Aspects Regarding Vegetation on and at Levees

R. Haselsteiner
Bjoernsen Consulting Engineers, Koblenz, Germany

ABSTRACT

The current German codes and guidelines do not cover all practical aspects for the design, construction and operation of levees. Especially regulations for vegetation - grass-like vegetation layers or woody vegetation – on and at levees show inconsistencies. Mandatory design requirements as well as several case studies, some examples pf levee and tree failures, and re-known and controversially discussed projects in Germany are presented. After sharing German experiences the paper closes with design aspects including one up-to-date case study for which a self-moving press-in equipment for the placement of steel sheet piles was used to conserve existing trees in the near vicinity of a levee because of environmental reasons.

1 INTRODUCTION

Levees are a part of nature and environment. Therefore, ecology and landscape are important issues for levees whereas safety in form of the long-term stability of a levee is the dominating aspect. Vegetation on levees in form of grass-like vegetation layers or lawn, bushes, reeds, and trees may show several positive and negative effects regarding the ecological value, landscaping, leisure amenities, the stability of levee, its durability and many more.

A well maintained strongly rooted lawn-like grass cover is dictated by the national codes and guidelines DIN 19712 and DWA-M 507 Part 1 as protection against surface erosion and environmental impacts. This kind of sod fulfils frequently also the expectations of landscaping and it complies with the state of the art in levee engineering which is commonly accepted by (almost) all stakeholders.

More difficult appears the handling of large bushes and trees on and at levees. The German code DIN 19712 forbids woody vegetation, except small bushes, on and at levees – generally – but admits exceptions in the same context, only a single paragraph later. This contradictious statements triggers frequently hot-tempered discussions between stakeholders such as environmentalists, residents, environmental protection agencies, etc. on the one hand and engineers, water authorities, and flood safety agencies and responsible parties on the other hand. In Germany several levee rehabilitation projects came under political fire since this conflict “trees on levees: yes or no” was not solved during the legal approval phase. Protests, appeals, and trials are the result which hinders the real aim of the project which is to reestablish and improve the flood safety.

But the solution of these complex and conflict-filled projects is not to solve the question “trees on levees: yes or no” but “flood safety: yes or no”. By the utilization of structural protection measures and designs the safety can be guaranteed with a long-term perspective, although trees might be tolerated on and at levees. An ordinary embankment fill without special protective elements should not be able to host any woody vegetation, particular large trees, in regard with safety considerations.

The author holds the opinion that there is always a solution to preserve trees on or at levees by, e. g., sheet piles, concrete walls or even simple root barriers, and other – sometimes massive – means. But, stakeholders and flood responsible agencies and parties should always be aware that these protective measures are cost intensive in consideration of both investment for construction and during operation and maintenance. Since the tax payer comes up for all these costs at the end the decision finding process in favor of an adequate solution with or without trees is an fundamental democratic act which is reflected by the compulsory procedure of participation during the design and approval phase.

2 VEGETATION ON AND AT LEVEES ACCORDING TO GERMAN GUIDELINES

2.1 *General*

For levees the code DIN 19712/2013 is decisive. The mentioned code is valid for all types of flood protection structures including earthen flood embankments such as levees, flood protection walls made of concrete or steel and mobile systems. This technical code bases on the older code DIN 19712 which was published in 1997 and was just valid for levees as it originated from the guideline DVWK-M 210 which was published in 1986 which also treated levees along rivers, exclusively.

In 1997 another guideline was published which concentrated on ecological aspects regarding levees (DVWK-M 226) which partly was considered in the old DIN 19712/1997. The technical guideline DWVK-M 210/1986 was updated and published as DWA-M 507-1 in the year 2011, the fundament of DIN 19712/2013 in form and content.

Unfortunately, DIN 19712/2013 was prepared in order to cover all types of flood protection structures along rivers but did not succeed in providing the same detailed regulations for flood protection walls and mobile systems as for levees since it originates from very detailed technical earlier guideline DWA-M 507-1/2011. Throughout DIN 19712 the other types received less attention and in most aspects only a corresponding handling as for levees is recommended which is insufficient in the opinion of the author since walls and mobile systems are completely different structures showing different static behavior, different materials, and different needs in maintenance, operation and flood defense. Nevertheless, DIN 19712 is quite elaborate for embankments/levees although showing some contradicts especially in respect to woody vegetation.

The general layout of a dike/levee section is shown in Figure 1 which reflects the standard case. The levee shows the minimum required geometric layout in order to fulfill the stability and durability requirements. In general, the levee itself should be free of woody vegetation including a dike protection zone of 5 m at both toes. Only the upper part of the downstream slope may host small bushes when the embankment shows a protective additional fill. Trees should show a minimum distance of 10 m and very large, strongly rooting, and fast growing trees, such as poplars, should stay minimum 30 m away from the dike toes. Bushes may be placed at a distance of 5 m in fore- and hinterland. All other zones and areas are to be covered by roads, revetments, ways, etc. or “simply” a vegetation layer in form of a strong rooted sod.

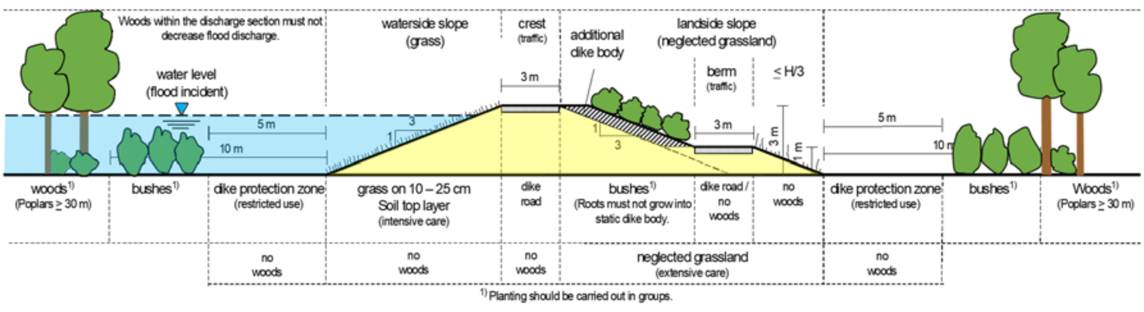

Figure 1. Standard levee/dike section with zones describing mandatory and tolerable forms of vegetation according to DIN 19712 and DWVW-M 226/1997 (taken from Haselsteiner, 2019)

The positive and negative effects of woody vegetation on and at levees are discussed and explained in detail in many publications and papers such as DIN 19712/2013, DWA-M 507-1+2, Haselsteiner & Strobl (2006), Haselsteiner (2007, 2007A, 2010, 2010A, 2018, 2018A), Lammeranner & Haselsteiner (2010), LfW BY (1990), Winski (2004), etc.

The up-to-date regulations result from elaborate works, e. g., performed in the 1970s and 1980s in Bavaria where many trees on levees were mapped, inspected, and partly excavated in order to determine the extension of roots through levees (LfW BY, 1990). The results were quite surprising since the trees developed a complete different root system compared to the genetic codification. Once you understand the tree as a living organism this reflects just the trees' adaptation for survival in respect of the environmental conditions, such as water, light, nutrition, mechanical resistance, etc. and the physical needs of the tree which is also comprising the stability of the tree itself. In Figure 2 some selected examples for extensive roots in levees are shown which shall provide an impression of the potential intensity of root systems in or though levees.

Figure 2: Roots through levees exhibited after dike breaches (left: failed dike at the River Mulde 2002, Source: Landestalsperrenverwaltung Sachsen / right: dike breach at the River Ammer in Bavaria in 1999, Source: WWA Weilheim)

In this context it is noted that the roads and ways have usually to be kept free from vegetation in order to allow a safe and appropriate inspection, supervision and defense by either vehicles or pedestrians. For exceptional cases gravel lawn is used for the covering of a levee way, when no explicit requirements for heavy load traffic are postulated and, sometimes, when the traffic should be limited for cyclist or other touristic activities, e. g., in order to protect nearby endangered species during breeding, resting, or feeding or the privacy of residents.

2.2 *Protective Vegetation Layer in Form of Sods*

The vegetation layer which protects the surface of the levee against erosion and environmental impacts shall strongly root the vegetation base layer. It shall be durable and develop a dense and complete covering sod without any voids (DIN 19712) which protects the surface also against heavy loads. Main aspects for the vegetation are discussed in DVWK-M 226 and in DWA-M 507 Part 2 which is still in preparation and will replace DVWK-M 226. Typical resistance values of dike covers and revetments are listed in Haselsteiner (2007). A grass cover may resist maximum flow velocities of 2.0 m/s or shear stresses of up to 50 N/m² according to experience and literature. For short periods also larger loads can be sustained.

Two selected pictures of grass covered levees are shown in Figure 3. Where sheep grazing was applied the vegetation shows irregularities, which does not mean that this specific surface condition is not fit for purpose (left picture). The right picture illustrates the result of effective cultivation works on the right and "not so" effective results on the left which can be clearly identified by the visible grass mass.

The best time for the evaluation of the erosion resistivity by visual inspection is winter and before spring after or before growing season. Although, during overtopping full-scale test on grass covered slopes (see also Haselsteiner et al., 2008) the protective effect of long grass blades or sprouts against erosion was observed, a reliable, long-term resistance can only be provided by the close, surface-near interlinked root network which is fixed deeply into the soil by adequate deep roots.

In the mentioned literature (Haselsteiner, 2007) also the composition of the vegetation base layers in form of sieve curve ranges is discussed briefly. For sods a gravelly, silty sand seems to be a suitable base. The more gravel the dryer the soil becomes so that in special cases the nutrient-poor grassland are placed directly on a sand-gravel body. Sometimes a humous substratum is scattered on the surface in order to have a better and faster initial growing phase. Usually, the vegetation base layer shows a thickness of 15 to 20 cm, sometimes reaching 30 cm, in some cases also only 10 cm. For nutrient-poor grassland this thickness may be reduced to a few centimeters in total.

Figure 3: Vegetation layers in form of grass covers of selected case studies (left: upstream slope of Rhine main levee in 2017 with sheep herd in the back / right: downstream slope of a Rhine levee showing different management/cultivation measures from 2019 / Source: BCE)

In the corresponding German code, DIN 19712, nutrient-poor grassland is only allowed on areas with minor loads assuming this type of grass cover develops a less resistant erosion protection effectiveness. In consideration of up-to-date scientific results this option of application at minor loaded areas seems to be incorrect since nutrient-poor grassland may develop much more roots and a more intense root system than normal "standard" sods. The erosion resistivity is depending on the root system which is represented also by its weight. In DVWK-M 226/1997, in SLfL (2005) and according to other authors the root mass of those "poor" grasslands was determined larger than for ordinary sods which is an solid indication that also the resistance against external loads should be also equal or stronger.

During the first vegetation periods, when the root system is not fully developed, other temporary means might be required in order to guarantee the erosion protection, such as the application of coco mats fixed with wood nails or sprayed seed mats. Experiences with prefabricated rolled sods were positive as also special grass and herb blends were applied in the sods.

Recently, classical blends composed of grass and herb seed were used at levees showing a mixture of 4 to 12 different seed sorts, frequently less than 10 (DVWK-M 226, 1997; Haselsteiner, 2007). Experiences show that the starter seed blend was frequently "suppressed" by invasive sorts which were frequently "aggressive" neophytes. In order to conserve the environmental balance and to repel the invasion of neophytes in Germany the legislative needed to react.

Thus, the environmental legislation nowadays dictates that autochthonous seeds have to be used for the vegetation layer, exclusively. The federal law on nature protection § 40 (4) forbids the application of foreign seeds in the open landscape since 1st March 2020. Thus, the collection, production and application methods had to be reorganized. Due to the high, sudden demand the production capacity does not meet the demand so that the two methods collection of seeds from adequate places and transplantation of sods are frequently applied for levee rehabilitation works nowadays. Because of the costs for the transplantation of sods the flood agencies tend to collect and store seeds from suitable habitats adequately before the works are carried out. The collection and storage are usually also executed by specialized companies and in correspondence with requirements of the nature protection agencies.

The needs of maintenance of grass-like covers or sods are also discussed controversially among specialists of different professions. In practice frequently the sods are mowed two times, some claim more frequent actions. According to some levee directives the grazing by sheep is mandatory which also requires experience and, particularly, a sod mixture which should be tasty for an animal with an IQ equal to that of primates. The more intelligent the more cherry picking is the character which may have an adverse effect on the quality of the sods.

Scientific results also illustrate that regular mowing is the reason for deeper and more developed root systems compared to sheep grazing since the sheep pick the plants or parts of it and harm the plants and roots so that the development of roots may be hindered. Whereas the employment of machinery provides a clean cut of the sprout which is not harming the root system (SLfL, 2005). In order to minimize the harmful effect of grazing the sheep need to be relocated frequently, and the grazed areas might be mowed or treated afterwards additionally.

In Germany the environmental impact assessment includes the balancing of impact/intervention and compensation. The federal states provide mandatory methodologies for the determination of the balance. Experiences with levee projects show that a main part of the compensation can be done by converting the levee slopes areas from intensive utilized, fertilized meadowland with a medium amount of species to less intensive, natural grassland combined with sheep grazing with many species (+25 % credits) (see Kleber-Lerchbaumer, 2018). Although, federal compensation directives dictate stricter compensation measures as mentioned here, such as, e. g., full or over-compensation of removed trees, but also allows balancing by the implementation of eco-accounts or compensation payments if required by the specific circumstances and if agreed by the responsible environmental protection agency.

2.3 *Woody Vegetation on and at Levees*

As shown in Figure 1 on and at normal “standard” levees the upcoming, growing or planting of woody vegetation in form of bushes or trees is avoided, in general, since also DIN 19712 and related guidelines are quite strict in the formulation mainly in respect to the standard case of a levee. But, as aforementioned, for exceptional cases woody vegetation is allowed if some precautious measures are taken, e. g., the application of static systems/elements which are guaranteeing the stability of the levee also in case of a tree failure, or the oversizing of the embankment, so that the trees may fail without showing an effect on the static required levee body and on the flood safety at all (Kerres & Haselsteiner, 2018; Haselsteiner, 2018C).

In consideration of the general regulations for the standard case which are illustrated in Figure 1, the exceptional cases will be regulated more in detail in DWA-M 507 Part 2 which is still in preparation. The evaluation matrix which is shown in Figure 4 shall enable to prepare project specific designs in consideration of structural “safety” measures such as the application of oversize sections or static elements such as steel sheet piles. Line 1 represents the “standard case” as shown in Figure 1, the other three cases are “exceptional cases” which allow the appearance of trees almost everywhere in consideration of the safety measures except on the ways and roads (line 4) as an extreme counterpart solution to the “standard case”.

The matrix splits the levee section into zones (W: waterside/upstream, L: landside/downstream, horizontal) and protection measures (vertical), and allows trees and bushes according to a specific risk class (rc) of the bushes/trees (see Table 1). Biological parameters such as potential height, root growth, growing velocity, the ability to create suckers, the resistance against moisture and flooding, etc. are considered whereas the decisive figure is the potential height since this also indicates somehow the root growths and the risk for tree failure. A similar classification of trees is provided by BAW MSD (2011). In Haselsteiner (2007) distinctive notations and comments are made for potential application issues which mainly aim always to guarantee a root-free static relevant dam body or the corresponding static resistance by other systems.

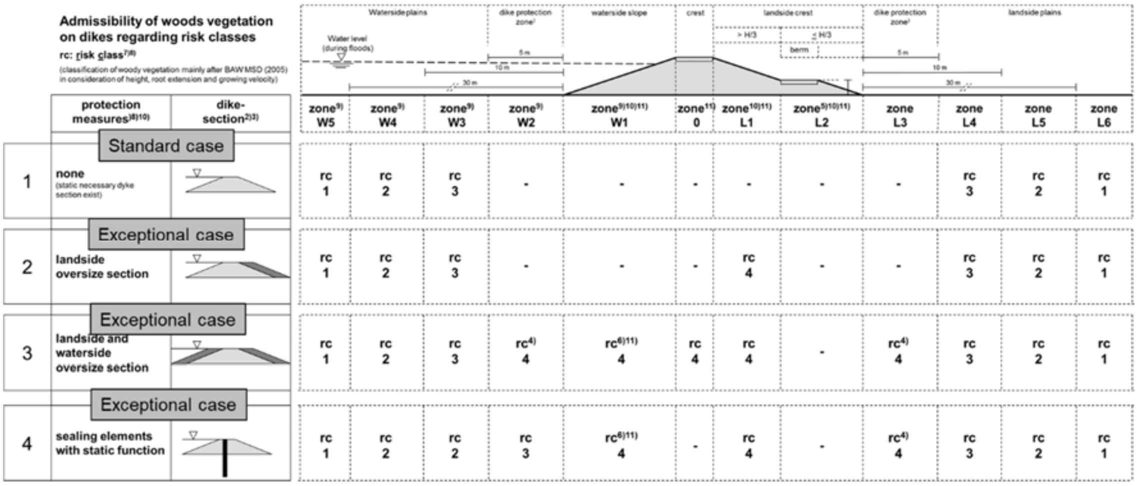

Figure 4: Evaluation matrix for the admissibility of woody vegetation on levees regarding risk classes (rc) (modified from Haselsteiner, 2007; see Haselsteiner, 2019)

In the public the discussion regarding risks of trees on levees is frequently reduced to the topic of a tree failure so that, on the contrary, once the tree failure is somehow unlikely to happen the safety of the levee is no longer doubted. Although, the tree failure might be one of the failure/load cases to consider during the design or the evaluation of an existing levee the geohydraulic failure in form of strong seepage and erosion processes could be a much higher risk since it cannot be evaluated as accurate as the stability of a tree for which methods and experience is available (Wessolly & Erb, 1998). Especially for old single trees with a ratio of height to diameter of less than, let’s say conservatively speaking 20, stability problems are unlikely to occur since the tree has established its stability by an adequate growth policy according to the loads occurred. LfW BY (1990) registered almost 200 tree failures by windblow of which 90 % accumulated for trees with a diameter less than or equal to 0.5 m which again gives a kind of indication what kind of trees are endangered significantly by windblow. But, the occurrence of leakages and erosion along the root pathways can neither be excluded nor be evaluated accurately, so that this remain a more or less unknown risk which are the most dangerous risks (for engineers).

This is also the reason that cutting down a tree is only a small part of the solution. As dictated in all reasonable codes and guidelines, also abroad (see USACE, 2007, 2014; Marks & Tschantz, 2002), the roots have to be removed completely and the levee body has to be rebuilt in consideration of the state of the art engineering methods. The consequence of this is usually that the cheap removal of the tree trunk has to be followed by the complete removal and rehabilitation of the complete levee along the root system which may reach many meters. For single poplars reported root lengths of 40 to 50 m are not unusual.

Last but not least a tree is a living organism that will not live forever. Hand in hand with the evaluation of the levee safety also the value of a tree need to be assessed mainly ecologically but also in regard with landscape and leisure aspects. Due to legal duties for trees within public areas the safety has to be maintained by the responsible party regularly, which means generally a biannual inspection followed by corresponding care measures if required, which may also dictate the felling of a tree if the tree represents a risk.

Table 1: Risk classes for woody vegetation of selected species of bushes and trees; adapted and shortened from Haselsteiner (2007)

risk class	German	English	Botanic
1	Bergahorn	sycamore maple	Acer pseudoplatanus
	Bergulme	wych elm	Ulmus glabra
	Esche	ash	Fraxinus excelsior
	Eßkastanie	chestnut	Castanea sativa
	Stieleiche	common, English oak	Quercus robur
	Weißtanne	white fir	Abies alba
2	Bruchweide	willow	Salix fragilis
	Eberesche/Vogelbeere	sorb, mountain ash	Sorbus aucuparia
	Sandbirke	birch tree	Betula pendula
	Schwarzerle	alder	Alnus glutinosa
	Speierling	sorb-tree	Sobus domestica
	Winterlinde	littleleaf linden	Tilia cordata
3	Grauweide	golden willow	Salix cinerea
	Hasel	hazel	Corylus avellana
	Spindelstrauch / Pfaffenhütchen	evonymus	Euonymus europaeus
	Weichselkirsche	sour cherry	Prunus mahaleb
	Weissdorn (eingriffelig)	hawthorn	Crataegus monogyna
	Wolliger Schneeball	snowball bush	Viburnum lantana
4	Berberitze	barberry	Berberis vulgaris
	Brombeere	blackberry	Rubus fructicosus
	Faulbaum	buckthorn	Rhamnus frangula
	Himbeere	raspberry	Rubus idaeus
	Schlehdorn	blackthorn	Prunus spinosa

3 EXPERIENCES AND SELECTED CASE STUDIES IN REGARD WITH WOODY VEGETATION

In this overall context it has to be also mentioned that especially for the allowance of trees on and at levees always a specific case-by-case analysis have to be performed. For example, for some levees in Bavaria which protect “only” agricultural areas a dike breach is accepted also in consideration of the occurring small damage so that neither the stability of the dike nor supervision, maintenance, and defense are required. These levees are not maintained and through the years are completely covered by large trees and woods (Figure 5).

Figure 5: Extensive woody vegetation on levees on Bavaria (left: wooded dike at River Iller (Bavaria) near Altenstadt with a trail on dike crest, Source: TU Munich / right: complete wooded dike at River Danube near Dillingen in a nature protection area, Source: StMUGV, a ministry of Bavaria / both taken from Haselsteiner, 2019)

Decades ago trees were planted on levees on purpose in order to stabilize the embankments as shown in Figure 6. Mostly alleys were applied which were also instruments of landscaping. In order to have a quick effect fast growing trees were selected which are the most dangerous trees according to the experience and knowledge of today.

Figure 5: Planted trees and alleys on old levees in Germany (left: flood protection dike at the river Koessnach near with poplars and meadow, 1985 / right: flood protection dike at the river Danube with landside poplar row and waterside bushes and grass/meadow, 1985 / taken from Pflug & Hacker, 1999)

But also the effect of large trees and their roots are still discussed controversially. Wessolly (2020) still claims that trees show an overall positive effect on the stability of levees referring to many case studies and hundreds of years of experience along channels and levees in Europe. Tree pulling tests were performed in order to evaluate the stability of many of trees on levees (Wessolly, 2007). These pulling tests are usually performed under dry conditions so that the levee body and the root system is not saturated and shows a better strength behavior compared to flooded, saturated conditions. The author does not know a single test which was performed under realistic (extreme) conditions in regard to seepage. The decisive test is the test on the weakest part of the chain which evolves over services period of 80 to 100 years. In addition the geostatic failure is only one of the potential failure mechanism. Erosion, suffusion, extensive seepage flow, etc. may also harm the levee and lead to a progressing failure process which is not depending on the stability of the tree itself.

The basis of design and the evaluation of existing levees has to be based on engineering judgement which includes all sorts of means such as experience, analyses, knowledge, etc. But it has always the same aim to guarantee the flood safety in form of the stability, geostatic and geohydraulic. As soon as the effect of something, e. g., an intensive rooting through the levee body cannot be evaluated, the complete levee cannot be evaluated as safe just because it has not failed before. This would be contradictious to modern engineering principles and attitudes. And this is also the reason why unprotected, unstrengthened levees, as represented by the standard case, cannot sustain woody vegetation unless the levee is protected against the impact of woody vegetation.

The failure of trees cannot be always predicted or evaluated accurately enough, as many failures show during storm events in the last decades (Figure 6). Fortunately, the tree failures did not coincide with flood events so that the levee could be rehabilitated without any major risk for flooding.

In reported cases (see also Figure 2) levees failed where trees were located, but whether the tree was the reason for failure or the tree and its roots did slow down the failure process cannot be evaluated afterwards since the subject of interest is gone and all attempts for the description of the actual failing procedure would be pure speculation.

The long-term positive experience with wooded flood or channel embankment dams does not comply with a modern engineering approach. Only that a structure “survived” so many years does not mean that it was ever loaded by the design loads and would perform in the design load case as required showing sufficient reserves and safety margin in correspondence with the failure probability of an modern engineering structure. Concluding, in order to be able to guarantee the stability and durability during a life/service period of 80 to 100 years a levee which should host woody vegetation needs to be designed and strengthened in correspondence with all the requirements stipulated in the codes and guidelines including both geostatic and geohydraulic stability as well.

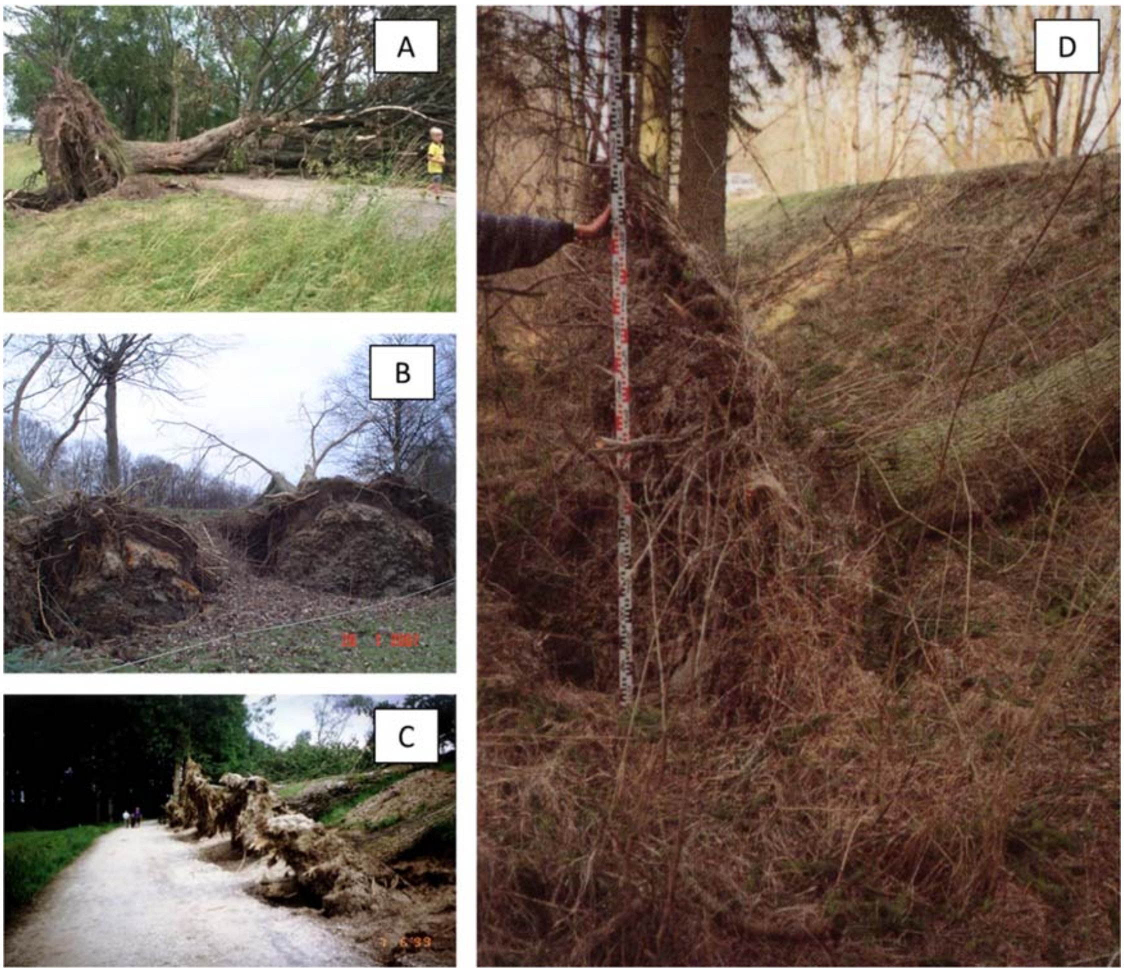

Figure 6: Selected tree failures by windthrow at levees in Germany (A: windthrow at a Rhine levee during the storm Ela 2014 in Duesseldorf, Source: SEBD / B: windthrow at levees with the Black Magpie during storm Kyrill 2007, Source: LUA Brandenburg / C: thrown row of poplars at the landside levee toe in 1999, Source: StMUVG / D: Thrown spruce at the landside levee toe at the river Lech in Bavaria, Source: LfW BY 1990)

In a growing number of projects the topic trees and flood protection structures is escalating in Germany, e. g., Bremen, Mannheim, Duesseldorf, and many other places. Mainly safety considerations postulate the removal of the tree(s) and the rehabilitation of the flood protection structures whereas the objectors frequently claim the positive effects of trees, such as the improvement of stability by biological reinforcement, the provision of habitat for endangered species, positive effects on the microclimate, etc. Sometimes the hot-tempered discussion escalate so that the police needed to interfere against activists in order to protect tree felling works (Figure 7, right picture). In Bremen the design for the rehabilitation of an old levee includes the removal a row of plane trees along the Small Weser River which became a political issue reaching to the top politics of the city (Figure 7, left picture).

Figure 7: Current, public discussed levee projects in Germany (left: plane trees along the Small Weser in Bremen, Source: Wessolly, 2020 / right: tree felling works in Augsburg 2018 under the protection of police forces, Source: Münchner Merkur, dpa, Stefan Puchner)

In the vicinity of the small town Orsoy at the Rhine River the presence of a linden tree/basswood is splitting the community. The tree is called "Dicker Bär" (engl.: "Fat Bear") (Figure 8). The responsible flood safety agency identified an unacceptable, immanent risk triggered by the tree which is mainly caused by its location in the middle of the levee and its strong and large root system. The immanent risk was already attested by an expertise of an independent university.

Before this expertise another expert opinion was prepared by a tree specialist confirming the stability of the tree. The case has gone to court after the flood agency applied for a felling allowance at the responsible environmental agency which was rejected. The decision how to handle the issue "Fat Bear" is pending and a final judgement is awaited for early 2021.

Figure 8: Single large tree "Dicker Bär" on a levee in the vicinity of the town Orsoy at the Lower Rhine region (left: total view during summer / right: close-up of trunk, Source: BCE)

For the town Duesseldorf a study was prepared for all the flood protection structures where woody vegetation is/was close or is/was located directly on the structures. In advance approximately 4,700 trees were mapped and registered or if they were already registered the register data was updated. In Figure 9 two special levee examples are shown to provide an impression of the levees in Duesseldorf which were investigated within the mentioned study.

The mapping included an evaluation of the general conditions such as height, diameter, illnesses/diseases, age, and also residual life time. In many cases the determined value of a tree was not sufficient for claiming preservation action so that in the course of rehabilitation works a removal of the trees could be accepted when the legal, normal procedure for compensation etc. are followed up. This study (BCE, 2019) concentrated on the development of a standard procedure for handling existing and potential future woody vegetation on and at flood protection structures in the course of the realization of rehabilitation projects (Figure 10). Hand in hand with the shown flow chart a measure catalogue was prepared in order to support the selection of measures during the processes E and F.

Figure 9: Trees on levees within the vicinity of the town Duesseldorf at the River Rhine (left: row of poplars on the crest of the "Lohauser" levee in Duesseldorf, Source: Bezirksregierung Duesseldorf / right: poplars on the relatively wide-crested "Niederkasseler" levee in Duesseldorf – 2015, Source: BCE)

The study did not only investigate the impact of trees on earthen embankments such as levees but also on massive flood protection walls. According to DIN 19712 flood protection walls shall be handled analog to levees in respect to woody vegetation which means a minimum distance of 10 m from the structure itself which does not reflect the real effect from trees on massive concrete structures. The study also concludes that for flood protection walls a different approach should be applied as dictated in DIN 19712. In general, a minimum distance of 2.0 m from the tree trunk to the flood protection wall could be sufficient.

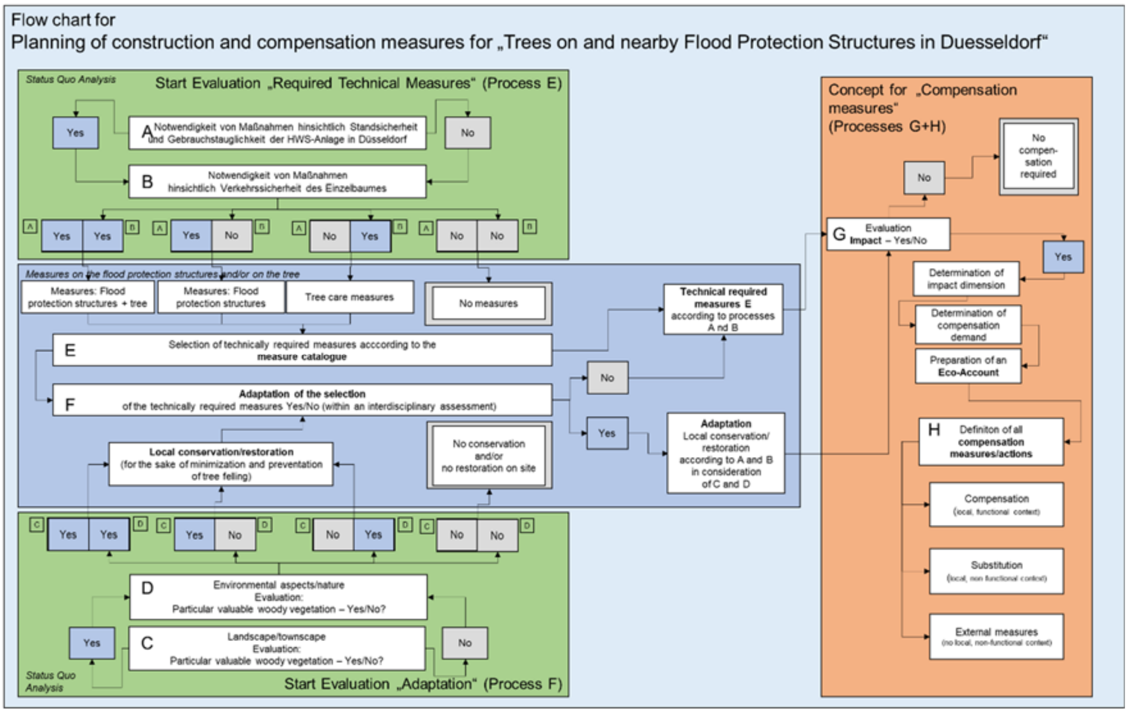

Figure 10: Flow chart of a standard procedure for the planning of construction and compensation measures prepared for the project "Trees on and nearby Flood Protection Structures in Duesseldorf" (BCE, 2019)

Experiences in Germany show that problems with trees at flood protection or shoreline walls are very rare. The author does not no one single case.

4 DESIGN RELEVANT ASPECTS FOR TREE RESILIENT LEVEES

Following aspects should be considered for allowing woody vegetation in one of the defined zones according to Figure 4:

- For normal designed levees ("standard case") woody vegetation is barely allowed or applicable. The risks especially in regard with seepage and erosion processes are not predictable on a long term perspective (Figure 4 – Standard Case, Line 1). Thus, if trees shall be conserved or planted protective measures have to be carried out.
- The oversizing of the levee body by adding additional width up- or downstream is dominated by the availability of space. In urban area space is frequently rare so that oversizing is not possible (Figure 4 – Exceptional Cases, Line 2 and 3).
- Frequently, existing levees where already large trees are located show an oversized profile as it is shown in Figure 9. The problem with old, existing levees with large trees is that this oversized profile is not providing enough protection/safety since the dam body is likely to be strongly rooted which is considered to be harmful in respect to stability.
- In practice the widening of levee crests or berms is usually done at the downstream slope since the utilization of upstream flow section area is unfavorable in respect to the mandatory requirement of the federal water act not to reduce retention volume (Figure 4 – Exceptional Cases, Line 2 and 3).
- The dimension of oversizing the levee body is always an evaluation from case to case and the intended design and acceptable size/height of woody vegetation. The dimension of the levee oversize was already discussed during several projects and authorities suggested that the widening shall be equal to the maximum future height of the vegetation which is usually an unrealistic approach since the costs for the additional levee body, and for the purchase of the private property, etc. are immense and the available space is limited, as aforementioned. In single cases so-called "tree bastions" are applied in order to control the costs and provide spots with enough space in the downstream slope (Figure 4 – Exceptional Cases, Line 2 and 3).
- Static elements such as steel sheet piles or reinforced slurry walls may take over the stability function of a levee so that trees may be left on or at the levee (Figure 4 – Exceptional Case, Line 4).
- The static element is usually designed for a load case/design situation where the tree completely fails and the slope is strongly or totally eroded or slipped away which results in a static vertical distance which has to be born by the static element (cantilever situation). Depending on the location of the tree the failure of the upstream or downstream slope can be critical for the determination of the internal strength of the static element and the embedment length. As a rule of thumb the total embedment length which is reaching into the underground can be assumed as two times of the cantilever length (Figure 4 – Exceptional Case, Line 4).
- Sealing elements, especially natural sealings made of clayey, sandy silts, show no distinctive resistance against rooting. Reported case studies confirm that already single roots may completely annul the sealing function. Therefore, sealings should be protected against roots. According to the authors opinion steel sheet piles or concrete slurry walls or similar elements behave more or less resistant against roots if no defects are produced during construction.
- The rooting of drain elements may diminish the draining capacity of pipes or coarse gravelly soils. If required, root protection layers should be applied similar to the protection of sealings.
- If trees remain on or at the levee annual or biannual inspections have to be performed in order to guarantee public safety and to evaluate the stability of the tree and required

care measures to eliminate potential risks. This has to be done hand in hand with the general maintenance works for the levee.

- If roads or ways are evident for supervision and defense works during floods the accessibility of these pathways has to be guaranteed, especially during floods. Frequently, the scenario of a tree failure by windblow is considered which has to be handled by first an adequate maintenance and inspection of trees and second by an effective integration of measures within the emergency action plan for floods. Trees which are blocking roads should be removed by the relief units in a due time what means immediately during floods. It has to be noted the problem is not the blocking of roads by the failure of a single tree which can be removed within some hours also without special preparatory measures. But if a storm strikes the levee area which may host rows and alleys of trees not only one tree may fall.
- The extent of root systems may be extraordinary and will not comply to tree characteristics which develop in plane, unhindered and optimum conditions. One should know that the strong roots are reaching generally 1.5 to 2.0 m from the trunk area which does not mean that single strong roots may exhibit much thicker and longer dimensions which is valid for, e. g., locusts, poplars, and others. A site specific evaluation of the tree characteristic is generally recommended.
- In the course of construction works roots may be hurt or cut. The cutting of strong roots should be avoided by the application of an adequate distance from the trunk. An excavation and pretreatment of the roots may increase the chances for the tree to survive. Additional loads on root systems may also lead to an decease of roots and, consequently, also of the tree. Root protection bridges were applied successfully at single projects in Germany in order to avoid the additional stresses on roots. Generally, this is an expensive measure for the preservation of some single trees.
- Strong, thick roots may show considerable resistance to piling works so that an advance excavation trench could help cut and eliminate roots and ease the piling works.

Mainly in urban areas the conservation of existing woody vegetation on flood protection structures is frequently the favorite design alternative in consideration of all interests and aspects of all project participants and stakeholders. In order to achieve the conservation of existing trees in urban conditions the application of space-saving techniques for the implementation of static elements is evident. For this purpose the self-move press-in procedure for sheet piles, as applied in harbor areas, is a suitable solution as shown in the case study in Figure 11. The existing levee is generally conserved. The trees in a distance of less then 1.5 to 2.0 m from the axis of the sheet piles will be removed which is also valid for the crown of the trees, but the rest will be also conserved.

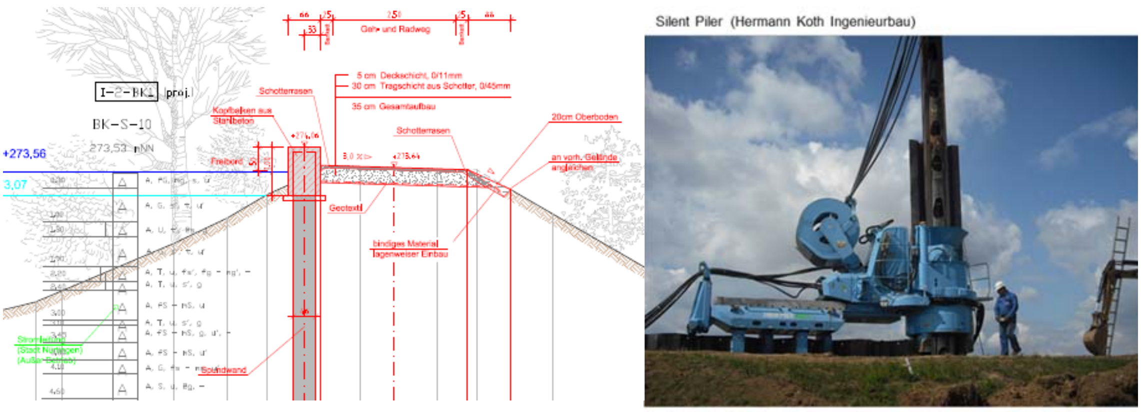

Figure 11: Design of a levee rehabilitation along the River Neckar for the town Nuertingen in the south of Germany (left: typical cross section with a self-moving, pressed-in sheet pile, Source: BCE / right: self-moving. press-in equipment “Silent Piler”, Source: Hermann Koth Ingenieurbau)

By this design the impact on the biotopes and habitats could be minimized crucially. This minimization of the environmental impact is a key factor for the approval and realization of the complete project since compensation of extensive impact is difficult and the conservation of the existing situation is also a political issue which is evident for the acceptance by the stakeholders and the public.

Generally, the shown case study represents a costly method compared to other ways of rehabilitation. But the comparison of the costs of the alternatives cannot be done so easily, since the favorite solution can be realized whilst the other alternatives which are showing a much larger impact cannot be realized. Thus, the theoretically cost-intensive favorite solution is still the most economic one in consideration of the avoided flood damage.

5 REFERENCES

BAW MSD. 2005. Standsicherheit von Dämmen an Bundeswasserstraßen (MSD). *Merkblatt, Bundesanstalt für Wasserbau (BAW), Karlsruhe*

BCE. 2019. Bäume an und auf HWS-Bauwerken in Düsseldorf. *Studie für den Stadtentwässerungsbetrieb Düsseldorf (SEBD), Björnsen Beratende Ingenieure GmbH (BCE), Koblenz (unpublished, but available)*

DIN 19712. 1997. Deiche an Fließgewässern. *Deutsches Institut für Normung (DIN), Berlin*

DIN 19712. 2013. Hochwasserschutzanlagen an Fließgewässern. *Deutsches Institut für Normung (DIN), Berlin*

DVWK-M 210. 1986. Flussdeiche. *Merkblätter zur Wasserwirtschaft, Heft 210, Deutscher Verband für Wasserwirtschaft und Kulturbau, Verlag Paul Parey, Hamburg und Berlin*

DVWK 226. 1993: Landschaftsökologische Gesichtspunkte bei Flussdeichen. *Merkblätter zur Wasserwirtschaft, Heft 226, Deutscher Verband für Wasserwirtschaft und Kulturbau (DVWK), Verlag Paul Parey, Hamburg und Berlin*

DWA-M 507-1. 2011. Deiche an Fließgewässern - Teil 1: Planung, Bau und Betrieb. *Merkblatt 507-1, Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V. (DWA), Hennef*

DWA-M 507-2. 2021. Deiche an Fließgewässern - Teil 2: Landschaftsökologische Gesichtspunkte an Deichen. *Merkblatt 507-2, Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V. (DWA), Hennef (in preparation)*

Haselsteiner, R., Strobl, Th. 2006. Deichertüchtigung unter besonderer Berücksichtigung von Gehölzen. *Sicherung von Dämmen, Deichen und Stauanlagen: Handbuch für Theorie und Praxis, Hrsg. Hermann und Jensen, Universitätsverlag Siegen – universi, Vol. II, S. 325 – 353*

Haselsteiner, R.; Strobl, Th.; Heerten, G.; Werth, K. 2008. Overflow Protection of Flood Embankments with Geosynthetics. *EuroGeo 4, Geosynthetics in Civil Engineering Applications, September 2008, Edinburgh, Scotland*

Haselsteiner, R. 2007. Hochwasserschutzdeiche an Fließgewässern und ihre Durchsickerung. *Phd-Thesis. Lehrstuhl und Versuchsanstalt für Wasserbau und Wasserwirtschaft, Mitteilungsheft Nr. 111, Technische Universität München*

Haselsteiner, R. 2007A. The Design of Dikes with Woody Vegetation - German Standards, Experiences and Concepts. *The vegetation challenge: A scientific and engineering examination of managing vegetation along California's Central Valley levees that protect urban and rural areas from devasting floods. Technical Symposium, 28./29.08.2007, Sacramento (USA)*

Haselsteiner, R.; Strobl, Th.; Heerten, G.; Werth, K. 2008. Overflow Protection of Flood Embankments with Geosynthetics. *EuroGeo 4, Geosynthetics in Civil Engineering Applications, September 2008, Edinburgh, Scotland*

Haselsteiner, R. 2010. Der Bewuchs an und auf Hochwasserschutzdeichen an Fließgewässern aus technischer und naturschutzfachlicher Sicht. *Dresdner Wasserbaukolloquium, 17.-18.03.2010 in Dresden, Inst. für Wasserbau und Technische Hydromechanik, Wasserb. Mitteil., Heft 40, S. 373-382*

Haselsteiner, R. 2010A. Woody Vegetation on Small Embankments. *8th ICOLD European Club Symposium, "From research to design in European practice", 22th - 23th September 2010 in Innsbruck, Austria.*

Haselsteiner, R. 2018. Current Methods and Trends for Levee Rehabilitation Works in Germany. *International Symposium on Dams "26th ICOLD World Congress", ICOLD, 2018, Vienna*

Haselsteiner, R. 2018A. Gehölze an und auf Hochwasserschutzanlagen an Fließgewässern. *48. Internationales Wasserbau-Symposium Aachen (IWASA) „D³ - Deckwerke, Deiche und Dämme", 6. Siegener Symposium „Sicherung von Dämmen, Deichen und Stauanlagen", 18.-19.01.2018 in Aachen*

Haselsteiner, R. 2019. Woody Vegetation on Levees in Germany – Requirements, technical solutions and case studies. *ICOLD 2019 Annual Meeting/Symposium, Sustainable and Safe Dams Around the World,* *09-14.06.2019, Presentation for the TC Workshops - LE – Dams, Levees and flood protection structures and systems, Ottawa, Canada*

Kerres, D.; Haselsteiner, R. 2018. Design of Deep Soil Mixing Walls and their Advantages over Conventional Sealing for Embankment Dams. *International Symposium on Dams "ATCOLD Symposium Hydro Engineering", ICOLD, 2018, Vienna*

Lammeranner, W.; Haselsteiner, R. 2010. Ingenieurbiologische Bauweisen an Hochwasserschutzdeichen. *Dresdner Wasserbaukolloquium, "Wasserbau und Umwelt - Anforderungen, Methoden und Lösungen", Institut für Wasserbau und Technische Hydromechanik, 17.-18.03.2010, Dresden, Institut für Wasserbau und Technische Hydromechanik, Wasserbauliche Mitteilungen, Heft 40, S. 191-200*

LfW BY. 1990. Gehölze auf Deichen. Dokumentation von Baumwurzelaufgrabungen und Windwurf von Gehölzen. *Heft 5/89 Informationsberichte, Bayerisches Landesamt für Wasserwirtschaft, München.*

Kleber-Lerchbaumer, U. 2018. Naturschutzfachliche Gesichtspunkte und Anforderungen. *DWA-Deichtage, 12.-13.09.2018, Bremen*

Pflug, W.; Hacker, E. 1999. Flussdeiche und Flussdämme. Bewuchs und Standsicherheit. *Jahrbuch 4 der Gesellschaft für Ingenieurbiologie e. V., Hrsg. Pflug und Hacker, Aachen*

SLfL. 2005. Bewirtschaftung von Deichen. *Schriftenreihe der Sächsichen Landesanstalt für Landwirtschaft, Heft 11, 10. Jahrgang*

Marks, D. B.; Tschantz, B. A. 2002. A Technical Manual on the Effects of Tree and Woody Vegetation Root Penetrations on the Safety of Earthen Dams. *Marks Enterprises Of NC, PLLC, North Carolina*

USACE. 2007. Treatment of Vegetation within Local Flood-Damage Reduction Systems. *White Paper (Final Draft), US Army Corps of Engineers (USACE), Washington DC*

USACE. 2014. Guidelines for Landscape Planning and Vegetation Management at Levees, Floodwalls, Embankment Dams and Appurtenant Structures. *US Army Corps of Engineers (USACE), ETL 1110-2-583, Washington DC*

Wessolly, L.; Erb, M. 1998. Handbuch der Baumstatik und Baumkontrolle. *Patzer Verlag, Berlin Hannover. Wessolly, L.: Rosskastanien auf einem Rheindeich: Wechselwirkungen und Sicherheiten. Tagungsband 1. Departmentkongress Bautechnik und Naturgefahren, Vienna*

Wessolly, L. 2007. Rosskastanien auf einem Rheindeich: Wechselwirkungen und Sicherheiten. *Tagungsband 1. Departmentkongress Bautechnik und Naturgefahren, Vienna*

Wessolly, L. 2020. Bäume auf Deichen und Dämmen. *Pro Baum – Zeitschrift für Pflanzung, Pflege und Erhaltung, 03/2020, p. 22-28*

Winski, A. 2004. Literaturstudie zum Verhalten von Wurzeln unter natürlichen Bedingungen sowie auf Deichen. *Erläuterungsbericht, Gewässerdirektion Südlicher Oberrhein – Hochrhein, Bereich Offenburg, Teningen 2004 (unpublished, but available)*