# Woody Vegetation on Small Embankment Dams

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## Abstract

The maintenance of embankment dams with permanent or temporary reservoirs are frequently dominated by the works to control the vegetation on the embankments. Young woody vegetation and more particularly, large trees may endanger the functionality of the embankment and may cause damage and even lead to a complete failure. Where maintenance works were neglected over decades, the authorities and owners responsible would face many questions regarding the safety of their facilities, possible measures and future planning to keep the vegetation to a safe and controlled level. For the purpose of providing an overview of the whole topic the author incorporated several references and summarized the basic design criteria for vegetation treatment on embankments. Further more, a general concept introducing specific zones is proposed. This concept can be considered as a basic recommendation and can be modified for specific cases corresponding to local conditions.

## Introduction

The impact of woody vegetation is reduced with increasing dam height due to the limited range of roots. Therefore, this paper will mainly focus on small embankment dams with a height less than 40-50m. Usually no uncontrolled, oversize bushes and trees should be cultivated on dams at all regardless of the size of the dam. In particular, the integrity of small embankments such as flood protection levees with heights less than 5m can be considerably affected by woody vegetation. Recent experiences with floods in Western Europe revealed that breaches of flood embankment dams were frequently related to oversized trees on or close to embankment structures.

Although embankment dams with permanent or temporary reservoirs are usually maintained regularly, many case studies give reason for concerns regarding pumped storage embankment dams and flood retaining reservoir dams. In regard to the vegetation regulations and concepts permanent and temporary reservoirs have to be treated separately. Since for temporary reservoirs the upstream slope is also usually covered by vegetation unless surface sealants are applied which prevent the growth of vegetation.

## Regulations, Codes, Best Practice

**General**

The issue of "vegetation and its effect on embankment dams" is mainly relevant to small embankment dams. Therefore, for high embankment dams (H > 50m) regulations and design criteria concerning vegetation are less available. Woody vegetation usually comprises both bushes and trees. The transition from a bush to a tree is fluent. Of course, regulations and design manuals are mainly prepared in order to avoid the impact of large trees with heights greater than 10m.

**Regulations & Codes & Fundamental Design Criteria**

German and international design codes, manuals and regulations are mainly prepared on the basis of experience with floods and hence, are aimed at flood embankment dams [1] [2] [3] and water channel embankment dams [4] with a limited height. Also in the United States the Army Corps of Engineers (USACE) encountered also the necessity of regulation in the form of limitation of woody vegetation on flood embankments (levees) [5] and extended the original engineering design code for levees published in 2000 [6]. The treatment of vegetation on embankment dams is intensively discussed [7] by American engineers and researchers.

Corresponding to the cited literature sources the regulations range from allowing no woody vegetation on the embankment to allowing some limited vegetation. All the cited sources agree that uncontrolled forms of vegetation reflect a high risk for stability etc. and does usually not comply with the technical requirements of embankment dams. But, exceptions may be accepted if the consequences of harm or the failure of an embankment can be tolerated.

The fundamental principles for handling woody vegetation on embankments are summarized as follows in consideration of the basic aim that the structure has to show full functionality and operability permanently [1] [3]:

- No woody vegetation directly on the crest, roads and other ways
- No woody vegetation on homogenous, not oversized embankment dams which are subject to rooting; harmful

rooting into the embankment dam body has to be prevented by efficient means
- No vegetation at overflow sections or spillways
- Limited forms of vegetation at the slopes as long as the stability of the embankment dam is not endangered; upstream slopes should be kept free if hydraulic and geotechnical aspects are compromise by the presence of woody vegetation
- Consideration of hydraulic aspects if woody vegetation is applied within the floodplains
- No woody vegetation within the area of seepage exits
- Unspecified forms of woody vegetation not within a safety corridor upstream and downstream of the embankment toe also in order to avoid scouring effects and rooting of e. g. natural clay seals
- Single trees are more harmful than tree groups; maintenance aspects should be considered
- Removal of trees together with the complete root ball in consideration of safety aspects

Furthermore, the impact of all forms of roots on the concerned soils and embankments should be avoided in terms of stability, operability, serviceability and durability. Deep roots are particularly dangerous for sealing elements and drainage bodies. Tree failure can lead to a total failure of the embankment if overtopping occurs. The effects of woody vegetation and its roots are summarized below.

**Effects of Woody Vegetation**

The available regulations comprise both the primary and secondary effects and impacts of woody vegetation and its roots as follows [4] [7] [8] [9]:
- Holes and damage due to tree failure
- Increased permeability of low permeability soils and fill material by roots; increased seepage flow and forces (also: wind induced pumping effect)
- Interference of drainage and filter zones causing a change in permeability and erosion processes
- Additional static load on to slope
- Hindrance of close sod cover by shadowing of trees
- Difficulties for maintenance works and increase of maintenance costs
- Hampering of inspection and supervision works, particularly during flood and extreme water levels
- Damage to other structures on or at the embankments
- Attraction of digging animals

The failure mechanisms of embankment structures are complex in regard to both development and detection. In special cases the processes can develop over years without noticeable changes in the behavior and conditions of the affected structures. Whereas once the critical equilibrium state is reached or exceeded the failure and breach mechanism can progress very quickly, particularly when erosion processes are initiated by overtopping or backward erosion through the embankment or underground.

Case studies and experiences with damage caused and/or supported by woody vegetation are numerous. Particularly, flood embankments used to suffer from a lack of maintenance work when the major floods in Europe occurred. Woody vegetation growth and design deficiencies compounded the situation and risks to a critical level and caused tremendous financial damage [19].

## Proposed Design Principles

**General Methodology**

The allowance of woody vegetation on embankments have to be assessed hand in hand with the potential damage and the consequences within a prudent risk assessment. Of course, additional measures can always be taken to increase the stability and durability of the embankment. The following steps should be taken in order to evaluate the embankment and its purposes along with the inherent risk of allowing woody vegetation:
- Investigation and exploration of the existing embankment and its design including present and/or future forms of vegetation
- Definition of the purposes of the embankment hand in hand with its stability, operability, serviceability and durability
- Risk analysis including the determination of potential damage and the consequences of damage
- Preparation of a refurbishment, operation and maintenance plan in consideration of specific zones as shown later in this paper

One crucial part of the risk analysis is the identification of risk mitigation measures such as structural strengthening, maintenance and refurbishment measures. The mentioned technical aspects stability, operability, serviceability and durability should comply with environmental aspects, landscaping and local recreation. The latter aspects should yield to the principles of safety of the embankment if a corresponding damage potential and risk exist. If the risk and the potential damage are negligible, other aspects may be decisive and may also allow the emergence of uncontrolled woods. If embankments are part of flood defence systems and/or controlled reservoirs all forms of vegetation on the embankment usually have to be assessed and maintained in regard to safety and functionality aspects. Additional aspects discussing the uses of different forms of vegetation on and at dikes are presented in [14] [15]. An evaluation matrix for acceptable forms of vegetation on flood protection embankment is presented in [9].

For selected cases an assessment of the additional loads, load cases as well as the consequences of tree and root impact can

be carried out. For this purpose following aspects could be helpful:

- Roots prefer loose soils with enough water and nutrients. Coarse gravels are usually less rooted. A description of the rooting constraints is given in [7] [9] [10] [11] [19]. The root growth is generally affected by the density of the soils, by the (ground)water conditions, by the nutrients present, by the natural geotropism, by the tree class and its root type, by the sun and other boundary constraints such as geometry and design of the embankment, neighboring vegetation forms, etc.
- Trees with an unfavorable relation of height to trunk thickness tend to fall more frequently than others. Old trees are more likely to fall because of illnesses and material failures [13]. Close plantings result in an intensive increase in height while neglecting root growth so that the stability of such plantings can be critical if corresponding (wind) loads occur.
- Most technically feasible seals in embankments are not subject to rooting, except naturally low permeability soils or artificial seals with a considerable potential for imperfection. For sealing elements that are usually used for flood embankment an evaluation of the likelihood of being rooted is included in [9]. This evaluation confirms the mentioned aspect. Additionally, one should be aware that small roots of a few millimeters to centimeters may completely inhibit the ability of a sealing to function.
- Some root types cultivate shoots or rhizomes so that a tree removal has to go hand in hand with a removal of the complete root system which can develop enormous sizes. The milling of root balls and mixing with surrounding soil is considered not to meet the engineering requirements of embankment dams.
- Grass sods are usually the most favorable form of protective vegetation, being easy to maintain in regard to time and cost and gives the lowest risk to the embankment itself. Grass cover usually overtakes the function of superficial erosion protection [1] [2] [3]. The determination of the engineering parameters of grass sods is widely discussed in literature [12] [19].

**Proposed Zonal Design Criteria**

In order to help design engineers and owners to prepare a proper design and/or to assess the existing embankments the author would like to recommend the application of zones in accordance to the actual embankment conditions and boundary constraints. In general, embankments with permanent reservoirs or temporarily impounded embankments have to be treated differently. The discussed standard design mainly aim on small embankments with a height smaller than 40-50 m or even less. For permanent impounded embankments the upstream (U) zones differ to those of temporarily impounded dams. The downstream zones (D) and the crest (C) are more or less equal for both embankment types. Within the reservoir no woody vegetation should come up (zone 0).

A typical embankment dam with its zones for the regulation of woody vegetation is shown in Figure 1. The number of upstream and downstream zones can be adapted in regard to specific site conditions. For common cases the presented zones should be sufficient for the preparation of a prudent vegetation concept. For temporarily flooded forms of vegetations (“green flood retention reservoir”, floodplain forests) the hydraulic resistance to flood flows has to be checked against the planting plan. Usually, unfavourable plantings will be replaced by natural succession in form of floodplain forests depending on the frequency of flooding.

The design criteria for the zones C, 0 and U1 are as follows:

- Zone C: The crest width is selected in regard to safety and serviceability aspects. A minimum width of 3.0 m [1] or 3.5 m [16] can be sufficient for small embankments. High dams can have a crest width of 10-15 m and more. The sensitivity of the crest to the impact of woody vegetation has to be assessed in relation to the width. Usually, a road or way is located on the crest in order to enable supervision, inspection, passing and refurbishment. The road/way must be passable. Therefore, pavement or rural road engineering methods are applicable. For all cases, woody vegetation or even high grass is not acceptable. In exceptional cases, woody vegetation close to the road may be allowed if this is not counter to safety considerations. Then, the required clearance has to be ensured in the course of the legal maintenance duty [17]. This is particularly important if the embankments and adjacent structures are accessible for the public. Usually, grass shoulders without kerbs are used provide an edge to the road. Up- (U1/U2) and downstream (D1) of the crest (C) explicit safety zones of several meters with controlled grass vegetation may be used in order to protect the sensitive crest area against any harm.
- Zone 0: This zone comprises the waterside/upstream embankment which is impounded by a permanent reservoir. Due to the natural conditions within this zone no woody vegetation that could endanger superficial clay seals in particular should be allowed to grow. But, fluctuating water levels can allow the growth of woody vegetation between the maximum and minimum water levels. Usually the arising vegetation is reeds and other shore woods/grasses and have to be removed periodically.
- Zone U1: For the case that a reservoir is present (zone 0) zone U1 is located between the crest and the water level. The water level can be subject to fluctuations in regard to the operational aspects (see zone 0). Particularly if superficial sealants (asphalt, concrete, natural inclined clay seals, geosynthetic liners) are applied the roots may present a risk to the functionality of the sealant itself

and/or the applied filter and drainage zones. If sensitive superficial sealing elements are applied a project specific evaluation may be required [9]. Experience has shown that also within zone U1 reeds, bushes and similar small forms of vegetation may be cultivated without any problems. Core sealings are usually less affected by vegetation in zone U1. Frequently, riprap or similar superficial protection layers can be applied in order to prevent harmful vegetation growing. In some cases grouting of the riprap with asphaltic mastic can also be required.

The following design criteria concerning the upstream zones are only valid for embankments without a permanent reservoir:

- Zone U2: If there is no reservoir level zone, U2 also includes zone U1. In general, the vegetation within zone U2 has to be evaluated in consideration of the present hydraulic loads caused by flow velocities or/and seepage due to rapid draw down. If the design and the general boundary constraints allow, small bushes, trees and similar vegetation types may be acceptable. At the slopes, potential sliding failures have to be assessed hand in hand with tree failures. In specific cases the stability of trees (wind failure, wind break) can be assessed by evaluating the specific parameters tree height, trunk diameter, wind velocity, etc. [13] [20] [21]. Trees with a relatively big height in comparison to the dam height should not be tolerated on the slopes. Rapid growing and intensive rooting trees such as poplars or robinia are particularly critical. If superficial natural sealing elements are applied close to the slope surface usually no woody vegetation should be allowed in U2, and also U1.
- Zone U3: The protection zone U3, and also D3, are subject to similar utilization restrictions with regard to the vegetation as the zones U2 and D2, respectively. Zone U3 should be extended to also comprise maintenance ways and/or roads which are located close to the dam toe. For flood embankments a width of 4-5 m s applied in Germany. [7] extends its specific Zone 5 to half of the dam height downstream of the downstream dam toe also with regard to possible piping/erosion processes which could be initiated by tree roots. Usually, grass cover is the best form of vegetation for zone U3 and D3.
- Zone U4: Due to the closeness to the dam body only small bushes and trees are allowed within this zone in order to avoid root penetration of superficial sealing. Within floodplains the effect of the vegetation present on the hydraulic conditions has to be considered. The height of woody vegetation in this zone may be limited to no more than 5.0 m so that also any wind failure cannot harm the dam body as the width of zone U4 should be 5.0 m.
- Zone U5: Within this zone all forms of woody vegetation are allowed except large trees which exhibit rapid height growth and intensive rooting such as poplar and robinia. In [4] [19] a large number of trees are classified in accordance to the possible risks for embankments. Usually, the author's opinion is that a width of 20 m should be sufficient for zone U5. This also corresponds to German regulations.
- Zone U6: This zone should be located far away from the embankment so that all kinds of harm can be excluded with regard to rooting and tree failures. A distance of 30m from the dam toe should be applicable.

For the downstream zones D1, D3, D4, D5 and D6 the stated design criteria of the zones U2, U3, U4, U5 and U6 are valid analogously. Only for zone D2 specific criteria should be considered as follows:

- Zone D2: In order to enable a visual seepage monitoring the vegetation within zone D2 should be a grass cover. This zone should be extended if necessary in order to cover also close berm ways or maintenance/access roads. For a rough evaluation, zone D2 approximately comprises the area defined by one third of the dam height measured from the dam toe. For specific filter/drainage bodies this height can differ. The maintenance works have to be defined in order to enable permanent supervision and inspection. Experience during recent flood incidents showed that the early determination of possible seepage/erosion processes is critical in order to be able to initiate emergency countermeasures.

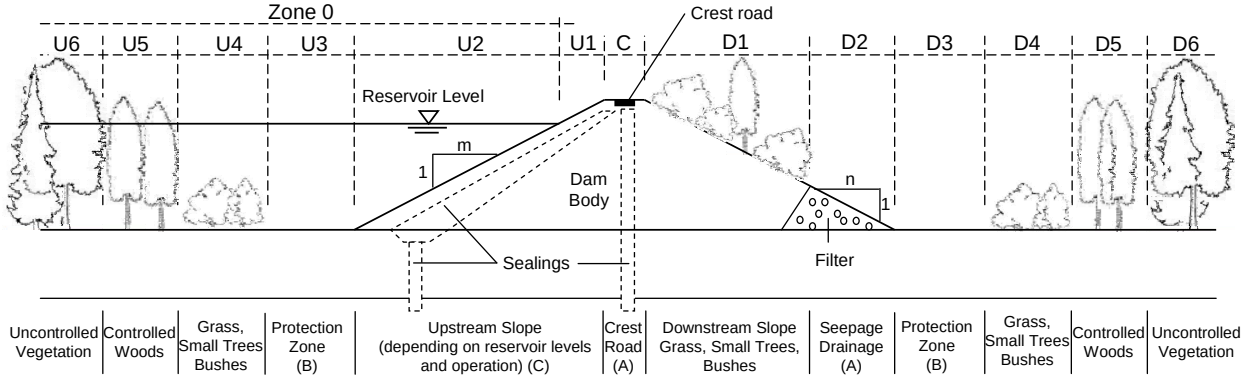
The zone concept presented herein can and should be modified and/or extended to meet local conditions and boundary constraints. The adding and refinement of zones can be applicable as well as the simplification of the proposed concept. Within the mentioned literature sources [3] [4] [7] [9] [19] methodologies are proposed which should enable the engineers responsible to customize and improve existing, or to prepare new vegetation concepts.

**Maintenance**

The maintenance of grass areas has to take place annually or twice a year depending on the local conditions. Whether the grass clippings have to be removed or can stay has to be decided case by case in close collaboration with ecologists and vegetation experts. If woody vegetation is permitted, a maintenance interval of 2-5 years is feasible. Spatial rotation is favourable in order to minimize interference to the local wildlife conditions.

The bushes and trees present in zones U1, U2, U4, U5, D1, D4 and D5 should be controlled in consideration of agreed specifications which limited the trunk thickness and/or the height. Periodically, a refreshment seeding should be applied to close the vegetation cover where necessary. Superficial

erosion should be avoided especially in areas where the removal of woody vegetation would leave an unprotected soil surface. The envisaged vegetation concept should also be evaluated in regard to economic aspects. The manual maintenance of woody vegetation can be expensive in comparison to the maintenance of grass cover that is done by machinery. Finally, the technical aspects must dominate.




*Notes:*
(A) It is assumed that usually no woody vegetation should come up within these zonings.
(B) Within the protection zones restricive utilizations have to be agreed in regard to e. g. agriculture.
(C) For temporary reservoirs small bushes and trees can be located on the upstream slopes. The superficial erosion protection has to be considered.

Figure 1: Proposed vegetation zones for embankment dams

**Refurbishment Measures**

In case of upcoming vegetation different measures can be taken. Additional to maintenance (see above) and removal measures (see below), the structural strengthening of the affected embankment can also be realized. Seepage control measures, root barriers or the enlargement of the dam body (filter, berms, etc.) are frequently applied in order to prevent any harmful impacts of woody vegetation [9].

Statically effective sealing elements are frequently applied for the refurbishment of flood embankments when woody vegetation has to be cultivated and corresponding load cases such as “tree failure” have to be considered. Usually, static effective sealings are sheet piles, reinforced mixed-in-place or milled soil-cement mixing methods, and they are applied to embankments with a height of less than 10 m. For higher embankments cut-off walls, milled cut-off walls or bore piles are commonly applied [22] [23] [25].

The easiest form of root barrier is the application of a sufficiently compacted gravel layer with a thickness of at least 0.5 m or even better 1.0 m. Geomembranes, sheet piles, etc. can be also applied in order to prevent root intrusion into the dam body [7] [24]. If enough resources are available (land, dam fill material, funds) the application of berms and extended dam shoulders are applicable in order to provide an oversized profile on order to avoid any harmful effects of woody vegetation and their roots.

In case of an endangerment to the dam stability, particularly for permanent reservoirs, urgent rehabilitation construction measures have to be carried out immediately. If changes to seepage conditions are observed a reservoir drawdown should be taken into consideration. Woody vegetation at flood embankments have caused problems so severe that a complete failure of the embankment could frequently only be prevented by massive flood fighting measures. Frequently the woody vegetation induced erosion and deformation processes caused a complete dike failure and led to considerable damage in the land downstream. Experience of this failure reason are gathered by the dozen during the floods 2002, 2005 and 2010 in Germany and in the east of Europe [5].

**Removal of Woody Vegetation**

The removal of woody vegetation and particularly of large trees that show a correspondingly high risk should be done corresponding to a special sequence during the winter months in order not to disturb the wildlife too much. Different tactics may be applied. On the one hand, the trees with the bigger diameters can be removed firstly. Usually trees with a diameter bigger than 1.0 m measured at 1.0 m height above ground level exhibit the largest risk in regard to roots and loading. In order to minimize the intervention of the wildlife conditions the process can be split over several years (3-5 years) and/or the small trees can be removed firstly. Experience in Germany shows that especially after floods the removal of woody vegetation on flood embankments and reservoirs can be carried out relatively easily, whereas opposition is frequently met from conservationists if the need for clearing is not emphasized by current dam disasters.

Particularly, for very small dams the removal of the tree ball represents a relatively expensive but necessary action which has usually to be taken in order to guarantee the dam

body according to prudent engineering requirements. For larger dams the tree roots may remain if all critical consequences can be excluded. The milling and mixing of the tree balls with the adjacent soil can also be acceptable in single cases. Usually, the milling method leaves a soil-wood-compound which can be subject to settlement and erosion and also exhibits poor shear parameters and relatively high permeability. The technically superior, but most expensive method is to remove the main tree ball mechanically, and, subsequently, the smaller roots manually. Finally, the excavation has to be refilled by appropriate, filter stable, compacted fill material. For small, wooded flood embankments (H < 2-3 m) a removal and reconstruction of the complete dam body is frequently the optimum solution [22].

## Conclusion

Although, a lot of experience, wide-spread knowledge and many manuals including vegetation regulations exist, many dam owners and responsible authorities realize that the actual vegetation seriously affects the stability, operability, serviceability and durability of their assets. In this case, refurbishment measures and prudent future maintenance concepts have usually to be realized in consideration of technical and economical aspects. The presented concept of introducing zones and defining the design/maintenance criteria correspondingly has proved itself and will assert itself in the national regulations for embankment dams worldwide in the near future.

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