Indirect bank protection in tidal areas

Data sheet (Version 2025)

Double pile rows with stone filling and openings in offset arrangement (BAW)

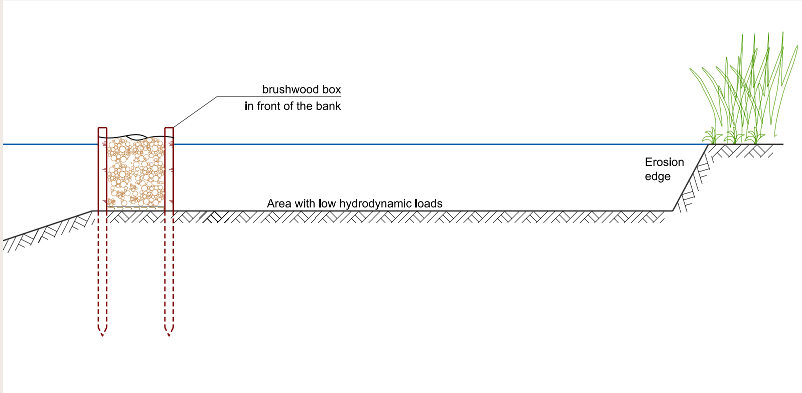

Diagram of an indirect bank protection (BAW)

OVERVIEW

Brief description

Indirect bank protection measures are installed in front of river banks and provide indirect protection of erosion edges on flat banks. As a rule, these structures are installed as double pile rows with tied fascines (brushwood box); see also data sheet *Direct bank protection: Brushwood box*.

These measures protect the banks indirectly by reducing current and wave loads and promoting the settling of sediment behind the structure. Fill material, dimensions, design or other aspects can vary according to site requirements. Depending on their dimensioning and design, they can create a small-scale mosaic of erosion and sedimentation areas. This promotes the development of diverse tidal flat structures, such as changing systems of channels and creeks and residual water areas at low tide. In the sheltered area around the structure, vegetation can establish and additionally contribute to bank protection. Subsequently, from the bank soils, depending on the grain sizes of the deposited sediments, stable soil fabric evolves.

Bank protection effect

Indirect protection through current and wave attenuation

The hydraulically conductive fill material (e.g. brushwood, stones) dampens the waves and currents close to the bank that are caused by tidal dynamics, sea state or ship traffic. The hydrodynamic loads on the bank are thus reduced. As a result, erosion is mitigated or, at best, stopped. In the area behind the structure more aggradation is to be expected because of the reduced flow velocities. This enhances bank protection. Fine sediments, algae, etc. can deposit in the packed fascine-work and increase the capacity for retaining sediment in this area.

Direct and indirect bank protection through growth of vegetation

Where slope inclination, flow and wave impact and elevation in relation to mean high water permit, vegetation establishes on the landside of the structures. The growth of vegetation has an additional dampening effect on currents and waves and makes it easier for sediment to deposit. Besides this indirect protection effect, the plant roots bind soil and therefore increase bank resistance to erosion. The broader and denser the vegetation cover, the more effective it is as bank protection. Vegetation also causes the formation of soil which enhances the effects mentioned above.

OVERVIEW

Advantages and disadvantages compared to a direct bank protection using riprap, concrete or steel	**Advantages** • High ecological benefit because dynamic development of bank area is allowed to some extent and characteristic, temporarily wetted estuarine habitats with low flow velocities are provided to typical plants and animals • Sediment deposition in previously eroding bank areas becomes possible • Use of renewable and native materials, ideally from own trees or bushes • Comparatively low cost of material • As a rule, manual installation and maintenance is possible without a need for large or special machinery • No or negligible disposal costs as predominantly sustainable materials are used **Disadvantages** • May require more staff for construction, monitoring and maintenance (especially with large-scale measures), depending on boundary conditions. This can be reduced by, among other things, choosing alternative design variants, so that the measure has a more sustainable and long-term effect and is still economical despite the need for more staff for construction. • Can potentially act as a barrier to animals. However, this can be prevented by certain modifications, e.g. by providing openings or installing fascines as ramps (for details see *Alternative designs* section).

ECOLOGICAL BENEFIT

compared to direct bank protection using riprap, concrete or steel

Hydromorphology	• Flow diversity • Creating wave-protected riparian areas with low flow velocities • Developing tidal flat and bank structures behind the protection structure; structural diversity depends on dimensioning and design
Habitats and their interconnectedness	Direct protection measures using riprap, concrete or steel can create barriers between the riparian habitat and the hinterland and thus obstacles to the movement of substances, sediments, plants and animals. Where such structures are dispensed with, the natural interconnectedness of habitats and their natural colonisation with some organisms is fostered. For instance, some protection designs can promote lateral migration of habitat-typical species such as fish. To ensure suitable conditions for typical species, habitat connectivity is essential for these plants and animals. This is achieved by increasing structural diversity. More diversity increases habitat quality and potential for colonisation by protected and/or endangered plant and animal species.
Vegetation	Creating wave-protected riparian areas with low flow velocities by indirect protection measures and the associated sedimentation processes can promote the following biotopes protected under the German Federal Nature Conservation Act (Bundesnaturschutzgesetz, BNatSchG): • Intertidal areas with growth of seaweed, e.g. diatoms or Vaucheria algae • Muddy soil vegetation (e.g. pink water-speedwell, goosefoot, bidens)

ECOLOGICAL BENEFIT

compared to direct bank protection using riprap, concrete or steel

- (Pioneer) reeds (e.g. softstem bulrush, sea-club-rush, slender spike-rush, reed, (lesser) bulrush, reed canary grass, accompanied by marsh-marigold, cotula)
- Tall forb vegetation (e.g. purple loosestrife, garden angelica, willow-herb, meadowsweet, hedge bindweed, broad-leaved ragwort)
- Softwood floodplain forest (e.g. white willow, purple willow, osier, almond willow, crack-willow and black-poplar)
- Saltmarshes in the outer estuary (e.g. glasswort, cord-grasses, common saltmarsh-grass)

With the establishment of this vegetation and greater diversity of flow velocities and structures near banks, there is an increasing potential for the development of habitats for other plants, such as the endangered club-rush (triangular and American club-rush, oblong bulrush) or the strictly protected Elbe water dropwort which is threatened with extinction.

Fauna

The structure itself as well as the potentially developing structures and vegetation behind it can provide habitats for various animal groups. Unlike the common seal, the grey seal is subject to special protection according to the BNatSchG, as are the following birds that are specially protected within the meaning of the Birds Directive. Some species are strictly protected. Under the BNatSchG, bat species and the beaver are strictly protected. The eel is specially protected.

- Small invertebrates that colonise hard substrates (e.g. mussels, barnacles, moss animals and cnidarians, depending on salinity conditions) can establish on the structure.
- A large diversity of species establishes in the intertidal flat soil which is formed by depositing sediments, depending on the salt content (fresh, brackish or salt water), such as worms (e.g. bristle worms), crustaceans (e.g. amphipods), clams (e.g. Asian clam, razor clams) and winkles (e.g. common periwinkle). They serve as an important source of feed for breeding and resting birds. In addition, open tidal flats can serve as resting places for seals, provided that they are sufficiently extensive.
- Reed developing in the shelter of the structure provides a habitat for a multitude of insects (e.g. beetles), crustaceans (e.g. isopods) and spiders, as well as for a great variety of birds that also use reed as a breeding habitat (e.g. eurasian bittern, reed warbler species, bearded tit). Fish (e.g. eel) hide in flooded reed areas during tidal high water and use them as feeding grounds. However, this requires fish-passable gaps in the structure that allow them to reach these areas during rising tide and leave them during falling tide.
- Softwood floodplain forests provide a sheltered habit for various small organisms (e.g. insects, spiders), bats (e.g. pond bat), birds (e.g. woodcock, golden oriole, penduline tit) and beavers.
- Salt marshes in the outer estuary are habitats for numerous insects (e.g. beetles, ants) and spiders. They are also important as breeding sites (e.g. common redshank) and foraging grounds (e.g. brent goose). The systems of creeks and ditches serve as feeding habitat for fish (e.g. eel, flounder, three-spined stickleback).

ECOLOGICAL BENEFIT

compared to direct bank protection using riprap, concrete or steel

Ecosystem services	Compared to direct technical bank protection measures (e.g. sheet pile wall or riprap), the structures and vegetation establishing behind the structure can provide the following ecosystem services and benefits: • Habitats for riparian organisms in estuaries • Sediment regulation • Erosion protection through vegetation • Carbon storage through vegetation • Establishing vegetation enables the bank to recover from erosion events Enhanced recreational functions because area is experienced as a more natural landscape

RANGE OF APPLICATIONS, DIMENSIONING AND DESIGN

Range of applications	Protection structures in front of the bank are suitable where sufficiently large intertidal flat and shallow-water areas are available between the bank line and the fairway. They reduce loads and thus stabilise the bank line. However, they are not suitable for the protection of banks in short distance of a dike. The dimensions and arrangement are determined by the existing bank geometry (e.g. elevation of erosion edges) and hydrodynamic boundary conditions (characteristic water levels, waves, currents). As a rule, structures in front of the bank in tidal areas can be installed above mean low water. Indirect bank protection measures are suitable for busy waterways and are already in use on Lower Elbe and Lower Weser banks facing the fairway. Local empirical data are provided in, among others, the Collection of measures which is available at: https://ufersicherung-baw-bfg.baw.de/aestuarbereich/en/massnahmen.
Design and dimensioning	The design of indirect protection structures must be such that its elevation and the level of its upper edge is adapted to the topographic situation (bank geometry) and the hydrodynamic boundary conditions. The structures can be installed between mean high water and mean low water. Especially for installations at the elevation of mean low water, the limited time available for construction activities due to the daily tidal dynamics needs to be taken into account. Generally, the structure must be installed in a place where it leaves sufficient space for an independent dynamic bank development while ensuring the required level of protection. This must be decided on a case-by-case basis. The required height for the structure's upper edge depends on the embedment depth and the degree of load reduction required. In principle, the wave-reducing effect decreases the more the water level exceeds the upper edge of the structure. Structures with upper edges at the level of mean high water or lower are frequently sufficient on German federal waterways. If bank protection at water levels above mean high water is indispensable, the structure can be designed with an upper edge extending to a higher elevation. Experience has shown that in areas where the impact of currents and waves is very high, fascine material durability is limited. In these cases, using stones as fill material helps to ensure sufficient durability (see *Alternative designs* section).

RANGE OF APPLICATIONS, DIMENSIONING AND DESIGN

Where hydrodynamic loads are very high, a second brushwood box installed parallel to the first brushwood box can additionally reduce the impact on the bank and bank vegetation behind the structures.

In addition, habitat boundary conditions need to be considered to obtain an ecological benefit (see section on *Boundary conditions for habitats*).

Tolerance to hydrodynamic loads

Indirect bank protection structures can withstand the hydrodynamic loads occurring on highly frequented waterways, provided that they have the appropriate dimensions. To fulfil durability requirements, the structures need to be adapted, e.g. with respect to the fill material used (see *Alternative designs* section).

Specific measurements of the hydrodynamic loads acting on brushwood boxes in the tidal area are only available for the Wümme river, which is exclusively navigated by recreational craft. In this case maximum flow velocities of 0.9 m/s measured near the banks do not affect the stability of the brushwood boxes.

Alternative designs

Brushwood boxes with stone filling

(For more information refer to [2]):

Stone gabions or loose armour stones as fill material for brushwood boxes have proved a suitable alternative to fascines or brushwood on waterway sections with higher hydrodynamic loads. A higher durability is likely, as scarcely any loss of material has to be expected. The lower permeability of stone fillings compared to brushwood can result in higher wave reflection and, consequently, a higher scour risk for the structure. A suitable scour protection, e.g. a brushwood mattress, may therefore be needed. Alternatively, a stone cover on the brushwood filling or the placing of loose stones can increase the durability and stability of the brushwood box. From an ecological viewpoint, designs with biodegradable materials (driftwood, brushwood, live willow rods) are preferable as they provide habitats and feed for riparian plants and animals and foster habitat interconnectivity.

Brushwood mattress design

If the hydrodynamic impact or bank geometry require a higher or wider structure, a brushwood mattress can be installed. In this case, the fascine material is usually fixed to the ground by means of four tied pile rows, and is therefore wider than a brushwood box construction. Also, the fascine material is flattened at the sides and integrated with the ground. The resulting inclination of the structure on waterside and landside dampens the hydrodynamic impact on the brush mattress and mitigates scour risk. Refer to the data sheet *Direct bank protection: brushwood mattresses* for information on the approximate quantity of material required and necessary installation steps.

Openings in parallel structure

Openings for the exchange of sediment and aquatic organisms must be provided in relation to the length of the structure; see *Annex 1*. This increases the diversity of flows, structures and the habitat, and it is therefore important and useful for the promotion of a near-natural development of riparian habitats.

Moreover, the openings enable aquatic organisms that have ended up on the structure's landside during high water levels to return to the river when the tide is falling, or land animals that have ended up on the waterside to return to the river bank. It is important to find the right balance between bank protection and the desired dynamics in order to preserve the small-scale riparian structures described above. It is also recommended to provide openings with a width of approximately 10 m at least every 100 m.

RANGE OF APPLICATIONS, DIMENSIONING AND DESIGN

Additional orthogonal placement of fascines

For a greater ecological benefit, brushwood boxes can be additionally filled with fascines. These are placed at regular distances in an orthogonal position so that they protrude from the brushwood box on the waterside. This adaptation adds structure and, depending on the elevation of the brushwood box, can serve as refuge for juvenile fish during tidal high water. A high proportion of dead wood structures also has a positive effect on the area potentially available for colonisation by hard-substrate macrobenthic organisms.

Fascines installed as ramps can provide a means of escape for land animals with limited climbing abilities such as hedgehogs, sheep or fledglings.

Combination with small riparian inlet and openings in parallel structure

Additional shallow water can be created behind the structure. An opening in the parallel structure, offset at an angle, makes this zone accessible to fish and other aquatic organisms as a habitat and feeding area. It should have sufficient depth to be permanently filled with water and thus prevent, as a rule, massive fish deaths due to drying or lack of oxygen.

Combination with initial plantings

Initial plantings, e.g. of tidal reeds, or the installation of rootable willow brush mattresses on the landside of the structure can support the development of riparian vegetation or enhance bank protection. The relevant boundary conditions for a successful establishment of diverse species should be considered; see Boundary conditions for habitats section. Before planting reedbeds, the spontaneous natural development of reed should be awaited.

Design with scour protection

In areas with scour risk a scour protection is required in front of the brushwood box, using either a brushwood mattress (more ecological) or armour stones.

Habitat conditions

When dimensioning an indirect bank protection, the following environmental conditions are relevant for the target vegetation.

Flooding and salt tolerance

The flooding and salt tolerance vary depending on the plant species, wave- and current-induced stress and developmental stage of the plants. The higher the loads, the smaller the plant growth below mean high water.

Willows: Willows grow at elevations from 0.5 m below mean high water to mean high water [3]. However, if the loads are higher, they show the best development between 0.75 m and 1 m above mean high water. The limits of the salt content in the bottom water relevant for willows are not known precisely. There is evidence, however, that a salinity of 2 ‰ in the bottom water has no adverse effect on the plants' vitality [3].

Sea club-rush: The sea club-rush, which often forms part of the stock of plants below mean high water, has a high flood tolerance and is frequently found in the area between 0.5 m and 0.75 m below mean high water [5]. When competing with other species, its ideal growth height is attained at an inundation height of 0.5–1.5 m and with an inundation duration of 2–6 hours [6] [7]. The sea club-rush is more salt-tolerant than reed.

RANGE OF APPLICATIONS, DIMENSIONING AND DESIGN

	Reed:	Reed typically establishes around the mean high water line [5] [6]. Inundation periods of < 2 h per tide and inundation heights of < 0.5 m provide the best environment for reed [6] [7]. With inundation periods exceeding 6 hours per tide and inundation heights of more than 1.5 m, reed plants have no chance of survival, not even on wave-protected banks with low flow velocities such as the flat banks of tributaries.
	Halophytes:	Where the salinity exceeds 10 ‰, tidal reeds are replaced by cord-grasses, glasswort and common saltmarsh-grass. Cord-grass vegetation establishes below mean high water; glasswort and common saltmarsh-grass mainly above mean high water [8].
Tolerance of hydrodynamic stress	So far, there are not sufficient data available to define limit values for the total exposure of an established vegetation.	
	Willows:	see *Flooding- and salt tolerance*
	Sea club-rush:	With flow velocities below 0.2 m/s, which is often the case, the sea club-rush can expand; if the limit is exceeded, the reed population often declines [4] [6] [9]. Where wave heights regularly exceed 30 cm, the sea club-rush is unlikely to establish [9]. By contrast, wave heights that are mostly below 25 cm [9] [10] clearly increase the potential for colonisation.
	Reed:	Reed is less tolerant of waves and currents than sea club-rush. For reed to establish, banks need to be wave-protected and flow velocities have to be low, with wave heights usually below 20 cm [6] [7].
	Halophytes:	Cord-grass has a similar dynamic load tolerance as sea club-rush. Common saltmarsh-grass, on the other hand, is less tolerant.

COMPONENTS AND INSTALLATION

Construction	Construction is as described in the data sheet *Direct bank protection: Brushwood box*, which provides details such as components, work steps and installation instructions. It also contains additional information on dimensioning, which should be taken into account where necessary.

MAINTENANCE

The required maintenance effort depends on the local conditions and is determined by, among others, the intensity of wave- and flow-induced loads. Experience gained from measures implemented by the German Federal Waterways and Shipping Administration (WSV) has shown that indirect bank protection structures require maintenance intervals of 3–5 years and in some cases up to 10 years. The durability of the fascine material is crucial here; the material needs to be refilled or replaced on average every 3–5 years. In the event of very high dynamic loads, it may be necessary to refill the brushwood box on a yearly basis. In most cases, the piles are more durable (10 years or more) than the fascine material.

BfG Bundesanstalt für Gewässerkunde
BAW Bundesanstalt für Wasserbau

MAINTENANCE

Ideally, regular inspections are carried out to assess the condition and replace the fascine material if required. After a period of 6–10 years a complete repair, including the piles, is required in most cases if the effect of the measure is intended to continue. No further maintenance or renewal of the structure is required when vegetation has established on the landside of the direct bank protection and is in itself sufficient to ensure bank protection.

EXAMPLES

Examples on German federal waterways

Brushwood box structure on the Hullen foreland
Elbe-km 703.15 - 703.515, left bank
https://izw.baw.de/publikationen/alu-aestuare-massnahmen/0/Elb703li_01_01_EN.pdf

Brushwood training wall Warflether Sand
Lower Weser-km 23.500–24.900, left bank
https://izw.baw.de/publikationen/alu-aestuare-massnahmen/0/Uwe024li_01_01_EN.pdf

Brushwood box construction between groynes in Belum
Oste-km 73.375–73.610, left bank
https://izw.baw.de/publikationen/alu-aestuare-massnahmen/0/Ost073li_01_01_EN.pdf

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INSTITUTIONS / LINK

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Annex:

1. Technical drawings

Annex 1 Technical drawings

The drawings shown here must be adapted to local conditions.