical earthen dam structures which are protecting the hinterland/polder against flooding. The levees are designed for a design flood water level which is defined in consideration of the existing damage potential and risks.

In order to guarantee that these levees do fulfil their duty safely and durably codes and guidelines were established in Germany which consists mainly of DIN 19712/2013, DWA-M 507-1/2011, DWA- 507-2 (under preparation), DWA 2005, etc.

International guidelines are legally not binding in Germany and, therefore, are more or less neglected such as CIRIA (2013) and USACE (2014), although they contain valuable and helpful knowledge and experiences.

The code DIN 19712 was published in 2013 and it handles flood protection structures along rivers including levees, flood protection walls and mobile flood protection walls such as stop logs. Dams in general are regulated by DIN 19700. For embankment dams along national water ways the national institute prepared specific guidelines such as BAW MSD (2011). Further guidelines were prepared in order to define technical specification for special structures such as small flood retention dams, see DWA-M 522/2015. For flood retention dams which are regulated by DIN 19700 Part 12 the regulations of DIN 19712 for levees can also be applied, especially for topics such as vegetation (see also Haselsteiner et al., 2014).

The technical specifications regarding an earthen dam/levee are summarized in Figure 2. For levees without any additional stabilizing measures woody vegetation is more or less forbidden on and nearby levees. This is the result of the risks induced by woody vegetation as described, e. g., in DIN 19712, Haselsteiner & Strobl (2006), Haselsteiner (2010a,b; 2018, 2019).

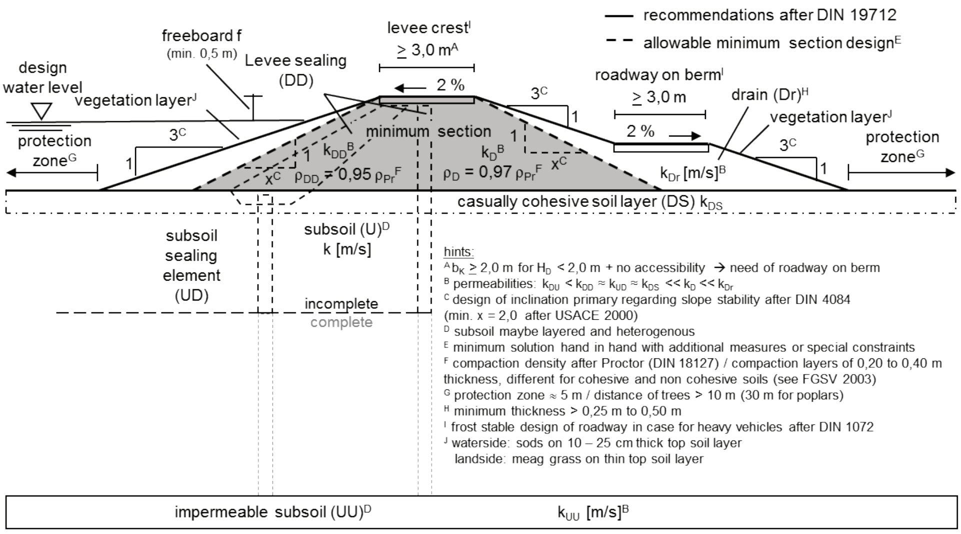


Figure 2 : Minimum statically required cross section and technical specification for a levee according to DIN 19712 and DWA-M 507-1.

DIN 19712 dictates that woody vegetation is affecting the stability and maintenance and therefore is not admissible. Trees must have a minimum distance of 10 m (30 m for poplars) from the levee toe (see also DVWK 226/1993). For a small levee these regulations result in a zoning as shown in Figure 3 which is showing the normal case regarding trees. In DIN 19712 already exceptional cases are introducing covering the cases when trees on and nearby levees shall be planted or conserved in the course of new construction or rehabilitation works.

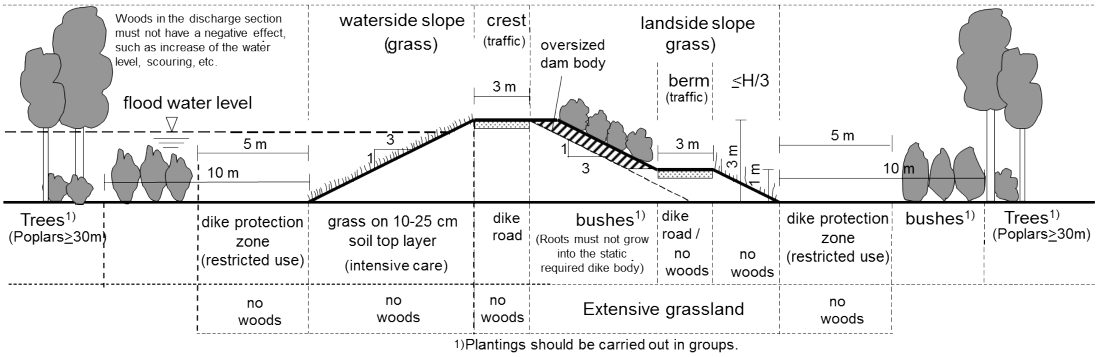
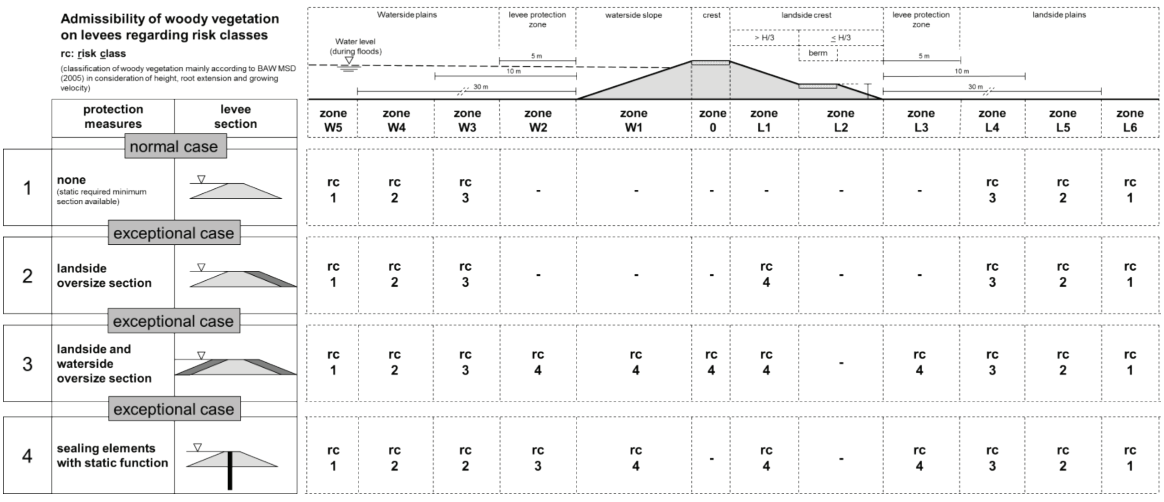


Figure 3 : Levee regulations for the normal case in consideration of woody vegetation in accordance to DIN 19712.

Especially, when levees shall be rehabilitated and environmentally valuable woody vegetation has developed on the levees, laws dictate conservation and/or compensation of the impact on woody vegetation, if the impact required and no alternatives are reasonable. For the avoidance and minimization of the impact huge investments are done in many project also because compensation area is frequently not available so that the complete project realization might be at risk because of environmental requirements and laws. For the rehabilitation of levees the same technical specifications as for new constructed levees are valid as included in DIN 19712 and DWA-M 507-1+2. The main difference is that a levee is already existing which needs to be investigated and evaluated in terms of stability and required rehabilitation measures (see Haselsteiner & Strobl, 2006; Haselsteiner, 2008; Haselsteiner & Riemke, 2017).

DIN 19712 already included the exceptional case in terms of woody vegetation. So if woody vegetation has to be tolerated on and nearby levees in form of a secondary use special specifications are given, such as the stability, functionality, maintenance, flood defense, etc. have to be guaranteed. Additionally, the maintenance and operations shall be performed so that the functionality of the flood protection structure is always guaranteed. The growing of large trees on levees as a result of neglected maintenance does stand against these principles. Thus, levees do not conform to the codes and guidelines as soon as the maintenance is not performed correspondingly which sets the dam operators in a precarious position if a levee would fail because of the neglect.

Nevertheless, there are conditions when woody vegetation is admissible on and nearby levees as indicated by Figure 4 for the normal case and the exceptional cases. Depending on the applied protection measures and the zoning as well as the woody vegetation type, which is here defined as a risk class, woody vegetation can be admissible almost on the complete levee. E. g., if a sealing element with static function (Figure 4, No. 4), which is an equivalent static system, is applied trees can be allowed on the complete levee, but the roads on the crest and berm should be free from woody vegetation which may also different in a particular case and project. Also if a huge oversize dam body is available which shows a crest width of 10 or 20 m (Figure 4, No. 2 and 3) the admissibility of woody vegetation can be evaluated differently to the normal case (Figure 4, No. 1) which corresponds to the situation shown in Figures 2 and 3.



	protection measures	levee section	zone W5	zone W4	zone W3	zone W2	zone W1	zone 0	zone L1	zone L2	zone L3	zone L4	zone L5	zone L6
	normal case													
1	none (static required minimum section available)		rc 1	rc 2	rc 3	-	-	-	-	-	-	rc 3	rc 2	rc 1
	exceptional case													
2	landside oversize section		rc 1	rc 2	rc 3	-	-	-	rc 4	-	-	rc 3	rc 2	rc 1
	exceptional case													
3	landside and waterside oversize section		rc 1	rc 2	rc 3	rc 4	rc 4	rc 4	rc 4	-	rc 4	rc 3	rc 2	rc 1
	exceptional case													
4	sealing elements with static function		rc 1	rc 2	rc 2	rc 3	rc 4	-	rc 4	-	rc 4	rc 3	rc 2	rc 1

Figure 4 : Detailed zoning for levee regulations showing the admissibility of woody vegetation in consideration of structural measures in accordance to DIN 19712 (adapted from DWA-M 507-2, in preparation)

More detailed information and recommendations are included in Haselsteiner (2007).

3. EXPERIENCES WITH TREES AND LEVEES IN GERMANY

In spite of the regulations and ideas described in chapter 2 of this paper, woody vegetation on and nearby flood protection structures are a common picture along the German rivers. Decades ago alley trees were planted on levees on purpose in order to stabilize the embankment. This habit originated from river engineering where river shorelines were protected by trees.

Also decades ago troublesome woods could be easily removed from levees which is not the case anymore thanks to a developed understanding of nature and nature protection measures which are expressed by the strict environmental laws of Germany and the European Union. Therefore, the removal of woods frequently requires permission from the responsible authorities and the removal can only be performed in the period from October to February after the environmental impact was assessed and a compensation plan was established.

Despite the cases shown in Figure 1 forest like vegetation were developing in the area of dikes so that many of the technical requirements are not given anymore, such as the stability, inspection and maintenance as well as the performance of defense works during extreme floods.

In Figure 6 a typical example of a levee is given. The levee is located in south of Germany within the city of Munich. The levee is on the right side of the River Isar and is close to the local zoo. The levee crest is used for the inhabitants for walking and sports. The vegetation is forest like. It is not visible that the way is also a crest road. The levee was rehabilitated by placing an equivalent static system into the dike body. The case study is explained later in the paper in chapter 4.

Many examples of similar conditions are available throughout Germany (see Figure 6 and Figure 7). During storm events many tree failures are documented which have torn huge crater into the dike body (Figure 8). The simultaneous appearance of wind storms and flood events is unlikely to occur but cannot be excluded. In Germany beginning of the year 2018 medium floods occurred on the Rhine River and its tributaries which were accompanied by a major storm event which stroke large parts of France and West Germany.

Figure 5 . Forest-like woody vegetation on and nearby a levee at the River Isar within the city of Munich in Germany (Bavaria) (taken from Haselsteiner, 2019).

Figure 6 : Single large trees on and close to levees at the River Loisach (Bavaria) (left), the River Gera (Thu-ringia) (middle) and the River Isar (Bavaria) (right) (taken from Haselsteiner, 2019).

Figure 7 : Forests developed around levees at the River Danube (left) and River Iler (right) in the south of Germany.

Figure 8 : Tree failures at levees as a cause of strong storm events after a storm 2014 (left) (Source: SEB Düs-seldorf) and 2007 (right) (Source: LUA Brandenburg).

For levees not only the tree itself and a failure of it is a major risk but the effect on the seepage conditions. The roots may completely penetrate a levee body which may lead to strong seepage flow accompanied by suffusion and erosion processes which again may lead to a total levee failure. Case studies report quite abnormal root growth and development which may differ to the typical root characteristics fundamentally (see LfW BY, 1990; Winski, 2004; Haselsteiner & Strobl, 2005). Selected examples are presented in Figure 9.

Figure 9 : Rooted levees at the River Ammer (left) (Source: WWA Weilheim) and River Danube (middle) (Source: LfW BY) and excavated roots of a poplar at a flood protection wall in Düsseldorf (right)

4 CASE STUDIES

4.1 Design of equivalent static systems

As equivalent static system steel sheet piles and soil mixing methods with inserted reinforcement in form of steel bars are applied in Germany. In special conditions also bored piles or plastic sheet piles can be applied.

As far as the failure of a tree needs to be considered as design situation or load case the design conditions need to be defined. Usually, the failure of trees results in a slope failure which might be worsened by erosion induced by water flow. In Figure 10 sketches of tree failures on the upstream and downstream slopes are shown. Tree failures on the upstream slope are usually handled as permanent design situation (P) and downstream failures maybe design for the accidental design situation (A). Since the equivalent static system, e. g. a steel sheet pile, is designed as a cantilever which has to be designed for the height difference from crest to the defined eroded slope body. For the preliminary design the depth of the sheet pile can be assumed to be two times of the defined height difference. Frequently the complete dam height is used for the height difference assuming that the complete levee failed. But, it might also be higher if streaming velocities or overflow cause erosion and scouring.

It depends on the local situation which of the tree failures is evident if trees are located on both slopes. Frequently a failure body with a radius of 1.5 m is considered reflecting the area penetrated by strong roots. For more information is included in Kerres & Haselsteiner (2018).

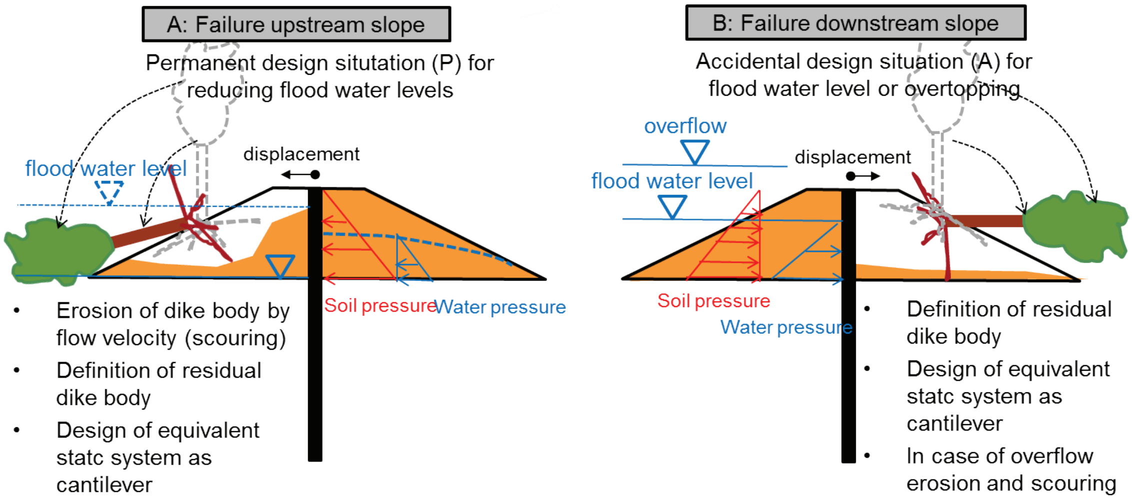


Figure 10 : Design situations for tree failure upstream (A) and downstream (B) including some hints.

4.2 Case studies of levee rehabilitation with equivalent static systems

As aforementioned in Figure 5 a levee in Munich at the River Isar showed forest-like vegetation. In order to conserve the most of the existing vegetation the responsible authorities decided to use the soil mixing method with reinforcement bars. Where the levee needed to be heightened a cantilever wall was added (Figure 11).

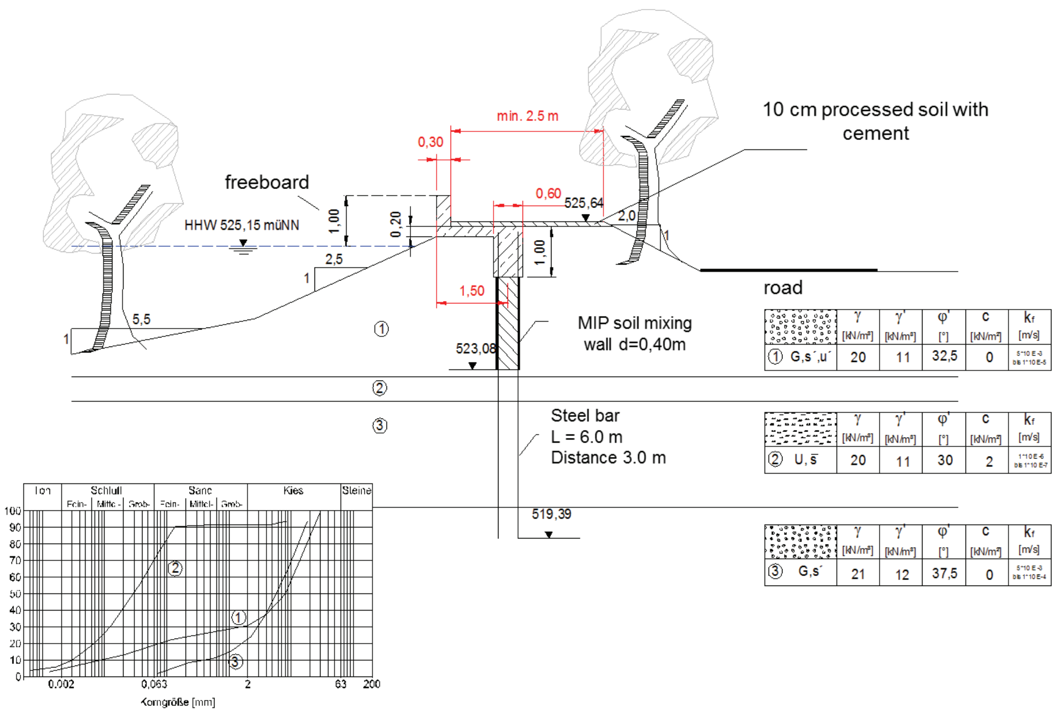


Figure 11 : Design section of a levee in Munich at the River Isar applying soil mixing method in order to con-serve trees.

In Figure 12 a levee at the River Saalach is shown. The levee is a new construction and in future large trees should be also allowed up to the levee toe in the levee protection zone upstream. Therefore, an equivalent static system was applied alternating steel sheet piles and soil mixing walls. Both selected methods are able to take over the static loads caused by potential tree failures. The steel sheet piles were applied in order to be able to adjust the embedment depths afterwards in order to be able to overcome negative effects of the applied sealing system on the groundwater conditions.

The embedment depth was designed in order to establish permeable groundwater windows in the subsoil. Thus, permeable alluvial gravels were not sealed which shall guarantee a proper groundwater exchange during normal flow conditions in the river. The design is quite simple since the static sealing element is taking over all stability issues and the dam body is only acting as a host of the crest road.

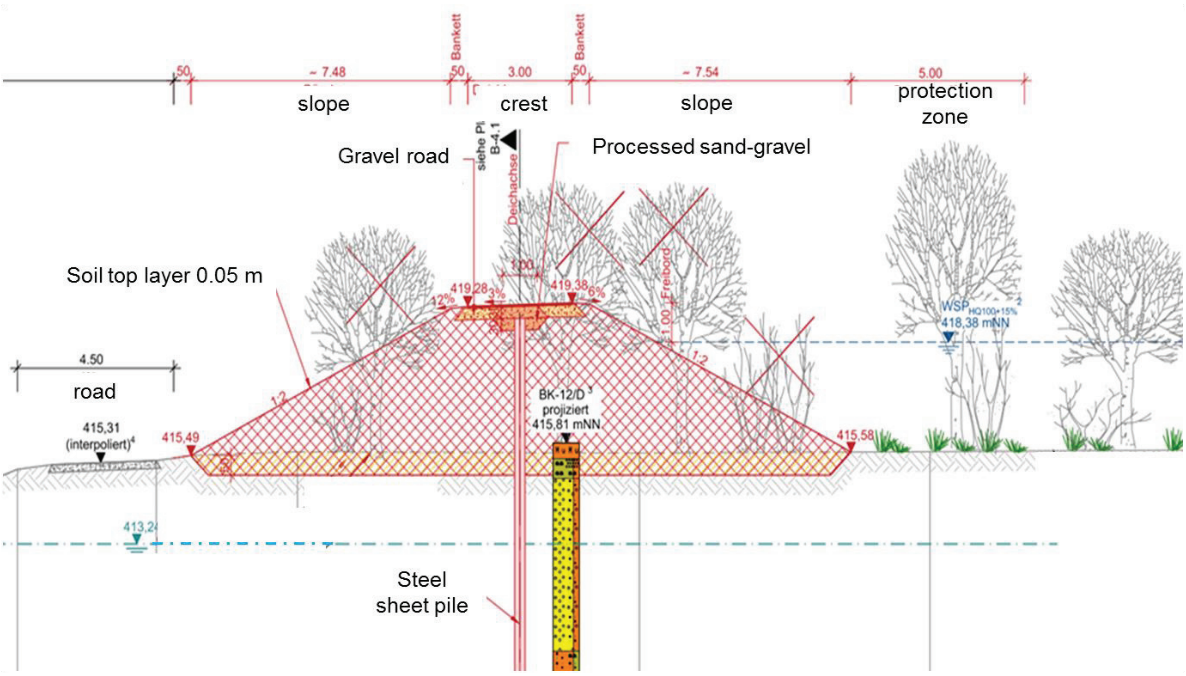


Figure 12 : Design section of a levee in Freilassing (Bavaria) at the River Saalach applying steel sheet piles and soil mixing method in order to allow trees.

In Nuertingen at the River Neckar close to Stuttgart flood protection measures are under design. The existing levees need rehabilitation due to stability concerns, height deficits and the occurrence of large trees (Figure 13). In the Neckar valley the available areas for compensation are very limited so that the owner put a high priority on the avoidance of environmental impact. Thus, the present design includes steel sheet piles and soil mixing walls in order to conserve existing woody vegetation as much as possible. Further, the steel sheet piles shall be hydraulically pressed so that no heavy equipment is required and the levee crest need not to be widened to approximately five meters in order to enable the access for heavy machinery. For this approach the owner accepts additional costs since the levees themselves show a height of maximum three to four meters.

Figure 13 : Existing levees along the Neckar River at the city of Nuertingen with large trees on both slopes (taken from Kerres & Haselsteiner, 2018).

In order not to show a negative effect on the groundwater conditions groundwater flow windows will be established and the steel sheets will be also sliced in order to make them more permeable.

As explained in section 4.1 for equivalent static systems the failure of a slope needs to be considered. For the selected case study the upstream slope failure induced by tree failure is evident. It is assumed that the 3.0 m high upstream levee body is completely missing and the static system has to hold height difference as a cantilever. For the soil reaction in the underground bedding moduli were determined. The aim of the design is to limit the deformation of the wall at the crest level to approximately 1/100 of the length of the wall and that the vertical forces can also be safely converted to the foundation. However, the conservative approach of defining design conditions would also allow the engineer to accept theoretical higher deformations.

Usually, the recommended construction method for steel sheet piles, which is hydraulic pressing here, requires a much higher modulus of resistance as required by the static loads so that the strength and resistance of the steel elements.

For the soil mixing walls the design requires a UCS = 5 N/mm² (= MPa) and reinforcement steel bars at a distance of 4.0 to 5.5 m.

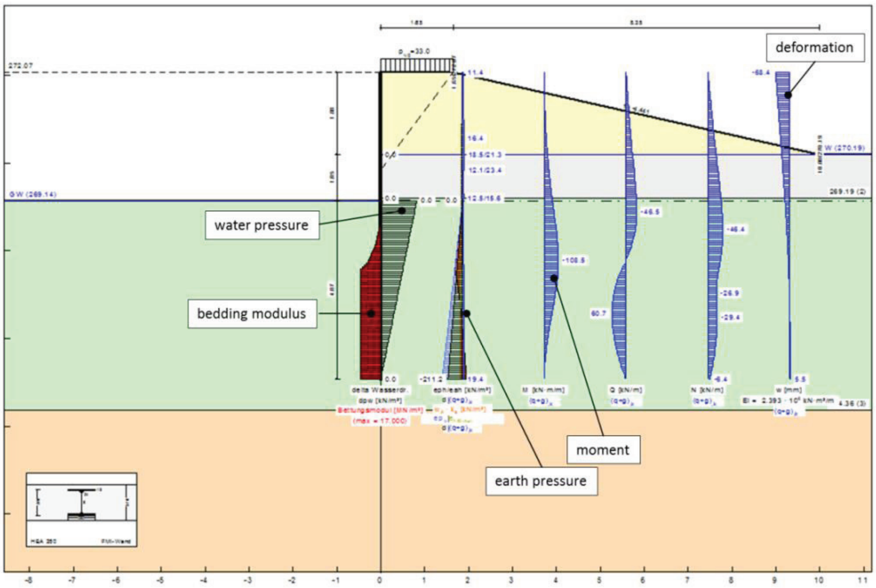


Figure 14 . Results for a design cross-section with a soil mixing wall depth of 7.0 m and a distance between the steel reinforcement piles of 1.2 m (taken from Kerres & Haselsteiner, 2018).

5. CONCLUSION

The conservation of woody vegetation on and nearby levees is frequently required due to environmental restrictions. The application of equivalent static systems is an efficient and safe method to guarantee the stability of a levee also in case of a large tree failure with subsequent slope erosion and scouring.

As soon as a robust steel sheet piles or similar structures are applied in consideration of adequate design situations the safety of the levee is guaranteed. Although, technically manageable the levee owners should be aware that woody vegetation will require more efforts and resources during operation. The investment for the establishment of a tree resistant levee is strongly depending on the local conditions such as the levee height, the trees and the underground conditions, etc. For small levees the application of reinforced soil mixing methods may result also in costly measures, whereas for large levees the application of steel sheet piles may still be cost efficient.

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