Linear Shallows

DEMONSTRATED USE SETTINGS:

- Canals/Rivers
- Lakes

MEASURE HIGHLIGHTS:

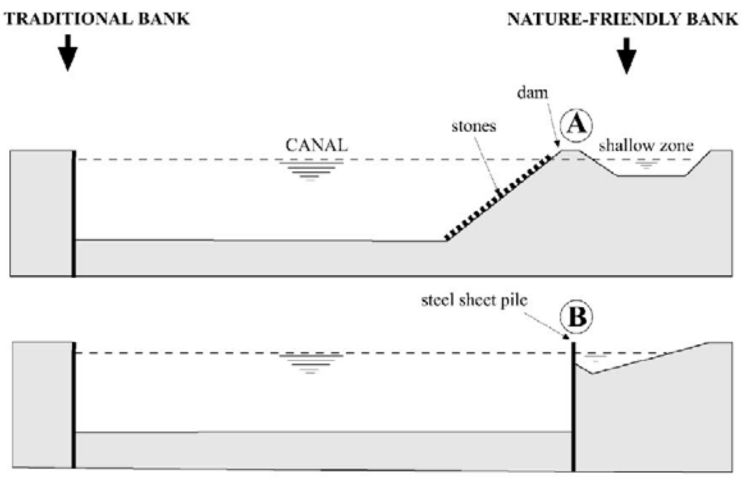
- Sheltered shallow zones connected to areas with high wave energy impacts and lacking variability in depth
- Can be built with or without vegetation
- Built from standard construction materials
- Located either outside or within existing channel
- Allows variations in water depth and/or saturated soils

BENEFITS PROVIDED:

- Shallow refugia for fish
- Spawning, Nesting Habitat for multiple species
- Herptile habitat
- Habitat for rooted aquatic and emergent macrophytes
- Physical habitat for low-energy plants and animals

Method Description – Linear shallows are used to introduce variation in form, vegetation, and habitat conditions into otherwise uniform, harsh, and barren channel settings. By creating protected yet connecting areas of shallow water underlain by hydric soils parallel to the active canal, this measure allows the introduction of riparian wetland habitat, nesting, and spawning grounds, and off-channel refugia for fish. Linear shallows have been constructed along artificial canals using two methods. One method requires driving sheetpiles within the cross section of an earth embankment canal. Another method employs the construction of a sheet pile wall or riprapped berm running parallel along the lateral landward edge of the canal. The waterward edge of the barrier may slope quite steeply to the canal, and the landward zone is then filled with suitable substrate to allow shallow water depth. Shallow zones may either been maintained at depth or allowed to silt-in enough to develop rooted aquatic and emergent macrophytes as well as helophytes. Besides providing protection from wave action for all life stages of fish, shallows provided much-needed shallow water habitat for fish spawning and rearing. Shallows must intermittently open to the main canal to enable connectivity of the habitats and for fish to escape from navigational traffic to the calmer waters. In order to allow water and habitat circulation without exposing the linear shallows to excess wave energy, baffle type openings are typically used. This measure has been utilized and studies waterways such as the Twentekanaal and Zuid-Willemsvaart canal in the Netherlands which are similar to many European canals due to general absence of aquatic vegetation, little to no functional riparian zone, and flow dynamics are severely impacted, along with reduced hydrologic connectivity to floodplains or spawning/nursery areas. Additionally this measure has been used and reported on at Lake Havel in Germany where navigational and recreational traffic create suspended sediment impacts, and high nutrient loading and poor water quality caused further stress to aquatic life.

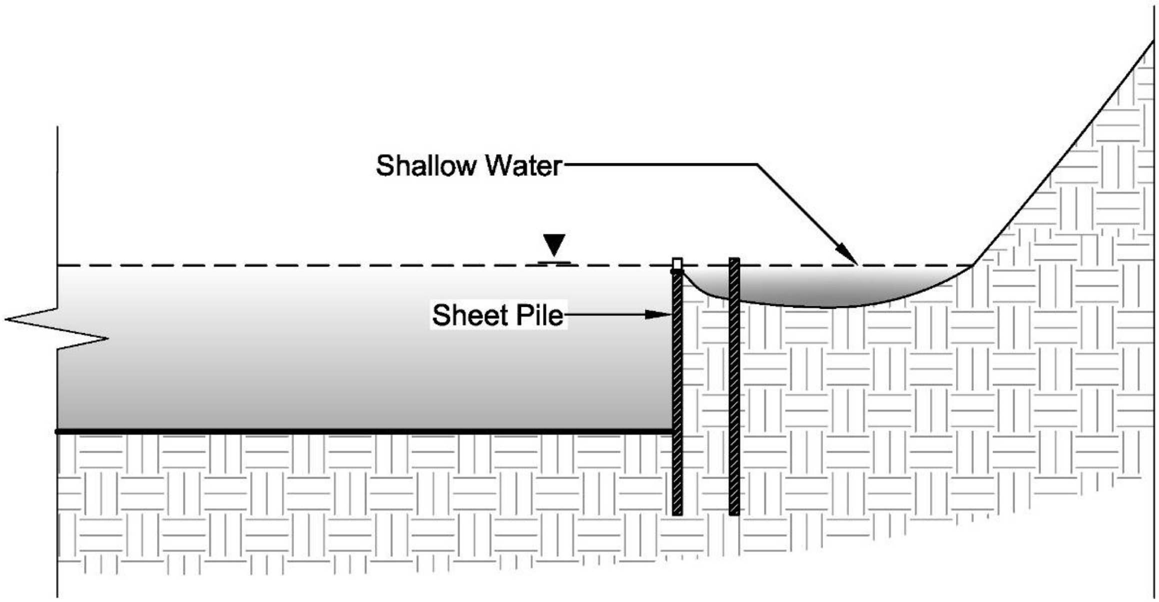
Habitat Enhancement Values – Natural waterbodies depend on diverse slopes, substrates, and plant communities in riparian areas to provide an array of habitat niches, and combinations thereof, that support and foster various phases of the life cycles of many fish, birds, herptiles, and invertebrates. Canal construction removes variability in the microhabitats of water bodies and creates limiting factors for numerous organisms. Artificial canals feature simple cross sections, highly uniform profiles, and harsh wave energy levels leading to an absence and/or impoverishment of riparian habitats. Navigational traffic is high, with high wave energy in otherwise limnetic zones. Linear shallows provide an arrangement wherein a wide range of water depths, soil types, and plant communities may be established according to targeted habitat objectives. Typical linear shallows include a continuum of unvegetated deep to shallow habitats as well as emergent and



submerged macrophytic vegetation. Substrate may be fine to coarse, but is protected from resuspension due to the sheltered location. Fish species adapted to low energy zones generally use shallow aquatic vegetated zones for spawning and nursery habitat. Wading birds use shallow open water habitats for feeding. Herptiles and small mammals use soft soil embankments for nesting and hibernation. The variation in water depths and vegetation provides conditions for multiple invertebrates which in turn provide food for other organisms. This measure corrects for the lack of diverse aquatic communities in canals impaired by absence of aquatic macrophytes, lack of exposed coarse sediments, uniform depths, little or no functional riparian zone, lotic habitat has been impacted or eliminated, little to no vegetation or structural shading and shallow refugia along banks, poor connection to floodplains or off-channel ponds, and hard impenetrable banks. The aim of the Dutch study of linear shallows effectiveness was to examine the relationships between the aquatic plant community established after construction with the physical and chemical characteristics of the water body. The system was employed in two navigation canals which experienced about 15,000 boats in 1999, mostly commercial. Not included in prior study, but for possible evaluation would be the use of gravel-like substrates on the landward side of the berms/sheet piles to allow for varying of water depths, development/establishment of fish breeding zones and fish refugia, and expedited functioning of the habitat enhancement method. Artificial islands of floating vegetation within the protected shallow zones may also enhance the method and speed of functionality.

Implementation Factors – Linear shallows are most appropriately located where wave action from navigational traffic is high, and there is sufficient width of the canal and its right-of-way to provide habitat zones approximately 15 to 40 feet in width. Length of linear shallows may vary according to land availability, and one long connected shallow may be created, or a series of separate appendages may be configured. In any case the pile or berm used to separate the linear shallows from the canal should equal the typical maximum wake height, and should have breaks at least every 300 linear feet to allow water circulation (less if fine textured substrate is desired within the shallows). When wake overtops the structure it must reenter the canal through the periodic openings. The openings themselves must be configured with baffled overlaps to minimize wave impact, and the shallows and openings must be engineered to withstand scour during various water level and wave conditions. This measure can be built using standard equipment and products familiar to the construction and navigation industries, though the arrangement and positioning departs from typical marine engineering applications. Construction may be performed by barge or land access depending on cost and other variables. High sediment loads may silt-in the areas over time, necessitating periodic removal of fine sediments. This may set back the natural development of the vegetated shallows community, but also affords an opportunity for nutrient removal from the canal. It may be

useful to oversee the natural succession of the areas and remove vegetative material that develops overly thick root systems that could limit access to the areas by fish, if wake scour does not adequately provide self-clearing. The location of the shallow areas should be closely monitored and in accessible areas to allow for observation of sediment accumulation or floatables blocking the openings or dominating the structure within the shallow refuge area in order to maintain maximum habitat productivity as well as visual appeal. It is best to construct this measure in locations where stormwater inputs and other landward impacts will not affect the stability and function of the linear shallows.



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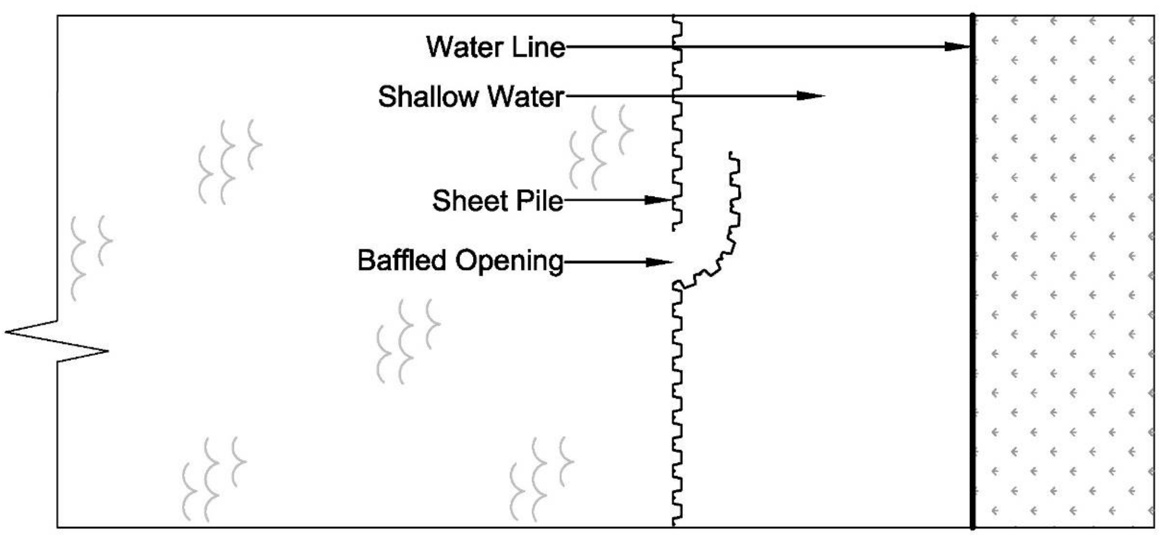


Plan n.t.s.

LINEAR SHALLOWS

Floating Vegetation

DEMONSTRATED USE SETTINGS:

- Rivers/canals
- Lakes/reservoirs
- Water treatment lagoons

MEASURE HIGHLIGHTS:

- Vegetation supported by buoyant structures
- Provides habitat above water for birds, mammals, reptiles, etc.
- Provides underwater root zone habitat for fish and invertebrates
- Scalable by attaching individual units together
- Adjust to fluctuating water levels

BENEFITS PROVIDED:

- Provides fish habitat:
  - Cover
  - Shade
  - Food source
  - Oxygen
- Reduces wave energies
- Improves water quality
- Provides bird habitat
- Can be purchased ready for installation, or "home-made"
- Water column fish refugia
- Bird nesting habitat
- Herptile (turtle) habitat
- Habitat for rooted aquatic and emergent macrophytes
- Protection from wave energy

Method Description – Floating vegetation generically describes the construction and installation of floating elements that support living wetland plant communities. These systems mimic naturally occurring floating masses of wetland vegetation typical in various regions, although they are engineered and contain artificial buoyant materials. While the specific construction materials and techniques of the floating element itself may vary, the concept involves constructing a platform that floats while supporting a mattress of mature, self-maintaining wetland vegetation. These elements are often referred to as Floating Islands. The technique was introduced decades ago in Germany and there are many projects world-wide that have successfully deployed floating vegetation.

A common and tested method comprises of a structural framework of durable, sealed tubing that provides floatation and supports a geofabric reinforced platform of vegetation. The entire unit is typically triangular in design in order to resist high physical forces present due to ice formation, though other shapes are common in ice-free locations. The triangular design also reduces the likelihood that the element can capsize from large wave energies. For simpler applications where space is at a premium, simple tubular modules of coir encased in synthetic mesh attached to buoyant pipes may create linear floating vegetation systems. Additionally an array of round or free-form systems has been created for specific applications.

The tubular floatation elements are constructed of various plastics, such as HDPE and PVC, or metal, such as stainless steel filled with closed cell foam. The tubing elements are joined at the corners using a variety of techniques, all of which allow for flexibility and movement of the individual elements. This allows the overall floating platform to flex with the waves, and allows for a significant function of wave energy dissipation. The vegetated platform varies among individual designs, but is similar in that the platform is suspended between the floating tubular elements. The vegetation is often grown within a nursery setting, within a growth medium such as a coir (coconut fiber) mattress, or a synthetic geotextile, or a combination. It is recommended that the vegetation mat be well established prior to installation and exposure to high energy sites. The floating elements support the mattress such that the green, leafy portions of the vegetation grow above waterline, while the roots dangle below the mattress into the water column.

Habitat Enhancement Values – Floating vegetation units provide both terrestrial (island) habitats for birds, mammals, reptiles, etc, by providing resting, basking breeding and nesting, and grazing habitat. They also provide cover and are ideal for protection from predators and from disturbance by man which typically occurs via land. Floating vegetation also provides unusual and excellent habitat below the waterline for fish. The roots of the vegetation extend down, dangling into the waterbody where they provide physical cover for depths of up to six feet. Simple linear systems create conditions similar to riverine undercut banks, while large systems create expanded areas of floating vegetative cover as occurs in some natural marsh systems. Floating vegetation shades and reduces water temperature while generating locally elevated oxygen levels released into the root zone through photosynthesis, especially during mid-day periods when urban waterways often experience depleted oxygen levels, thus providing a temporal refuge for fish. The physiological activities of the plants and associated microbes provide additional dissolved oxygen to the water column and through associated chemical activity can contribute to an improvement in water quality. Additionally, the dangling underwater root system reduces current and wave energies so suspended sediment begins to settle directly beneath the structure. There are instances where floating vegetation has been observed to root into sediment collected beneath them and over time, and the vegetation anchored and became indistinguishable from natural islands.

Implementation Factors – Floating vegetation is an ideal alternative when banks are too steep for natural vegetation or when trampling by animals or humans occurs (as in urban parks). They are used within the channel environment, in water of any depth, hence requiring no land acquisition and offering a very high degree of flexibility concerning siting. The single largest consideration for the use of floating vegetation is the location. When used in a publicly viewable area, they can provide highly aesthetic greening, improving the appearance and function of otherwise barren steep and/or solid embankments or walls unsuited for vegetation. Unlike other habitat improvement elements that may function underwater or through the establishment of subtle changes in channel form or surface material, floating vegetation offers function combined with recognizable strong visual appeal. When anchored within a navigation channel, the requirements of boat traffic can be addressed to allow passage of boats without obstructing traffic movement. Additionally, it is important that the floating materials not be struck and damaged by passing boats. Wave height is also a consideration as the floating units are susceptible to capsizing if affected by very large waves.

Closely related to this is the anchoring requirement. The floating elements can be anchored to the channel wall or shoreline if placed in close enough proximity, or can be anchored to the channel bottom. Anchoring is achieved by various means and should be carefully considered at the design stage. Buffer systems such as springs, pulleys or buoys help reduce strain and impact on anchors and lines used to secure islands in high energy locations. Floating vegetation may be removed from the waterbody in autumn in order to prune roots and foliage (for nutrient removal via disposal or composting), and to avoid exposure to ice impacts; however this level of maintenance is optional if systems are designed for year-round deployment.

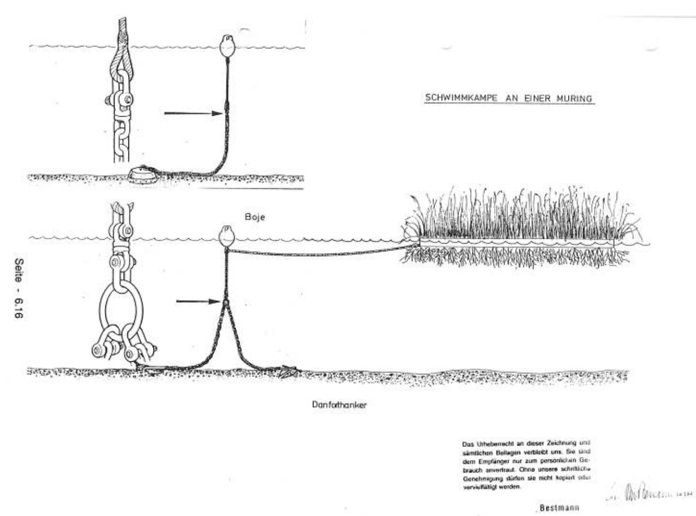
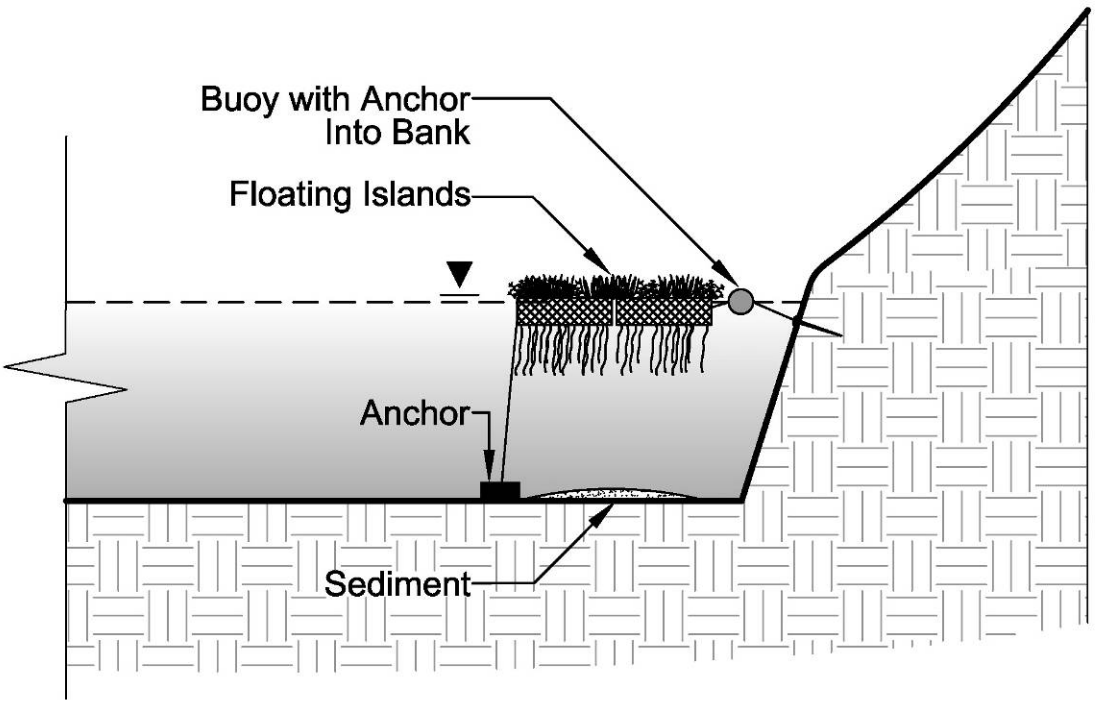


Image Source: Bestmann Green Systems Brochure



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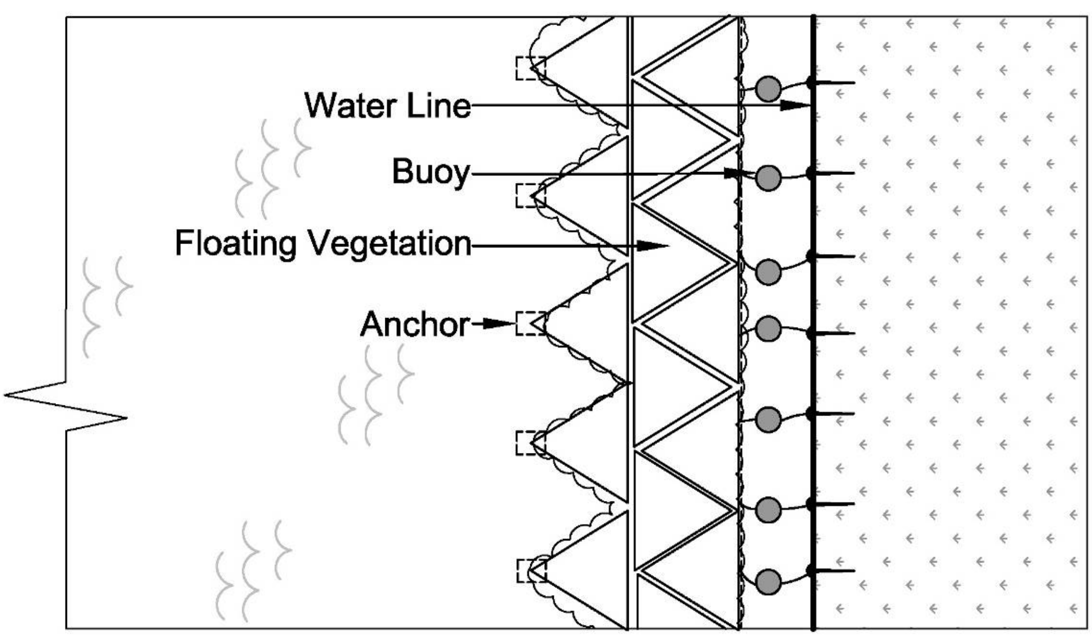
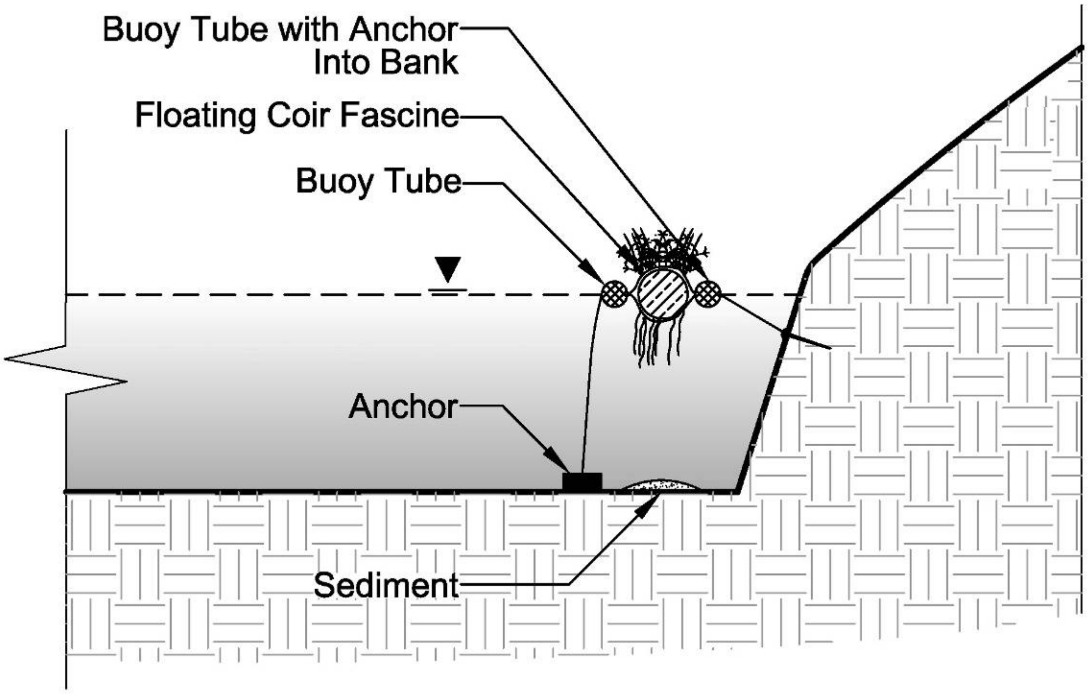


Plan n.t.s.

FLOATING VEGETATION



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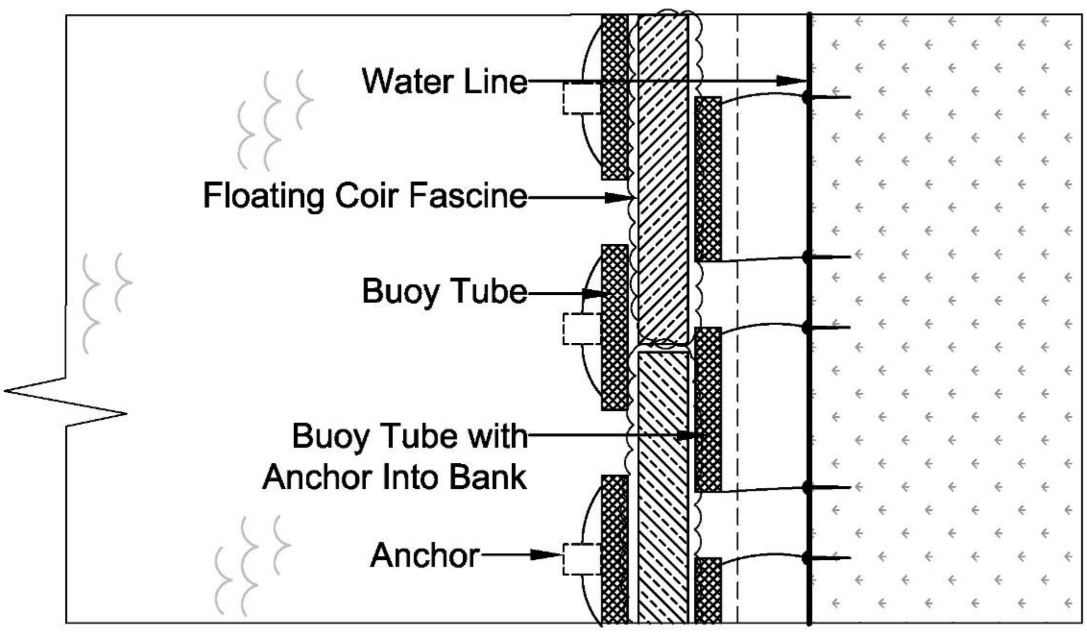


Plan n.t.s.

FLOATING VEGETATION

Artificial Seaweed

DEMONSTRATED USE SETTINGS:

- Rivers/canals
- Lakes
- Marine environments

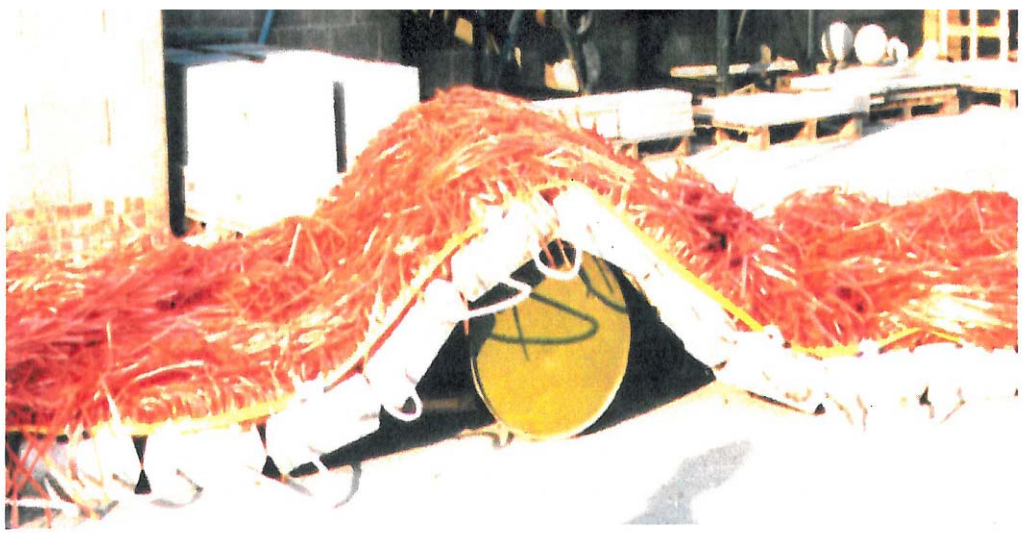
MEASURE HIGHLIGHTS:

- Stable mats with buoyant flexible fronds of synthetic polymer that mimics seaweed
- Suited for water quality and depths not tolerated by living vegetation
- Used in aquaculture and natural settings to improve habitat
- Varied size and mounting options
- Prefabricated and easily ordered
- Solid performance record

BENEFITS PROVIDED:

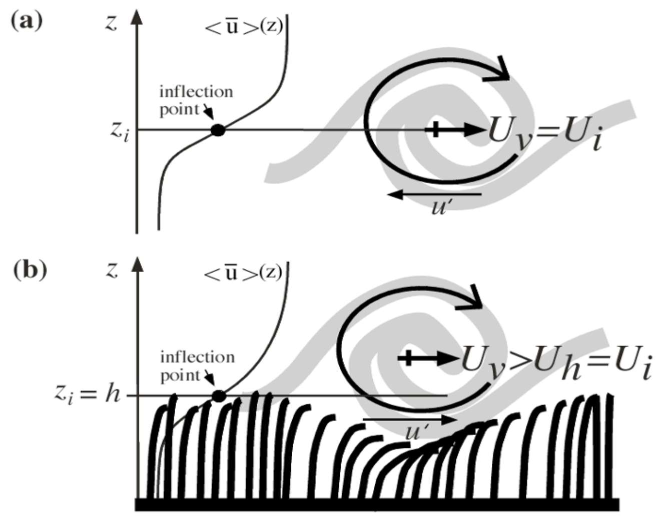
- Attenuates wave energy
- Reduces suspended solids
- Consolidates sediment by frond vibration
- Fronds are colonized by algae and microbes
- Provides refugia for fish within and leeward of fronds
- Protection from wave energy

Method Description – Seaweed and other forms of submerged aquatic vegetation play important roles in retaining sediment in high energy waterbodies. However, living plants do not withstand turbid water which blocks sunlight, high sediment loads which chronically abrade foliage, or intense energy levels causing ongoing scour. As a functional alternative based on biomimicry principles, synthetic materials may be use in lieu of vegetation. Artificial seaweed consists of prefabricated mats of high tensile strength woven webbing supporting buoyant fronds. Fronds are made of proprietary polymers designed to withstand high energies in marine engineering applications for a long design life. To ensure stability when placed, mats are either fastened to the ground with anchors or bolts, or attached to interconnected concrete block mattresses which provide mass. Commercially available units typically have options for frond lengths of 2 to 4 feet. Foliage elements cause viscous drag, reducing shear stresses exerted by moving water. Research has shown that kelp beds provide significant sinks for fluid energy and momentum due to elastic deformation of fronds and artificial seaweed works similarly. With reduction of energy in the water column, suspended sediments settle. As sediment builds up, exposed frond length is reduced, the mat creates less viscous drag, and the rate of sedimentation slows until a steady state is reached. Fronds promote formation of gently sloping banks which may extend six feet beyond the mat.

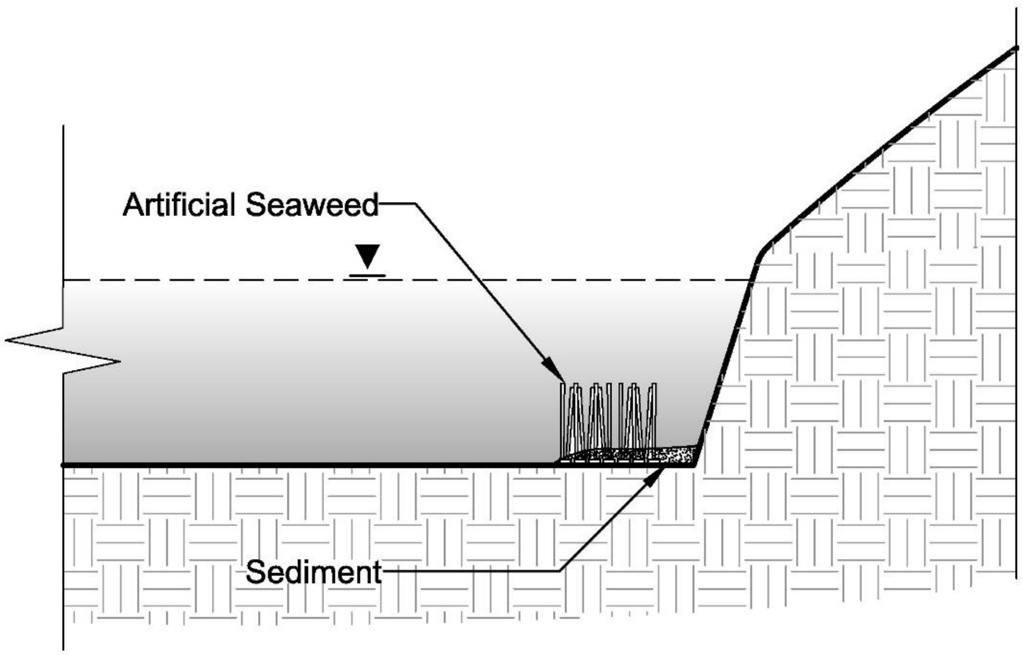


SSCS FRONDED CONCRETE MATTRESS OVER SIMULATED PIPELINE ~ Before attachment of the Safe Net. (150mm Base Blocks)

Habitat Enhancement Values – Artificial seaweed enhances aquatic habitat by creating low energy zones to shelter fish protected from wave energy and flow velocity. Refugia are created both within the fronds, and leeward of them. Additionally, fronds promote formation of sediment deposits with valuable physical properties for a range of macroinvertebrates and other organisms. The sediment bank created is considerably more stable and dense than surrounding unprotected sediments due to consolidation by the vibratory movement of fronds which promote packing and reinforcement. The creation of varied sediment texture and density alone increases habitat value due to suitability for a wide range of organisms, and dense sediments provide needed conditions for burrowing invertebrates. Artificial seaweed has been adapted for use in aquaculture as a means to reduce aggressive interactions and density-related stress due to its high effectiveness in providing resting and hiding areas. Also in aquaculture settings it has succeeded to increase the surface area for the growth of algae and periphyton communities upon which fish graze. Artificial seaweed may be deployed to dissipate energy in highly reflective environments where waves reflect off hard banks (echoing) and cause ongoing resuspension of sediment in order to create conditions fish can tolerate for survival. Or the systems can be deployed in lower energy settings or in combination with other measures in order to create conditions where a wide range of fish species can succeed in growth and reproduction as well.



Implementation Factors – Artificial seaweed is very effective at contributing to habitat enhancement where canal embankments are tall, steep, and or smooth and wave energy is poorly dissipated. Fronds will offer significant energy reduction, yet will tolerate high periodic impacts. Installation techniques depend on bottom substrate and navigational traffic patterns. If the woven mat and anchor system is appropriate then shipping and handling logistics are simple, though commercial divers will be needed for implementation. If the substrate demands concrete mattress for mass, crane barges are needed to bring heavy loads to site. Longer frond length delivers better performance, however propellers must not become entangled. Fronds reduce current velocity and related turbulence in the location being protected and offer significant reduction in sediment resuspension. Artificial seaweed may be used to control sediment transport patterns in order to promote or discourage deposition around other measures. Mats must be effectively anchored so that only fronds move with wave energy and mats remain stable. Performance trials demonstrate fronds perform best in continuous rows, and multiple rows provide substantial overlap of fronds, hence improved function.



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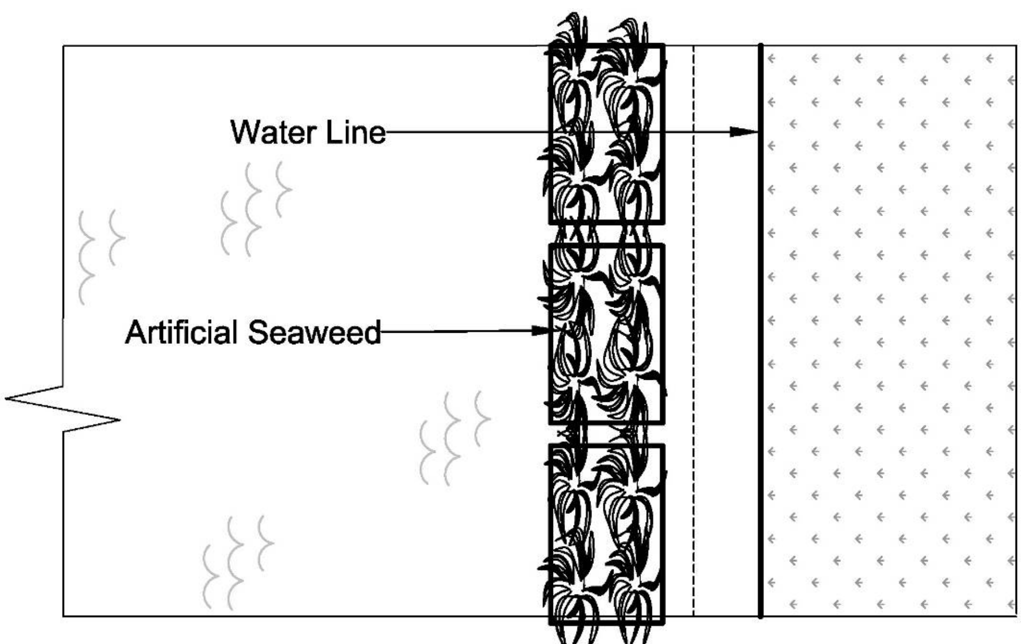


Plan n.t.s.

ARTIFICIAL SEAWEED

Chamber Revetment

DEMONSTRATED USE SETTINGS:

- Canals/Rivers
- Ports/Harbors
- Lakes

MEASURE HIGHLIGHTS:

- Rock filled mesh chambers applied to banks of varied slopes
- Suitable for high energy levels and navigation traffic
- Requires no additional right-of-way and does not encroach on shipping channel

BENEFITS PROVIDED:

- Creates overhanging cover for fish
- Increases oxygen levels
- Provides wave energy dissipation
- Interstitial space created for microorganisms

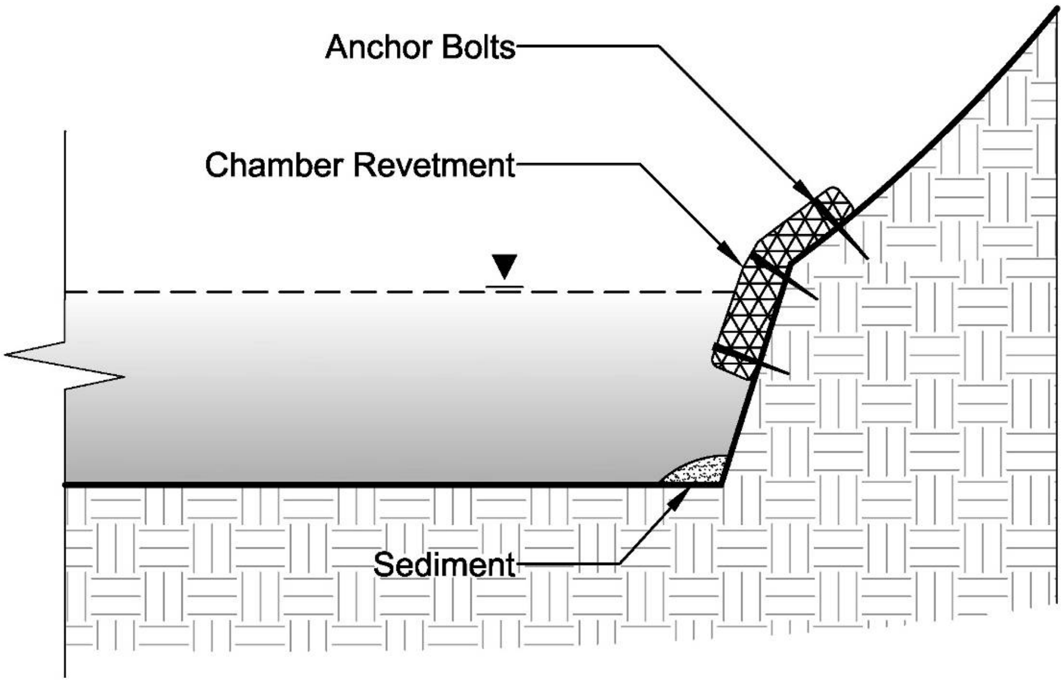
Method Description – Chamber revetments are rock-filled units of various shapes, encased in mesh of various materials and strengths. Typical forms include tubular shapes known as sack gabions, or laminar shapes known as marine mattresses. Mesh is made of woven wire, perforated extruded polymer sheets of high density polyethylene (HDPE) or polypropylene (PP), as well as knotted or interbraided mesh of high strength synthetic yarns. Units may be constructed with any dimension, but are typically 15 ft long, 6-12 inches thick, and various widths. Larger format units typically include interior chambers as well, in order to resist loss of load capacity and deformation over time. Units remain highly flexible and are able to conform to changes in slope angle and irregular bank slopes. Chamber revetments function as consolidated masses of relatively small rock where size and weight of the unit, not the individual stones provide stability, often incorporating graded riprap 5 to 8 inches in diameter, allowing stable yet highly porous coverage of banks in high energy settings. Cavities between stones can be filled with crushed porous stone or other kinds of rock. The porosity and inclusion of in-filled small rock functions in a variety of ways, breaking the organization of a wave and attenuating wave energy; providing capillary and water retention and wicking capacity such as with scoria, thereby creating conditions that permit colonization by microorganisms within voids; and filtering action to protect substrate below. Typical chamber revetments weigh at least 100 pounds per ft².

Image Courtesy of: Triton™, Tensar Earth Technologies, Inc.

Habitat Enhancement Values – Chamber revetment functions chiefly to provide energy dissipation and interstitial voids for invertebrate and bacterial populations, both of which indirectly improve fish habitat. By positioning the units near the normal waterline, both functions can be optimized. In order to create habitat for fish, as well as the invertebrates that are part of the food web, it is critical to provide wave attenuation in heavily trafficked channels. Most aquatic organisms are adapted for exposure to intermittent and low levels of suspended sediment and wave impact. However, within navigation canals there is chronic exposure to sediment abrasion and wave energy and many studies demonstrate that chronic turbidity causes physiological stress and that fish will migrate to seek clearer water. Studies measuring growth rate show that suspended solids also inhibit ability to feed, and young fish grow more slowly in turbid waters as particles adhere to and abrade gill surfaces. Chamber revetments can provide physical habitat near the waterline for fish and micro- and macro-organisms which develop within the rock, especially porous scoria, which provides a complex of interstices that can provide breeding habitat and cover for small organisms. Even small sack gabion type structures provide undercut bank type conditions to shelter fish. Additionally they introduce a compact and cost-effective zone of porous material for wave mitigation and microorganism colonization. Larger marine mattress type systems contribute more to dissipate wave energy, providing reduced sediment resuspension affecting fish. Unlike coarse riprap which does not permit significant colonization by organisms, chamber revetment uses mesh to encase smaller and even porous rocks above and below the waterline in order to provide abundant interstitial space. Wave impacts can serve to prevent sedimentation which blocks and fills void spaces, hence allowing the surface to continue performing ongoing functions that mimic coarse sediment beds in terms of macro and microorganism habitat. Wave impact also can promote alternate wetting and drying cycles within interstitial voids that can develop water quality functions similar to those utilized in trickling media type wastewater systems. Management of water quality, in particular dissolved oxygen level, is critical to allow fish survival, and even fish passage through severely impaired areas, hence linking physical and biochemical processes with fish habitat productivity.

Implementation Factors – Chamber revetments are typically installed on the bank below and above the waterline on banks of virtually any slope. They add value most when deployed on smooth bank surfaces which are devoid of interstitial spaces found in soil and even riprap bank cover. Because chamber revetments protrude no more then 10-12 inches from the channel bank they do not interfere with shipping traffic and hence are suitable for narrow canal areas, as well heavy traffic areas. Many exterior mesh materials used in chamber revetment construction have been applied extensively in marine engineering applications including within shipping lanes where impact by boats, as well as high intensity and frequency of waves are common. Some materials, especially the HDPE types, are highly resistant to impact and abrasion under extreme stress levels. Chamber revetment is highly stable in the face of ice, under fluctuating water levels, and in settings where foot traffic is heavy, though they can be susceptible to vandalism. Compared to other measures, they are the most highly suited for sites with heavy navigation traffic and other physical impacts to the bank zone. However, they lack the benefits provided due to the presence of living vegetation, and also due to wave energy dissipation or refuge creation deeper in the water column. Their impact is largely focused on improving physical conditions through energy dissipation, and though targeted habitat features close to the waterline. Chamber revetments are typically assembled off-site and transported ready for placement. However, their high mass requires a crane barge for placement and depending on the site conditions can require extensive anchoring. On steeper the bank slope, more anchoring is required.

Image Courtesy of: Triton™, Tensar Earth Technologies, Inc.



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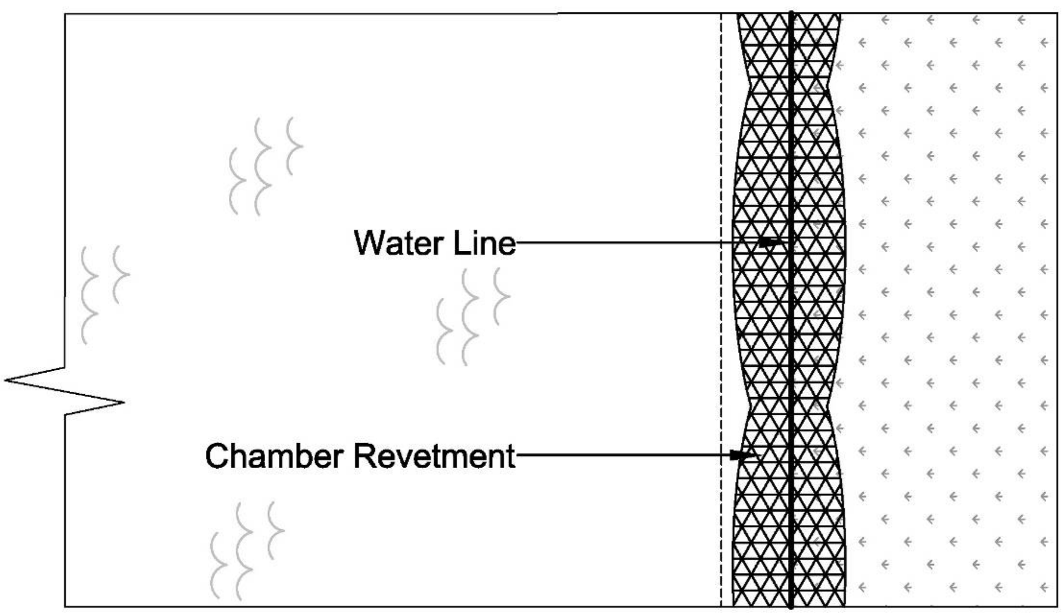


Plan n.t.s.

CHAMBER REVETMENT

Vegetated Revetment

DEMONSTRATED USE SETTINGS

- Canals/rivers
- Lakes/reservoirs

MEASURE HIGHLIGHTS:

- Shoreline vegetation
- Provides habitat above water for birds, mammals, reptiles, etc.
- Can be purchased ready for installation, or "home-made"
- Provides below waterline habitat fish
- Scalable by attaching individual units together
- Immediate protection and revegetation of the amphibic bank zone
- Defines and forms water's edge in urban areas
- Effective solutions in locations where grazing by waterfowl can be a problem

BENEFITS PROVIDED:

- Provides Fish Habitat
  - Cover
  - Shade
  - Food source
  - Oxygen
- Improves Water Quality
- Provides Bird Habitat
- Bird Nesting Habitat
- Habitat for Rooted Aquatic and Emergent Macrophytes
- Protection From Wave Energy

Method Description – Vegetated revetment is an effective way to protect banks from erosion from wave energy. Traditional and tested forms of riprap revetment achieve their primary purpose by weight and the wedging action of stones lying beside and on top of one another. Generally, the heavier and rougher the stones and the thicker the riprap layer, the more effectively it will protect the bank. However, standard riprap is not satisfactory from an ecological standpoint in many applications. Vegetative revetment not only protects banks from erosion and attenuates wave energy, but it also provides a biologically rich habitat above and below the waterline. Vegetated revetment consists of mattress shaped modules that can be constructed in any dimension, but are typically 15 ft long, 6 ft wide, and 6-8 inches thick and are laid on the bank at the waterline. The size and weight of the unit, not the individual stones, serves to provide stability. They contain a fill of graded riprap ranging in particle size from 3 to 6 inches in diameter. The cavities between the stones are filled with crushed porous stone or other kinds of rock. The capillary and water retention capacity of porous rock such as scoria ensures that water is stored and available above the water level, thereby creating conditions that permit colonization by plants and also providing voids for population by invertebrates and microbes. The gradation of the riprap and the use of various fine materials to fill the cavities provide suitable conditions for root development and optimal filtering action to protect the substrate below. Typically, the revetment weighs about 80 pounds per ft^2 including vegetation.

Placement of individual vegetated revetment modules is easily accomplished when using a crane and requires little manual labor.

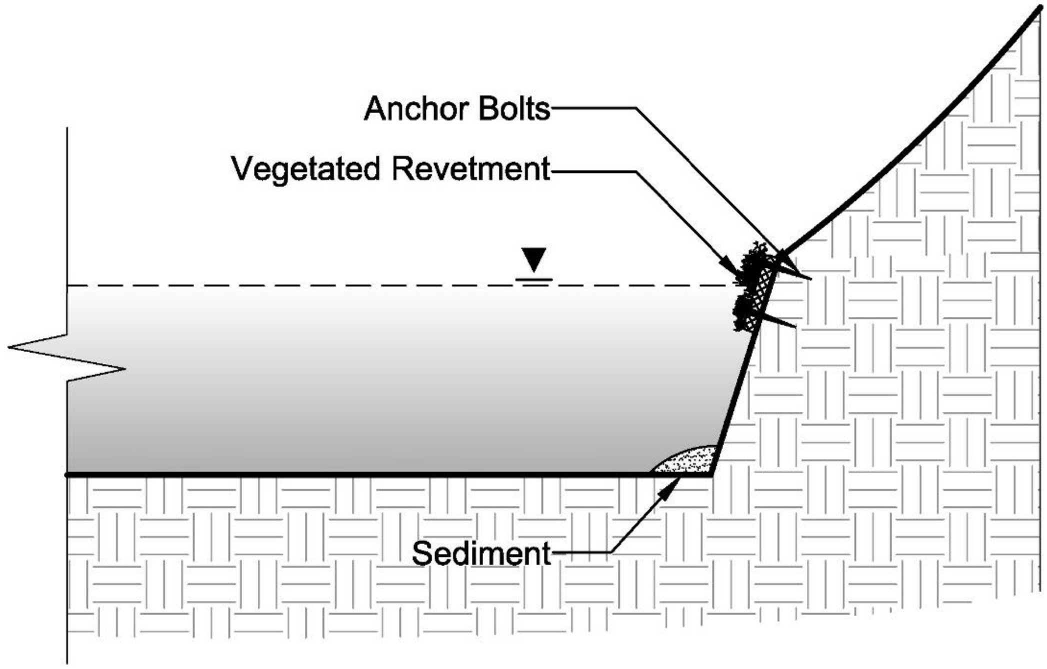
The external reinforcement of each module consists of high-strength coarse durable synthetic fiber net which allows handling and transport without difficulty and also ensures shape is retained. Textile layers are added to the standard-type revetment that stabilize the fine materials and serve as filters to prevent migration of bank material. Vegetated revetment remains permanently permeable and no water pressure can build up beneath it due to root action. Vegetated revetments are planted with facultative and wetland emergent plant species depending on position on the bank. Because the wave energies are often hostile to plant establishment, though tolerable to mature stands of plants, it is recommended to use a one or two season growth period in a nursery prior to installation. The protected establishment period allows the roots and rhizomes to penetrate the substrate layers, grow around the various particles and intertwine with one another. Once on site, the established plants will continue to grow outward from providing shade over the water and the roots wherever possible will attached to the substrate or dangle in the water. In this way, the revetment becomes permanently integrated into the landscape, forming a strong visually attractive and somewhat natural-looking bank that offers many habitat functions in addition to reliable armor.

Habitat Enhancement Values – Vegetated revetment provides both terrestrial habitat for birds, mammals, reptiles, etc, by providing resting, basking breeding and nesting, and grazing habitat. It also provides excellent physical habitat below the waterline for fish and micro- and macro-organisms. Emergent vegetation grows within the rock, porous scoria, and fabric matrix. The roots as well as the matrix itself provide a complex of interstices that can provide breeding habitat and cover. The overhanging vegetation provides shade for fish and reduces water temperature. Wave energy is dissipated, providing zones of reduced sediment resuspension and turbulence affecting fish. The physiological activities of the plants and associated microbes provides additional dissolved oxygen to the water column and through associated chemical activity can contribute to an improvement in water quality and fish survival during periods of oxygen depletion. Rather than rough, large-size riprap which does not permit spontaneous colonization by plants, this measure uses mesh and fabric wrapped around smaller rocks with integrated wetland and/or upland plants already established prior to placement. The roots and rhizomes extend into the substrate below after placement, thus ensuring that the revetment is securely anchored in the subsoil, and other anchors may be used on steep banks. Due to the permeability of the revetment layers and the drainage characteristics of the roots and rhizomes formed by the vegetation, vegetated revetments maintain their filtering ability and can be colonized by plants and animals above and below waterline.

When installed on riverbanks and canals, transport and installation is often times best accomplished through the use of a barged equipped with a crane.

Implementation Factors – Vegetated revetments are designed for erosion- prone sites due to wave energies and fluctuating water levels such as canals, lakeshores, and in tidal situations such as tidal rivers or ocean front. The revetment structure permits them to retain moisture for long periods of time and thus provides an environment conducive for plants to grow even if the water level has dropped due to low tide or canal management. Conversely, short periods of high water inundation are typically not a problem for the plants and associated structural materials. The vegetation selected for the revetment depends on an analysis of the site conditions and the intent of the project. Preference is typically given to hardy, native species that can quickly become established and can withstand difficult site conditions including wave energies, floating organics and other debris, variable water quality, etc. The most appropriate form of transport of the modules is by barge. Modules can be temporarily stacked for transport, but should be immediately installed upon arrival to the site. Due to the slab-like construction, the large, relatively heavy modules are most often placed by means of hoisting gear. The angle of the slope on which they are placed should be reduced as much as permitted by local conditions to minimize slippage, or suitable anchors must be used. The design and selection of underlayment is governed by the same accepted geotechnical principles as are used for conventional revetment.

Experience gained during the engineering works on the Rhine River in Germany led to the development of standard modules for highly impacted banks. The primary application of vegetated revetment was for application on commercially navigable canals and natural waterways in Germany. The highest loads are generated by single vessels proceeding along one side of the canal causing secondary waves up to 1.2 meters high. A significant wave height of 70 cm was assumed for design purposes. Collected data suggests that vegetated revetment's stability against area loads is three times greater than the stability of loose riprap and unlike riprap, significantly attenuates wave reflection due to the elastic deformation of plant stems.



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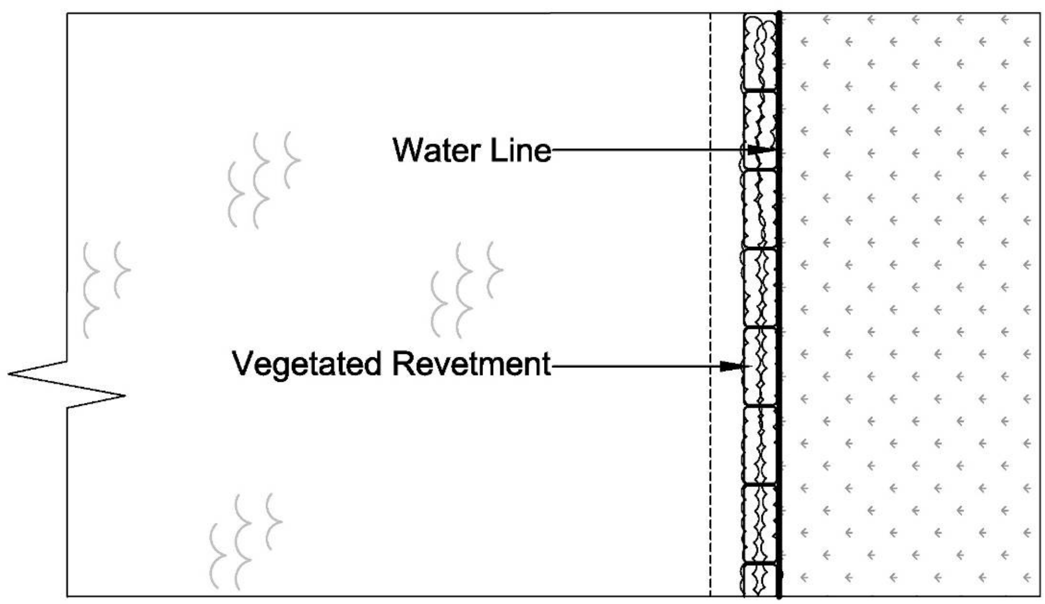

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VEGETATED REVETMENT

Sunken Structure

DEMONSTRATED USE SETTINGS:

- Navigable waterways
- Rivers
- Marine environments

MEASURE HIGHLIGHTS:

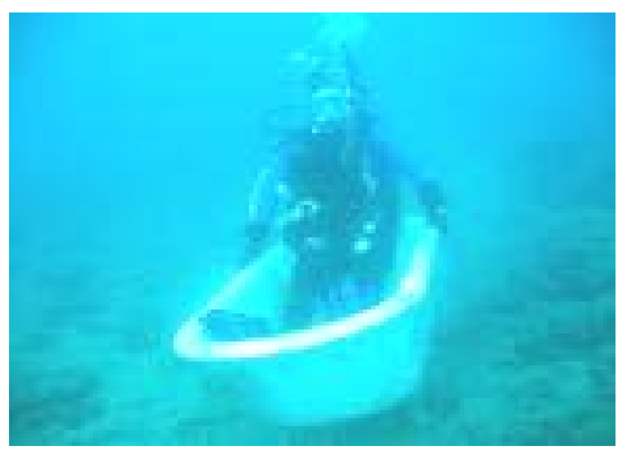
- Artificial materials resting on waterbody bottom to mimic large woody debris, undercut banks, boulderfields, and other natural in-stream habitat features
- Ability to engineer location, stability, and performance of physical habitat niches, unlike with natural materials
- Many shapes and materials
- Targeted Fish Habitat Enhancement Technique
- Potential for Salvage and Reuse of Recycled Materials
- Placement Equipment Access by barge or Land

BENEFITS PROVIDED:

- Promotes sorting of sediment and variety of substrate for macroinvertebrates
- Protection from waves and suspended sediments
- Provides refugia, ambush points and resting places for fish
- Use by fish and microorganisms, and submerged aquatic plants
- Incorporates green building principles of adaptive reuse of materials

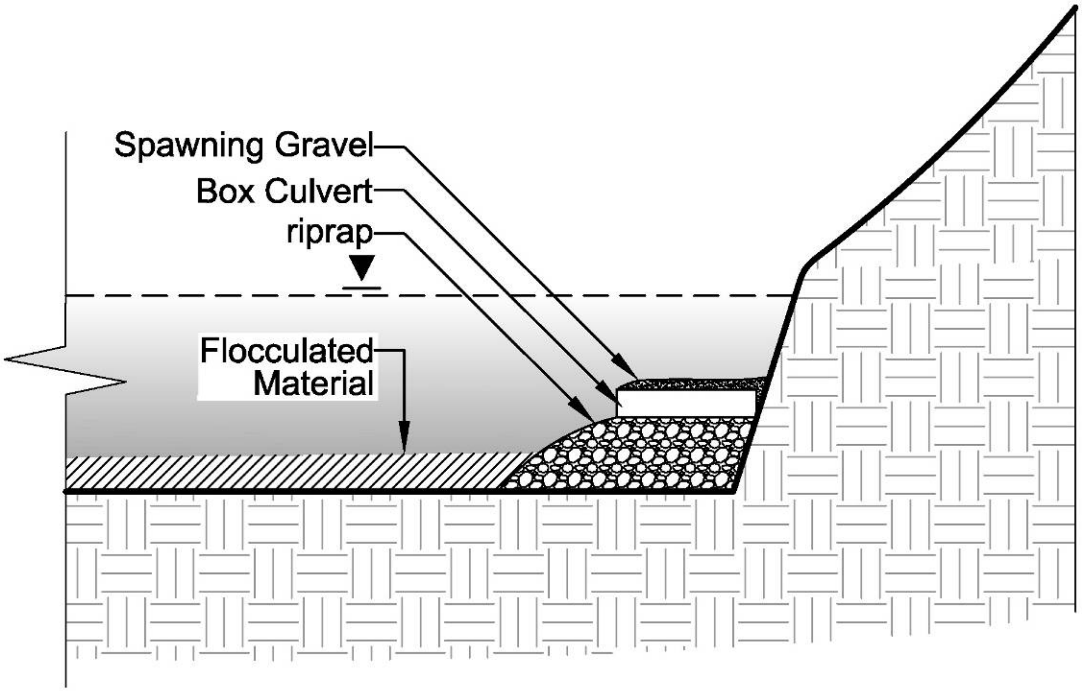
Method Description – Sunken structure describes a broad category of solid, dense materials placed into waterways for the purpose of enhancing physical habitat diversity and type. In aquatic environments, variation of physical form of bed, banks, and naturally occurring debris has long been understood to provide essential physical habitat niches for fish and other organisms. In recent decades, artificial structures have been used to create physical habitat purposefully, as with sinking ships to form artificial reefs in shallow seas. Additionally, structures placed for bank and shore stabilization or other purposes, as well as accidentally placed objects, have been observed to provide effective habitat, often increasing fish populations by as much as 400 percent or more when lack of physical habitat was a key limiting factor influencing ecosystem productivity. Canals and other artificial and heavily managed waterways lack diversity of form and benefit from increased physical structure for habitat, and many types of sunken structure have been used with success. Boats, barges, bridges, and cars have all been used for this purpose, but are not recommended due to the high cost of addressing environmental issues due to contaminants found in paint, fuel, fluids, and other elements combined with the appearance of illicit dumping; however they are effective and affordable.

Structure must be complex in shape to provide a high number of holes and hiding places and be heavy enough to prevent shifting or movement. Additionally, the materials should be chemically and biologically inert, with known mass, dimensions, and lifespan in order to allow responsible and rigorous design. The concept of structure to enhance aquatic habitat is well understood and there are many proprietary structures available, as well as standard non-proprietary designs that have been adopted by public agencies. Examples of these systems include precast concrete units such as jack-shaped elements which perform like large woody debris; perforated hemispheres ideally suited to shellfish colonization; and box culverts which mimic deep hiding cavity conditions found at undercut banks near pools in rivers (often referred to as LUNKER structures). Additionally, recent approaches have sought to divert construction and demolition waste from landfills and repurpose materials for sunken aquatic structure at very low cost. Such materials include bathtubs, toilets, sinks, concrete pieces, catch basins, precast stairs, and clay, metal, or concrete pipes.



Habitat Enhancement Values – Elements are typically clustered, stacked, and where practical connected together to create complex structures. Regardless of material used, research indicates that lines or closely spaced nodes of sunken structure are more effective than single structures for attracting fish. While sunken structure generally offers a similar range of habitat functions, the actual performance for fish habitat enhancement depends on where they are placed, how they are configured, and other variables of the site including most notably water quality.
However, there are distinct differences based on the type of measure deployed. High stability concrete jack units are designed to interlock into a flexible, highly permeable matrix. They can be installed either randomly or in a uniform pattern, and the interstices formed provide approximately 40% void space in a uniform placement pattern. The voids provide habitat for fish and other organisms and promote sediment collection, sorting, and stabilization which fosters further habitat enhancement, offering habitat improvements closely analogous to large woody debris present in natural rivers as jams or random pieces. Precast perforated hemispheres provide refugia and resting places for smaller fish species and age classes and offer maximum attachment surface for bivalves and submerged aquatic vegetation. Box culvert type materials, including broken or off-spec items, may be placed directly on the waterway bottom or on a bedding layer of riprap in order to control their depth in relation to water surface and sediment active on the bed (either suspended sediments or loose flocculated materials). Depending on position within the water column, the LUNKER type structures will attract different fish species for use as refugia or ambush points. Additionally coarse sand or gravel may be applied atop a box culvert structure to establish suitable spawning nest material above the zone where sedimentation occurs. Various sunken structure systems made of recycled and salvaged building materials can be configured to achieve forms and functions similar to those mentioned above, based on how they are assembled. The structures generally provide refugia from wake impacts, hiding and resting places for fish in various life stages, and predatory ambush points for piscivores. It is possible and ecologically sound to provide caves and cover for fish by using almost any large heavy structure.

Implementation Factors – Sunken structure is valuable in locations where channel form is devoid of physical variation. Where water depth is adequate to provide clearance beneath shipping traffic, structures may be deployed anywhere within the channel. In shallow water depths sunken structure often offers little value and can create navigational hazards, and hence is not recommended. In intermediate depths, structure can be successfully deployed at channel margins or selected nodes that are clearly marked. Navigational permits may be required at local and/or federal levels although precedent exists for most structures within navigable waterways. The structure must be placed along the bottom of the banks to avoid conflict with shipping traffic. Concrete, porcelain, and metal typically do not incorporate hazardous or toxic compounds and their physical and chemical properties and structural lifespan are well characterized, lending them to engineered applications. Unlike many natural structural elements, most notably large woody debris, these materials have no tendency to float or biodegrade, and exhibit predictable behavior which allows rigorous and responsible engineering procedures called for in urban waterways where public safety and navigational risks dominate. Regardless of what material is used, it can be moved by a crane barge and lowered intentionally into place. Precast concrete hollow mounds with different diameter and shape holes and are intended to sit on the bottom of a waterbody to create habitat. They can be constructed in many different sizes, off- or on-site with an easy-to-use, portable, fiberglass mold either by a certified distributor or by volunteers (after training). They can be easily modified with concrete footers added to increase weight, decrease subsidence on soft bottoms, and accommodate anchoring systems if required. Recycled material will require advanced planning of logistics to find and deliver when required, or coordination with an existing debris recycling program.



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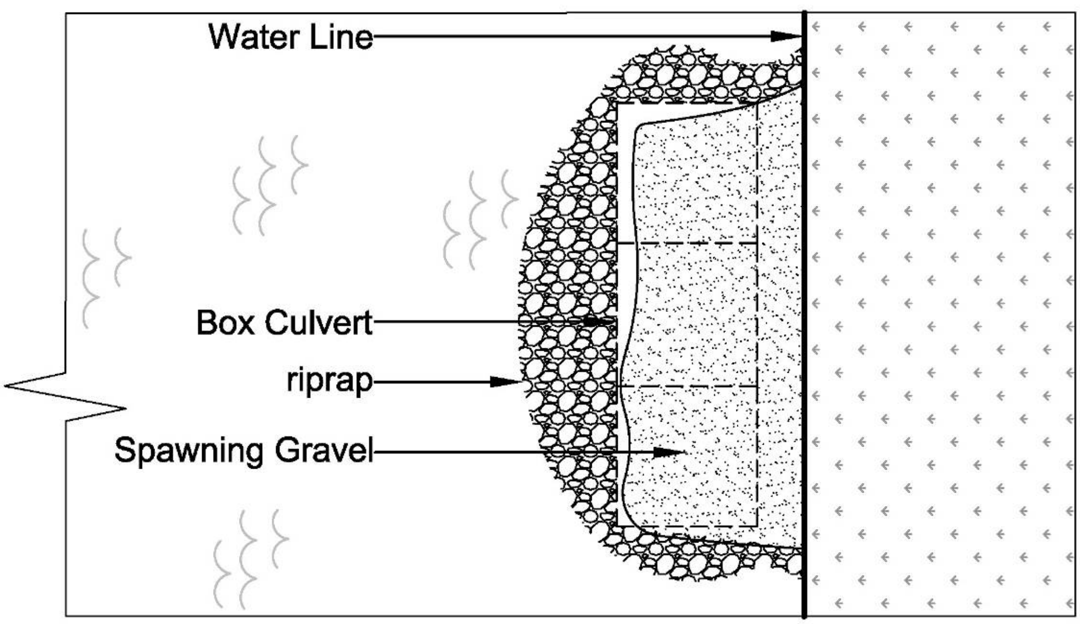

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SUNKEN STRUCTURE