Engineered Approaches for Limiting Erosion along Sheltered Shorelines: A Review of Existing Methods

Prepared for:

Hudson River Valley Greenway
Hudson River National Estuarine
Research Reserve

As a part of:

The Hudson River
Sustainable Shorelines Project

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STEVENS INSTITUTE of TECHNOLOGY
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THE CENTER FOR MARITIME SYSTEMS

HUDSON RIVER SUSTAINABLE SHORELINES

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About the Hudson River Estuary

The Hudson River Estuary is a narrow, 152 mile arm of the sea that extends from the southern tip of Manhattan north to the Troy Dam. The maximum width of the river is 3 miles in the Tappan Zee, but most of the river is 0.5-1 mile wide, and the upper section near Albany is less than 0.5 miles wide. Much of the river is 20-50 feet deep, and a 32 foot deep navigation channel extends all the way to Albany. However, the river also contains extensive shallow-water areas that are less than 5 feet deep at low tide, many of which support wetlands or beds of submersed vegetation. Much of the river bottom is sand or mud, although patches of gravel, cobble, relict oyster reefs, and debris do exist. The average tidal range along the Hudson River is about 4 feet, peaking at 5 feet at either end of the estuary. In periods of normal freshwater flows, strong tidal flows (often greater than 2 feet/second) reverse the direction of water flow every 6 hours throughout the entire estuary, and are roughly 10 times as large as downriver flow of fresh water. Water levels are also determined chiefly by tides, but can be strongly affected by high flows from upriver and tributaries, and by storm surges. The transition from fresh to saltwater occurs in the lower half of the river, depending on freshwater flows and tides.

Forces impinging on the Hudson's shores include wind-driven waves, wakes from commercial and recreational vessels, currents from tides and downriver flow, and floating debris and ice driven onshore by these forces. Depending on their exposure to wind, currents, wakes, and ice, and their position relative to the navigation channel and protective shallows, different parts of the Hudson's shores receive very different inputs of physical energy. Likewise, land uses on the landward side of the shore and water-dependent uses on the riverward side of the shore are highly variable along the Hudson. As a result, different parts of the Hudson place very different demands on engineered structures along the shore.

The shoreline has been dramatically altered over the last 150 years to support industry and other development, contain channel dredge spoils, and withstand erosion. About half of the shoreline has been conspicuously engineered with revetment, bulkhead, cribbing or reinforced with riprap. Many additional shorelines contain remnant engineered structures from previous human activities. The remaining "natural" shorelines (which, however, have been affected by human activities such as disposal of dredge spoil, invasive species, and contaminants) include a mix of wooded, grassy, and unvegetated communities on mud, sand, cobbles, and bedrock. Miller et al. (2006) performed an inventory of Hudson River shorelines between the Tappan Zee Bridge and the head of tide at the federal dam at Troy and proposed a 5 level classification scheme. Of the 250 miles of shorelines inventoried, 42% were hard engineered, 47% were natural, and 11% were natural with remnants of engineering structures. The most common shoreline structure was rip-rap (32%), followed by woody (29%) and unvegetated (16%) slopes. The dominant substrate found within the region was unconsolidated rock (52%), mud/sand (16%) and mixed soil/rock (12%).

About the Sustainable Shorelines Project

The Hudson River Sustainable Shorelines Project is a multi-year effort lead by the New York State Department of Environmental Conservation Hudson River National Estuarine Research Reserve in cooperation with the Greenway Conservancy for the Hudson River Valley. Partners in the project include Cary Institute for Ecosystem Studies, NYSDEC Hudson River Estuary Program and Stevens Institute of Technology. The Consensus Building Institute facilitates the project.

The project is supported by the National Estuarine Research Reserve System Science Collaborative, a partnership of the National Oceanic and Atmospheric Administration and the University of New Hampshire. The Science Collaborative puts Reserve-based science to work for coastal communities coping with the impacts of land use change, pollution, and habitat degradation in the context of a changing climate.

Disclaimer

The opinions expressed in this report are those of the authors and do not necessarily reflect those of the New York State Department of Environmental Conservation and the Greenway Conservancy for the Hudson River Valley or our funders. Reference to any specific product, service, process, or method does not constitute an implied or expressed recommendation or endorsement of it.

Terminology

There are many ways to describe both standard and innovative engineering methods to protect shoreline. The Hudson River Sustainable Shorelines Project uses the term ecologically enhanced engineered shoreline to denote innovative techniques that incorporate measures to enhance the attractiveness of the approach to both terrestrial and aquatic biota. Some documents and reports of the Hudson River Sustainable Shorelines Project may use other terms to convey this meaning, including: alternatives to hardening, bio-engineered, eco-alternatives, green, habitat-friendly, living, soft shorelines, or soft engineered shoreline.

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Introduction

The purpose of this document is to provide an overview of the engineered approaches currently being utilized to manage erosion along sheltered shorelines. In their natural state, shorelines tend to be dynamic, cycling through periods of erosion and accretion in response to changes in weather patterns and sediment supply. Along developed shorelines, such as those of the Hudson River Estuary, the dynamic nature of shorelines often conflicts with requirements to protect private property and infrastructure. In these areas a variety of engineered erosion control approaches are employed as a way of reducing or eliminating further land loss. Designing an appropriate shore protection measure for a particular location reflects a delicate balance between the required protection level and factors such as cost, aesthetics, and environmental impact.

In general, the lower energy along sheltered coastlines allows for greater creativity in designing shore protection projects; therefore a variety of different engineering approaches have been developed. These approaches range from shoreline armoring or hardening via bulkheads, revetments, gabions and other structures, to softer more natural methods such as vegetative plantings. In 2007, the National Academies Press released the report, *Mitigating Shore Erosion along Sheltered Coasts,* which advocated the development of a new management framework within which decision makers would be encouraged to consider the full spectrum of options available. Historically in the Hudson River Estuary, as elsewhere, ecological impact was rarely considered during the design of shore protection works; however the modern trend is to place significantly more emphasis on such considerations. Many of the approaches discussed in this document were developed in an attempt to try to balance the need for structural stabilization with ecological considerations. Such approaches fall into a category of techniques collectively referred to by the Sustainable Shorelines team as “ecologically enhanced shore protection alternatives”.

This document is intended to help make decision makers aware of the variety of different alternatives that have been utilized elsewhere, and is not intended to be specific to the Hudson River Estuary. Future work to be conducted under the Sustainable Shorelines Project will focus on a subset of the techniques presented here that are most appropriate for the Hudson River Estuary.

Engineering Terminology

In order to facilitate the understanding of the sections that follow, it is useful to set forth a few basic definitions commonly used by the engineering community. Figure 1 defines several terms frequently used to describe the geometry of the shoreline and any structures. In particular, *crest* refers to the top elevation of the structure, while *toe* refers to the base of the structure, typically on the side facing the water. The area between high and low tide is referred to as the *intertidal zone*, while the bottom and upland slopes are referred to as the bed and bank slopes, respectively. Figure 2 defines some additional terms that apply to the plan, or overhead view of a project. In the plan view, *flank* refers to the area immediately adjacent to the ends of the project, while *upland* and *nearshore* are used to refer to the areas immediately landward and seaward, respectively.

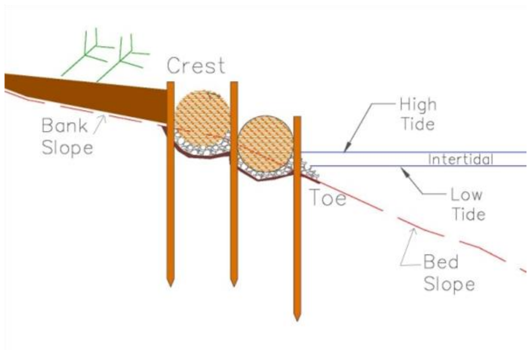


Figure 1: Engineering terminology profile view.

Figure 2: Engineering terminology plan view.

In addition to these terms, there are a host of terms which are frequently used to describe engineering projects that often have conflicting, or at least unclear definitions*.* The terms *hard* and *soft*, are among these. Traditionally, hard was used to refer to shoreline stabilization approaches that incorporated some sort of structural element, whether it be steel, concrete or rock. Conversely, soft was used almost exclusively to refer to approaches that did not incorporate a structural element, such as beach fills and/or plantings. Here we utilize the terms, but recognize there is a continuum between hard and soft (see below for more information).

Living shorelines is a term that has become popularized recently; however there is frequently a considerable amount of debate over what constitutes a living shoreline. The term is often used broadly to represent a system of protection that incorporates many of the individual approaches identified elsewhere in this document. Living shorelines can include both bank stabilization as well as methods to reduce the wave and/or current energy along the bank. Living shorelines are typically considered a "soft" approach to shoreline protection, because of the use of natural and often biodegradable techniques. The use of vegetation often plays a significant role in developing a living shoreline where the vegetation is used to help anchor the soil and prevent erosion, while at the same time trap new sediment. The vegetation also provides shelter and habitat for wildlife living along the shoreline and can act as a natural filter for removing pesticides and fertilizers. Natural buffers such as oyster and/or mussel reefs are also frequently used to dissipate energy, and create submerged habitats. Along some higher energy shorelines, a hybrid of solutions may be implemented, where low-profile in-water rock structures may be used to dissipate energy. Other materials frequently used along living shorelines include sand fill, and biodegradable materials such as natural fiber logs or rolls and organic matting. Some of the techniques which are discussed later in the document that incorporate many of the living shorelines principles are: living breakwaters, sills, live fascines, dormant posts, live stakes, reed clumps, coconut fiber rolls and brush mattresses.

Soil bioengineering is another generic term that can be used to refer to a variety of shoreline stabilization approaches, including some that can be classified as living shorelines. Soil bioengineering refers to the concept of utilizing vegetation to stabilize the soil along eroding banks. The vegetation provides immediate protection, and as the root systems develop, they bind the soil more tightly creating a resistance to sliding or shear. Soil bioengineering projects can also include structural components if additional bank protection is required. Examples of soil bioengineering approaches discussed in more detail later in this document include: brush mattresses, live stakes, joint plantings, vegetated geogrids, branch packing, dormant posts, and live fascines.

In part because of the confusion surrounding some of the existing terminology, and in part because of the inadequacy of traditional terms as more and more hybrid approaches are being developed, the sustainable shorelines team decided to adopt the phrase *ecologically enhanced* to refer to innovative techniques that incorporate measures to enhance the attractiveness of stabilization methods to both terrestrial and marine biota.

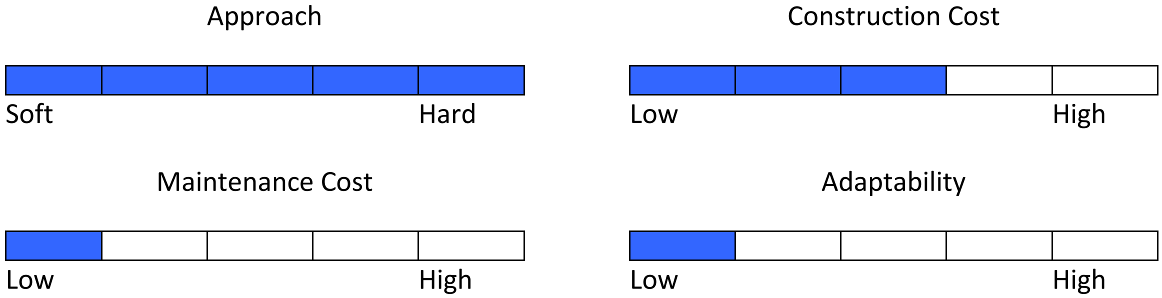
Methodology

The objective of this document is to provide a general overview of the variety of shore protection alternatives currently being used along sheltered shorelines, and is not intended to be specific to the Hudson River Estuary. A systematic approach is used to facilitate comparison of the alternatives, which are generally presented in the following order: shore face, shore parallel treatments; shore face, shore perpendicular treatments; and shore detached, shore parallel treatments. Each shoreline stabilization technique is qualitatively evaluated in 4 categories: *Approach, Construction Cost, Maintenance Cost, and Adaptability*. *Approach* refers to the type of shore protection strategy being employed and ranges from what has traditionally been referred to as “hard” by the engineering community (bulkheads for example), to more natural or “soft” approaches such as vegetative planting. *Construction Cost* takes into account the typical costs associated with initial construction, while *Maintenance Cost* refers to the cost of maintaining the system over its lifetime. *Adaptability* considers the effort required to modify in-place projects to handle new conditions brought on by climate change or other factors. A table summarizing these qualitative evaluations is presented at the end of the document.

More detailed information is presented in the descriptions which follow each evaluation. These descriptions vary in length depending on how well documented the technique is. Wherever possible, pictures and figures showing cross-sections and/or typical installations are provided. The descriptions are broken down into the following 6 categories: *Description, Design and Construction, Adaptability, Advantages, Disadvantages, and Similar Techniques*. The *Description* section provides a short discussion of the specified approach. The *Design and Construction* section contains information on some of the basic design and construction considerations associated with each approach. It should be noted that the information presented in this section is intended only to relay the basic design principles and that detailed designs **require much more information than** provided in this document. When available, cost information as well as information about operation and maintenance considerations are also presented in this section. Costs have been taken directly from the references cited and no inflation adjustment has been applied. The *Adaptability* section contains information related to the ability of the selected treatment to adapt to changing conditions either naturally or through anthropogenic intervention. Factors such as expected lifespan, durability, and the ease of modification are considered. In the A*dvantages* and *Disadvantages* sections, bulleted lists summarizing the positive and negative attributes of a given method are provided. *Similar Techniques* lists the alternative approaches or methods which are most similar to the one being discussed in the way that they interact with the physical forces at a site to reduce erosion at the shoreline. A glossary containing concise (1 or 2 sentence) descriptions of each approach is presented at the end of the document.

It should be noted, that each technique must address a variety of often competing concerns. The information presented within this document primarily relates to the engineering aspects of each approach. As a part of the design process, a responsible engineer needs to consider numerous factors beyond the scope of this document.

Bulkheads



Description

Bulkheads are one of the most common structures found along inland waterways. The primary purpose of a bulkhead is to prevent the loss of soil by encapsulating it behind an often impervious vertical wall. Bulkheads are commonly used at the base of bluffs or along steep shorelines, in areas where land has been reclaimed or filled, and in locations where space is limited (marinas for example). Because bulkheads can provide immediate access to deep water, they are frequently used near mooring facilities, in harbors and marinas, and along industrialized shorelines.

Bulkheads can be broadly classified on the basis of their main support mechanism. Gravity bulkheads rely on their size and weight for support. Cantilevered bulkheads are supported at one end, similar to a cantilever beam, and rely on embedment (depth of penetration) for support. Anchored bulkheads are cantilevered bulkheads, with an anchoring system added to provide additional support. Gravity bulkheads and cantilevered bulkheads are typically limited to lower energy and lower height applications. The addition of an anchoring system can extend the range of application of bulkheads; however if large waves are expected seawalls are more robust and should be considered as an alternative.

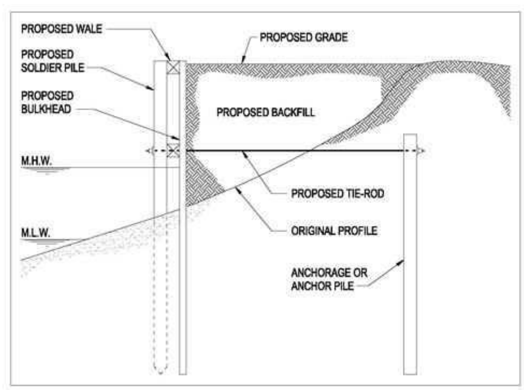


Figure 3: Typical bulkhead cross-section (NC DCM, 2008).

Bulkheads can be constructed of many different materials. Timber systems are common due to their generally low cost, but are limited to low height applications. Preservative treatments are essential for combating degradation of wood bulkhead systems due to marine and aquatic organisms. The service life of timber bulkheads tends to be less than 25 years. Concrete pile and panel configurations offer an alternative to timber bulkheads and can extend the service life of a bulkhead to more than 30 years.

Figure 4: Timber pile/wale bulkhead (NC DCM, 2008).

Steel and aluminum sheet piling are also commonly used to construct bulkheads. Aluminum is light weight and provides good corrosion resistance; however its low strength limits its use to low-height applications with softer substrates (soil conditions). Steel provides excellent strength characteristics for high wall exposure applications, and is generally easy to install even in harder substrates. Properly coated and maintained, steel bulkheads can have a service life in excess of 25 years.

More recently, synthetic materials have been used in bulkhead construction with increasing frequency. Vinyl and fiberglass products offer several advantages over traditional bulkhead materials including significant cost savings when compared to steel coupled with an increased service life (up to 50 years). In terms of strength, synthetic products are typically limited to moderate wall heights and installation in softer substrates.

Figure 5: Steel sheet pile bulkhead (photo credit: Emilie Hauser).

Design & Construction

Bulkhead design is heavily dependent on site parameters such as: mean water depth, variation of water level, ground water elevation, level of finished grade, soil conditions (both native and for any additional backfill material), and the anticipated amount of vertical surcharge or loading on the ground behind the bulkhead. This information is typically combined to construct earth pressure diagrams which describe the forces and moments (tendency to rotate) the structure will be subjected to. These diagrams serve as the basis for determining design parameters such as: the depth of penetration, the required thickness of the sheet piling, and if anchoring is required, the size and spacing of the tie rods, the size of the wales, and the size and location of the deadman.

The characteristics of the substrate on which a bulkhead is to be constructed are extremely important. With the exception of gravity bulkheads, bulkheads rely on embedment for their strength; therefore they must be anchored firmly into the ground to ensure stability. Interlocking sheet piles can be driven deeply into the ground if the foundation is granular; however holes must be drilled and grout or concrete used to anchor the sheets if bedrock is present. On harder substrates gravity bulkheads may be more appropriate. Other land based design concerns include the type of activity being performed behind the structure. The operation of forklifts and other heavy equipment behind a bulkhead can transfer significant loads to the soil, which if unaccounted for can result in structural failure.

On the water side, wave conditions play an important role in determining the effectiveness of a bulkhead. When constructed in a location where waves will continually impact the face of the bulkhead, proper materials and construction methods must be used to withstand the forces. In addition waves will have a tendency to scour material from the base of a bulkhead, therefore adequate toe protection must be provided. Bulkheads should not be constructed where wave action will cause excessive overtopping of the structure. This can result in scour behind the bulkhead, destabilizing it from the back side.

Stability will also be impacted by the local water table and any difference in water level across the face of the structure. If unaccounted for during the design phase, additional overturning moments could be created that would compromise stability.

Other water based design concerns include the loads and damages that the structure might endure from ice and debris flows. These include potential impact loadings as well uplift forces and overturning moments related to the freeze/thaw cycle.

Bulkheads generally have a moderate installation cost which reflects a balance between low material costs and high labor and equipment costs. Costs of between $1,200 and $6,500 per linear foot are typical (Blakenship, 2004). As a general rule, bulkheads should be evaluated every 5 to 6 years. Assessing their condition on a regular basis and performing preventative maintenance or minor repairs before they become major concerns can significantly prolong the life of a bulkhead. Repairs can cost anywhere from $100 - $400 per linear foot of wall (Blakenship, 2004). Complete replacement of a deteriorated bulkhead can easily cost twice as much as new bulkhead construction due to the added effort required to remove the old structure. Depending on the type of material used in construction, bulkheads have a typical lifespan of between 20 and 50 years.

Adaptability

Bulkheads are generally not very adaptable. Failure modes tend to be catastrophic rather than gradual offering little opportunity to adapt to changing conditions. As a fixed height wall, accommodation for future sea level rise is not possible without significant modifications, potentially requiring the replacement of the entire structure.

Advantages

Bulkheads have several advantages over other engineered shore protection approaches, among them are:

- Bulkheads are ideal when mooring and ship access are a primary consideration.
- Bulkheads are effective against soil erosion.
- Bulkheads can be used adjacent to bluffs or where land drops off very suddenly.
- Bulkheads can be used in areas subjected to low-moderate wave action.
- Bulkheads have a limited structural footprint.
- Bulkheads are fairly economical and require minimal maintenance.

Disadvantages

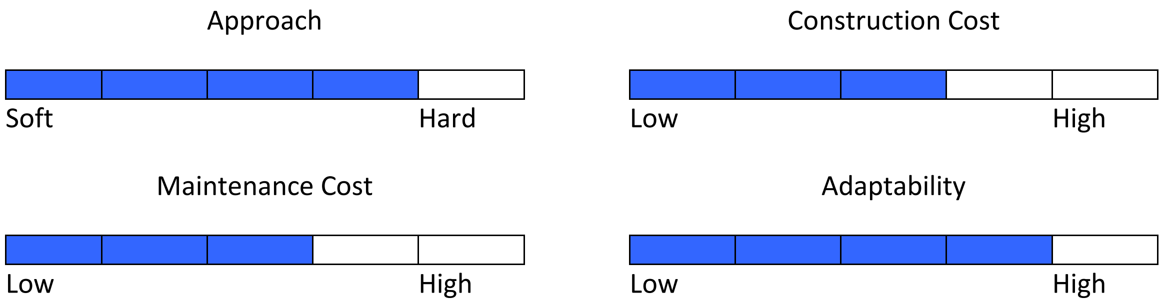
Bulkheads have several disadvantages compared to other engineered shore protection approaches, among them are:

- Bulkheads increase wave reflection which can lead to hazardous conditions and enhance erosion at the base of the structure.
- Bulkheads eliminate the supply of sand and gravel to the coast, frequently contributing to beach erosion.
- Bulkheads can change important shoreline characteristics and damage critical habitat areas used by fish, shellfish, birds, mammals, and other aquatic and terrestrial life.
- Bulkheads can increase the erosional pressure on adjacent areas (flanking).
- Bulkheads can restrict access to the shorezone.
- Bulkheads have a highly unnatural appearance which may be viewed by some as an eyesore.

Similar Techniques

Alternatives may include: gabions, revetments, crib walls, and green walls.

Gabions



Description

Gabions are stone filled wire mesh containers that are used to form retaining walls, sea walls, channel linings or revetments. The mesh baskets are usually filled with cobbles or crushed rock, and then stacked to form flexible, permeable, monolithic structures. The purpose of the gabion basket is to allow the use of smaller, cheaper stone which would be unstable if placed directly on the bank. Originally plants were used to construct the individual gabion units, but the modern approach uses wire mesh, which has been shown to be much more durable. The wire that forms the gabions can be galvanized or coated in plastic to reduce corrosion. Gabions can be stacked vertically to create a “gabion wall,” or placed along a slope to create a revetment. Vertical, stacked structures tend to be more susceptible to structural failure and have some of the same problems as bulkheads, including increased wave reflections, and scour along the toe and flank. Gabion revetments on the other hand can be much less intrusive, and if sloped correctly can actually become buried by sand and provide easier access to the water.

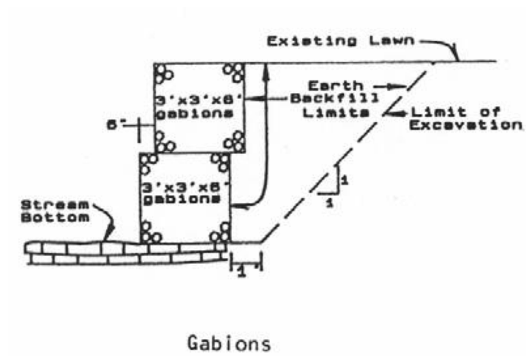


Figure 5 Typical gabion cross-section (NYS DEC, 2005).

Gabions are frequently separated into 3 different categories: gabion baskets, gabion mattresses, and sack gabions. Gabion baskets and mattresses are similar structures that are distinguished by their thickness and height. Gabion mattresses are smaller structures, typically less than 1 ft in height (MGS, 2006). Gabion mattresses are almost exclusively used to protect eroding stream beds and banks. Gabion baskets are normally taller structures with more structural integrity, and can range in height from 1 to 3 ft (MGS, 2006). Sack gabions, which are less commonly used, consist of mesh sacks filled with rocks, silt and/or sand.

The basket type construction of all 3 types of gabions allows the use of smaller rocks, which normally would not be effective in preventing erosion. This advantage makes gabions useful when the cost of transporting larger stones to a site is prohibitive. Compared to rip-rap projects constructed of similar sized stones, gabions typically require significantly less material to construct a stable design.

Figure 6: Terraced gabion wall (NRCS, 2011).

Unlike most structures, gabions can actually become more stable over time by collecting silt. Vegetation on the other hand can either stabilize or destabilize a gabion structure. Small vegetation can have a stabilizing effect by binding the structure together and increasing the siltation rate. Large vegetation however can have the opposite effect if the roots and stems are large enough to break the wire holding the baskets together. Normally, gabions are flexible enough that they can yield to a small amount of earth movement, while remaining fully efficient and structurally sound. Unlike solid structures, drainage through gabions occurs naturally, minimizing the tendency to create overturning moments (rotations) related to water level gradients (differences).

Design and Construction

There are several primary design considerations for gabion walls, including the stability of the foundation, the velocity/shear-stress resistance of the structure, and toe (base of the structure) and flank (end of the structure) protection.

The characteristics of the substrate (soil) on which gabions are constructed are essential to their performance. Fine material such as silt or fine sand, can be washed out through the baskets causing differential settlement. Likewise if the substrate is too weak, and incapable of supporting the weight of the gabion structure above, significant settlement may occur. In either case, if the resulting realignment is significant enough the forces experienced by the structure may exceed the design levels. Filter layers are frequently added to the base of gabion structures to help combat settlement problems.

Another key factor in the design of a gabion structure is the ability of the structure to withstand the lateral (along the structure) shear stresses induced by moving currents. This is particularly true in the case of gabion mattresses which are more likely to move than gabion baskets. Gabion mattresses have been used in high velocity waters; however, careful design is essential. Fischenich (2001) reported allowable shear stresses, and stream flow velocities of 10 lb/ft^2 and 14 to 19 ft/s, respectively, for gabions.

The construction of gabion structures is relatively straightforward and typically does not require a highly skilled workforce. The first step is to prepare the area on which the structure is to be built by smoothing the surface. Next, a filter fabric or gravel filter is typically placed to prevent the washout of fine material. The gabion baskets themselves are usually pre-fabricated off-site to reduce costs. Once on site, the baskets are connected and then filled. Once installed, the gabions may be covered and/or seeded to promote controlled vegetation growth.

Compared to other stream bank stabilization structures using similarly sized stone, the cost of gabions is relatively expensive. Price depends mostly on required dimensions, labor costs, availability of fill material and transport methods. Construction costs can range from $120/lf to $150/lf (includes assembly and filling of the baskets, wire for the baskets, stone fill, and basket closure) (MD Eastern Shore RC&C Council Inc.). Normally heavy equipment is not necessary for construction of a gabion wall; however the labor involved with basket closure can be substantial.

Typically gabions require minimal maintenance; however they should be checked for damage and broken wires on a routine basis. The most common repairs typically consist of fixing broken baskets and/or replacing missing rocks. Any large vegetation should be removed to reduce the likelihood of the baskets breaking. Erosion near the structure should also be monitored closely. If toe (base) and flank (end) protection is not included in the design, scour can occur at the base and along the edges of the structure, destabilizing it, or causing enhanced erosion on adjacent properties. Runoff flowing over the top of the structure can also cause enhanced erosion and should be monitored closely.

Adaptability

In terms of adaptability, gabion structures are quite flexible. As discussed above, the structures often become more stable with time and have some capacity to adapt naturally to changing conditions. Because of their modular nature, gabions lend themselves to adding units to increase their height and/or structural resiliency should conditions warrant.

Advantages

Gabions have several advantages over other engineered shore protection approaches, among them are:

- Gabions are frequently cheaper than similar sized structures constructed of large stone.
- The structural integrity of gabions can increase over time through natural accretion and/or vegetation growth.

- Scour and flanking of gabions are typically less compared to solid shear structures.
- Gabions can withstand relatively high velocity flows.
- Gabion walls can be molded to fit the contours of the stream bank.
- The shifting of stones due to the freeze/thaw cycle generally has minimal impact on the structure as long as the baskets remain intact.
- Heavy machinery is not required for construction.
- Maintenance costs associated with gabions are minimal.
- Gabions can be used in low-moderate wave energy environments.

Disadvantages

Gabions have several disadvantages compared to other engineered shore protection approaches, among them are:

- Gabions typically have a limited lifespan (5 to 15 yrs) due to the eventual failure of the wire mesh baskets.
- Broken gabions can result in cobbles and/or wire mesh scattered near the shoreline.
- Gabions have limited aesthetic appeal.
- Gabions reduce the sediment supply in the littoral zone.
- Gabions can negatively impact the nearshore habitat.
- Gabions can exacerbate erosion problems in adjacent areas.
- Ice and other debris can damage the wire mesh baskets.
- Gabions can alter/disrupt access to the shoreline.

Similar Techniques

Alternatives may include: revetments, bulkheads, green walls, crib walls.

Revetments

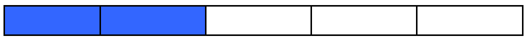
Approach

Soft Hard

Construction Cost

Low High

Maintenance Cost



Low High

Adaptability

Low High

Description

Revetments are shore attached structures built to protect natural sloping shorelines against wave energy and erosion. Revetments typically use large rocks or concrete armor units to dissipate wave energy and prevent further recession of the shoreline. Because the individual units are susceptible to movement under the right combination of forces, revetments are most effective in low-moderate wave conditions. Revetments can be used as a supplement to a seawall or dike at locations where both erosion and flooding are a problem.

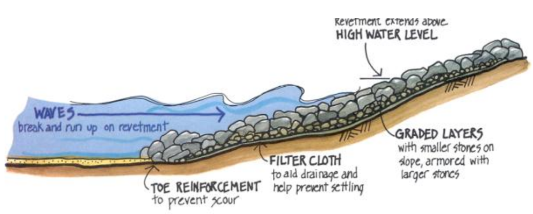


Figure 7: Typical revetment cross-section (USACE, St. Paul District).

The sloping, porous nature of revetments reduces the amount of energy reflected from the structure compared to vertical or impervious structures. This can lessen the amount of scour experienced at the base and along the flanks of the structure. Revetments differ from rip-rap protected slopes in that the material utilized is often larger, more uniform, and designed to resist a higher level of wave energy.

Figure 8: Rock revetment (NC DCM, 2008).

The 3 main components of a revetment are the armor layer, the filter layer, and the toe. The armor layer is made up of heavy, stable material that protects the shoreline against erosion. The filter layer supports the armor layer and allows water infiltration/exfiltration, without allowing the finer material to be washed out through the void space in the armor layer. The toe protects the base of the structure, which is particularly vulnerable to scour.

Revetments can be constructed of a variety of different materials. Stone revetments are the most common and are constructed from large quarry stone boulders. Depending on the availability and transportation costs, stone revetments can be expensive. If designed and constructed well, stone revetments can be extremely durable and can even resist damage from debris and ice.

In ocean front applications, pre-cast concrete armor units have been utilized in place of quarry stone when adequately sized stones are unavailable. Concrete armor units have the advantage of being designed such that the individual units inter-lock with one another, maximizing stability.

There are a variety of other materials that can be used to construct revetments as well. Rubble revetments are constructed from recycled stone or concrete typically sourced from local demolition projects. Due to the origin of the source material, rubble revetments tend to be economical; however they can be fairly unsightly and good quality control is required to prevent undesirable materials (metal, glass, etc.) from being mixed in with the rubble. Interlocking concrete or masonry blocks can be stacked in a staggered or sloped manner to form a revetment. Due to their typically limited size, concrete/masonry block revetments are less durable than other revetments and in particular are more susceptible to damage by ice and/or other debris. Solid concrete can also be used to cast-in-place revetments along an existing slope. While attractive and fairly sturdy, solid concrete revetments are typically very costly.

Design and Construction

The most relevant site characteristics and project constraints for revetment design include: the expected and extreme water level variations, the expected and extreme wave heights, material availability, bank slopes and existing grades, and soil properties. The crest elevation which is typically limited by the existing grade influences the amount of overtopping likely to occur at the structure. Other design considerations will include: required drainage systems, local surface runoff and overtopping runoff, flanking at the end of the structure, toe protection, filters, and underlayers.

Individual armor stones are typically sized on the basis of an empirical formula such as the Hudson formula,

$$W = \frac{\gamma H^3}{K_D (S-1)^3 \cot\theta}$$

Where, W is the weight of the individual stones, γ is the unit weight of the stone, H is the design wave height, S is the specific gravity of the stone, $\cot\theta$ is the slope of the structure, and K_D is a stability coefficient.

A typical construction sequence for a stone revetment begins with grading the site to the desired slope. Next a filter layer consisting of a geo-synthetic membrane and a layer of small rocks, or gravel is placed on the slope. The main armor units are then placed on the filter layer, with the largest rocks placed along the bottom of the bank. Extra protection is typically added at the toe and along the flanks to prevent erosion in these critical areas.

Revetments can be costly, ranging anywhere from $120/lf to $180/lf (Devore, 2010). Construction costs depend on the dimensions of the structure, the availability and cost of transporting materials to the site, and the cost of labor. The last 2 vary significantly from site to site.

Maintenance includes periodic inspections to identify any misplaced or deteriorated stones. Individual stones comprising a revetment can be prone to damage, displacement, or deterioration, which can lead to a reduction in the overall effectiveness of the structure. Typically this will not cause the structure to fail in its entirety. Frequently, repairs can be made before the damage becomes too severe.

Adaptability

Revetments are somewhat adaptable. While designed as static structures, the displacement of an individual armor stone typically does not result in a catastrophic failure of the entire structure. Repair or adaptation of an existing structure through adding additional armor units is typically possible, although potentially expensive due to the cost involved in sourcing, transporting, and placing heavy stone.

Advantages

Revetments have several advantages over other engineered shore protection approaches, among them are:

- Individual armor units are given an allowance for movement without causing the structure to become impaired.
- Revetment construction is straightforward; however heavy machinery is required.
- Revetments have low maintenance requirements and damages can easily be repaired.
- Revetments are adaptable and can be adjusted or modified to continue to provide protection in the future.
- Revetments can withstand relatively strong currents and low-moderate waves.
- The void spaces within revetments provide some habitat function as compared to shear, impervious surfaces.

Disadvantages

Revetments have several disadvantages compared to other engineered shore protection approaches, among them are:

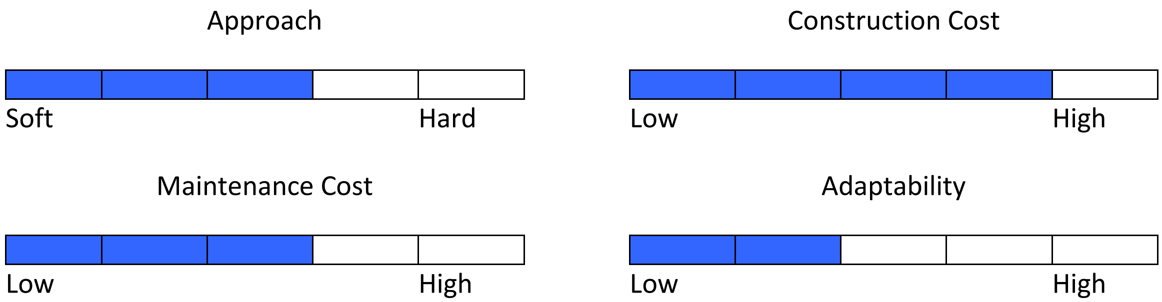
- Scouring occurs at the toe and flank of the structure and can increase erosion downstream.
- Material cost and transportation can be expensive.

- Large voids due to poorly placed rocks can be a hazard.
- Access to the shoreline is altered/disrupted.
- Revetments can be seen by some as an eyesore.

Similar Techniques

Alternatives may include: gabions, bulkheads, rootwad revetments, tree revetments, green walls, and crib walls.

Rootwad Revetments



Description

Rootwad revetments are a type of revetment fashioned out of the lower trunk and root fan of a felled tree. Rootwad revetment projects frequently incorporate other natural materials such as boulders and logs to enhance the amount of stream bank stabilization they provide. In addition to providing stabilization, rootwad revetments also provide an improved fish rearing and spawning habitat, when compared to traditional revetments. Typically, rootwad revetments are installed in a series along streams with meandering bends.

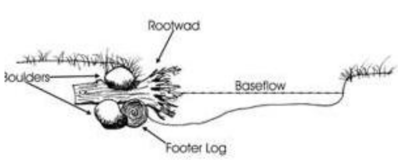


Figure 9: Rootwad revetment cross-section (Stormwater Management Resource Center).

Design and Construction

Unlike traditional revetments for which there are well-documented systematic design approaches, rootwad revetment layout and construction involves significantly more uncertainty. Like traditional revetments, overtopping is one of the primary causes of failure; therefore accurately determining the water level is essential. If the crest of the structure is sited too close to the water line overtopping will occur and the top of the structure will be exposed to scour, potentially compromising its structural integrity. Rootwad revetments also tend to be vulnerable to erosion at the toe (base) and flank (ends), therefore supplemental reinforcement is frequently added in these regions. Because of the increased vulnerability to toe erosion, rootwad revetments tend not to be effective in streams where the bed has been severely eroded and where undercutting of the structure is likely. Rootwad revetments also typically do not perform well on streams winding through rocky terrain or on narrow streams bounded by high banks.

The construction process for rootwad revetments, like the design process, is not well documented. A typical construction sequence involves anchoring a small-medium diameter (~16") tree trunk with rootwad into the stream bank, and excavating trenches for the installation of footer logs. Once the rootwads and footer logs have been placed, boulders can be used to help stabilize the structure, and site can be backfilled.

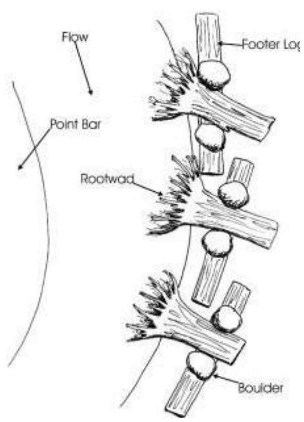


Figure 10: Rootwad revetment planview (Stormwater Management Resource Center).

Rootwad revetments are constructed entirely of natural materials; therefore the cost can vary significantly depending on the availability of source material. A typical cost per rootwad is between $200 and $1,700 (DCR, 2004). Rootwad revetments should be inspected on a regular basis, particularly after high flow events or floods, when overtopping and scour may be pronounced. Even during periods of calm weather, rootwad revetments should be inspected regularly as organic decay can compromise the structural integrity of the system.

Adaptability

Rootwad revetments are not very adaptable and are particularly sensitive to problems such as overtopping and decay which may be exacerbated by rising sea levels. Due to the details of the construction approach, modifying a rootwad revetment once placed is likely to require significant effort, which may include removing the original structure.

Advantages

Rootwad revetments have several advantages over other engineered shore protection approaches, among them are:

- Rootwad revetments provide a natural, ecologically friendly form of bank stabilization.
- Rootwad revetments can improve fish rearing and spawning habitats.
- Rootwad revetments have a more natural appearance than other engineered structures.

Disadvantages

Rootwad revetments have several disadvantages compared to other engineered shore protection approaches, among them are:

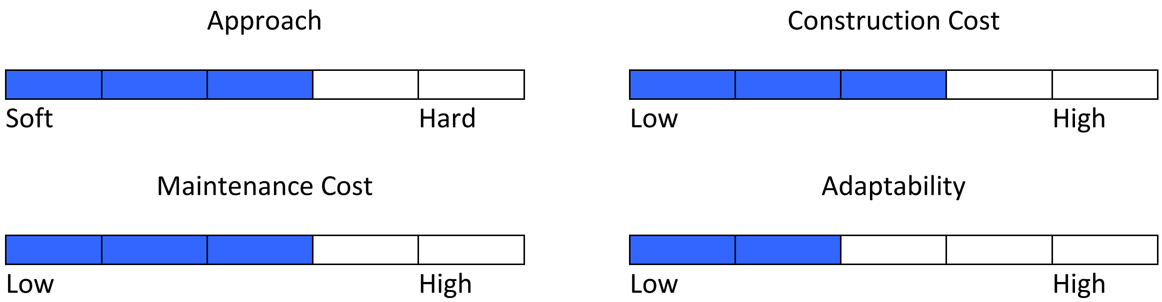
- Rootwad revetments are susceptible to damage due to rising water levels.
- Rootwad revetments are less effective in the sandy/silty soils typically found in river estuaries.

- Documentation of successful projects is sparse.
- Rootwad revetments restrict access to the shoreline. Rootwad revetments cannot be used in locations where frequent overtopping is expected or significant erosion of the streambed has already occurred.

Similar Techniques

Alternatives include: revetments, tree revetments, gabions, crib walls.

Tree Revetments



Description

A tree revetment is a revetment constructed of trees that are cabled together and anchored along a stream bank in order to provide protection. Tree revetments decrease erosion and can slow the nearshore currents so that silt and sand are deposited along the bank. Tree revetments are commonly constructed in areas where naturally occurring trees have become unstable and have been removed by erosional forces. By strategically placing these trees and cabling them together, the natural protection that would be provided by felled trees along the bank is enhanced. In addition, by anchoring them in one location, the longevity of the protection provided is increased. Tree revetments are often used as a temporary measure to protect the bank while new trees take hold. If the erosion is chronic, and the bank is too unstable however; the new trees may be unable to slow the erosion. Douglas fir, oak, hard maple, and beech trees are commonly used for tree revetments.

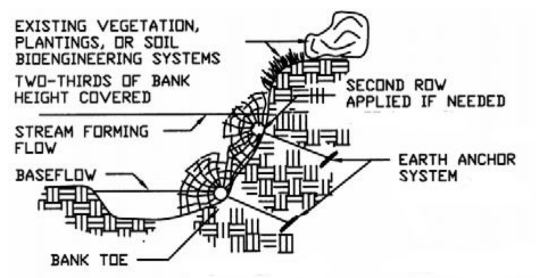


Figure 11: Typical tree revetment cross-section (NYS DEC, 2005).

Design and Construction

When designing a tree revetment the stream size, height of the bank, and average flow need to be taken into consideration. In general, tree revetments should not be used on stream banks taller than 12 feet in height (MDC, 1999). It is important that the extent of erosion on the shore be known prior to construction, as tree revetments can lead to increased erosion on unstable shorelines. The placement of the trees along the shoreline needs to be rather precise. The trees need to be high enough to control the erosion in the critical area, yet low enough to prevent water from undercutting the structure. Soil conditions should be investigated as they will dictate the size and placement of the anchoring system.

Figure 12: Tree revetment (Alaska Department of Fish and Game, 2012).

The construction of a tree revetment proceeds in 3 phases. The first phase begins with the placement of the anchors along the bank. The second phase involves placing the trees along the bank in an overlapping pattern, with their basal ends orientated upstream. The final step is to secure the trees to the anchors using a cabling system. In keeping with the natural theme, vegetative plantings or other soil bioengineering techniques are frequently used to enhance the protection provided and to encourage the development of a vegetative community.

Prices vary significantly, but the cost for a tree revetment can be between $5/lf and $25/lf or more (DCR, 2004), depending on the availability of material and labor costs. It has been found that tree revetments can last from 10 to 15 years, depending on how frequently the trees are submerged. Longevity and maintenance requirements will depend on the frequency and size of any floods endured and how well the ends of the structure are secured. After major flood events tree revetments should be inspected to ensure the cabling and anchor system remain intact.

Adaptability

Tree revetments are not very adaptable. As discussed above the elevation of the tree revetment along the bank plays an integral role in its success or failure. As a static structure pinned to an anchor, tree revetments are incapable of adjusting to changing water levels. The addition of a new layer requires connecting to an existing anchor or the installation of a new one and thus significant effort in terms of excavation.

Advantages

Tree revetments have several advantages over other engineered shore protection approaches, among them are:

- Tree revetments use material that is relatively inexpensive and readily available.
- Tree revetments can act as a natural sediment accumulator, enhancing certain habitats.
- Tree revetments mimic the natural protection provided by felled trees.
- Tree revetments are considered by most to be more aesthetically pleasing than many traditional shoreline protection approaches.

Disadvantages

Tree revetments have several disadvantages compared to other engineered shore protection approaches, among them are:

- Tree revetments can present a hazard if a tree is dislodged during a storm event.
- Tree revetments have a limited lifespan relative to other treatments.
- Tree revetments are susceptible to damage from ice and debris.
- Tree revetments require periodic inspections and maintenance.
- Tree revetments can increase erosion in unstable conditions.
- Tree revetments can limit access to the shoreline.
-

Similar Techniques

Alternatives may include: rootwad revetments, gabions, crib walls and revetments.

Rip-rap

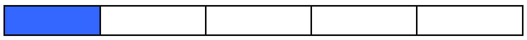
Approach

Soft Hard

Construction Cost

Low High

Maintenance Cost



Low High

Adaptability

Low High

Description

Rip-rap is frequently utilized to stabilize shorelines when the level of protection required is less than that which would require a revetment. Rip-rap stabilized shorelines utilize material that is significantly smaller and therefore less costly than the large stones used in the construction of a revetment. The placement of the material also requires less precision and thus less skilled labor than that of a revetment. Rip-rap slopes are typically constructed along natural slopes, so frequently less grading is required. The existing or graded slope is normally covered with a fabric filter and then backfilled with appropriately sized rocks up to the top of the slope. The material used in rip-rap projects tends to be more well graded, i.e. containing a mixture of stone sizes. Vegetation is frequently added as a component of a rip-rap stabilization project to provide additional erosion resistance as well as to increase the aesthetic and ecological value of the project. When constructed, rip-rap slopes retain a high degree of flexibility and can shift freely without destabilizing the entire structure.

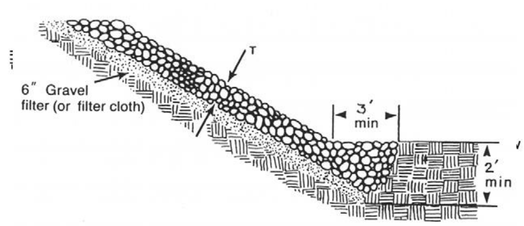


Figure 13: Typical rip-rap slope cross-section (NYS DEC, 2005).

Figure 14: Constructed rip-rap shore protection project (USDA, 1996).

Design and Construction

The primary design parameter in constructing a rip-rap stabilized slope is the selection of an appropriate gradation of stone sizes. The selection is based on the resistance to the expected wave and/or current forces, and includes mean as well as maximum and minimum values. Fischenrich (2001) reported stability thresholds of between 2.5 and 10.1 lb/ft^2 for shear stress, and between 5 and 18 ft/sec for current velocity for rip-rap between 6 and 24 inches in diameter. Other important design parameters include the height and thickness of rip-rap. Grain size analyses are typically performed on the local bed material to determine whether or not a filter layer is required.

Construction of a rip-rap stabilized slope begins with grading of the stream bank. A foundation is typically dug at the bottom of the slope and into the bank to prevent scour. Filter fabric is then placed on the graded slope, and covered in layers with stones from the foundation up to the top of the slope. If the top of the slope is not vegetated, vegetation can be planted to increase erosional resistance and to add to the aesthetic and ecological value of the project.

The cost of rip-rap revetments varies widely depending on the size and availability of the stone used in construction. Costs of between $30 and $55/lf are common (NRPCVT, 2004). Once in place, rip-rap slopes typically require minimal maintenance. After significant storm events, slopes should be checked to ensure that a significant protective layer of stone remains. In areas prone to ice floes, rip-rap slopes should be checked seasonally to identify any areas of ice scour/gouging. Repairs if required will typically consist of the replacement of lost material.

Adaptability

Rip-rap structures have long life spans, are self-adjusting, and extremely adaptable. Since the structures are composed of small, easily movable stones, when damage occurs and rocks are displaced, other rocks fall into the voids and fill the spaces. Sea level rise may increase the frequency of overtopping and increase scour at the crest of rip-rap slopes; however compensating for these issues by reinforcing critical areas is straightforward, and economical.

Advantages

Rip-rap slopes have several advantages over other engineered shore protection approaches, among them are:

- Rip-rap slopes are flexible and can be constructed to mold to the curvature of the stream bank.
- Rip-rap slopes are more economical than structures using larger stones.
- Rip-rap slopes have the capability to self-adjust.
- Rip-rap slopes can be used for relatively high velocity flows.
- Rip-rap slopes are extremely adaptable.
- Rip-rap slopes preserve access to the shoreline.

Disadvantages

Rip-rap has several disadvantages compared to other engineered shore protection approaches, among them are:

- The smaller stones used in constructing a rip-rap slope are less stable than the large heavy stones used to construct a revetment.
- Moving ice and debris can remove large quantities of stone at once.
- Inspections should be conducted regularly to identify areas in need of reinforcement.
- Rip-rap is unnatural and can be seen as an eyesore by some.

Similar Techniques

Alternatives may include: revetments, gabions.

Jack Fields

Approach

Soft — Hard

Construction Cost

Low — High

Maintenance Cost

Low — High

Adaptability

Low — High

Description

Jacks are large structures made of wood, concrete or steel which are placed in rows parallel to the bank of a stream to prevent erosion. Jacks armor the shoreline and can also trap sediment and debris. Jacks are typically placed in groups along the shoreline which are referred to as jack fields. When placed effectively adjacent to sediment laden water, some jack fields can trap enough sediment/debris to become embedded into the shoreline. In areas where high velocity currents, debris, and ice floes are expected, jack fields can become dislodged and individual units damaged, therefore jack field installations should be limited to lower flow situations. Anchoring systems can also be used to increase stability in high flow situations.

Design and Construction

Jacks are placed along the stream bed in rows parallel to the shore, with individual jacks placed less than one jack width apart to ensure a continuous line of protection. The jacks are anchored to the shoreline by attaching them to an anchor or piling. Extra vegetation can be added to both enhance the look and habitat value of the project, as well as to provide additional protection.

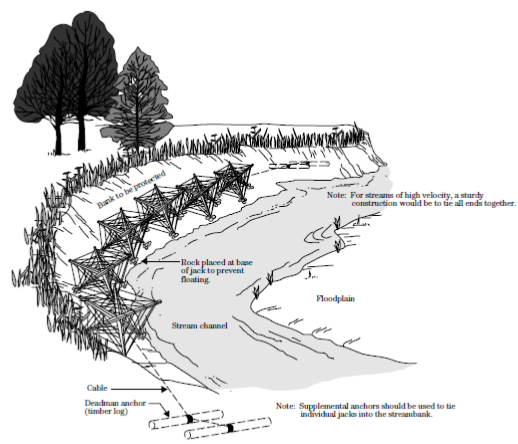


Figure 15: Typical jack field installation (USDA, 1996).

Figure 16: Jack field installation (USDA, 1996).

Detailed cost information on the jack field technique was not found.

Adaptability

Jack fields are not readily adaptable. Jack fields can be modified by adding additional jacks to the system; however tying them into an existing anchor may require significant effort.

Advantages

Jack fields have several advantages over other engineered shore protection approaches, among them are:

- Jack fields have the capacity to trap sediment along the shore.
- Jack fields can be used in conjunction with natural vegetation.
- Jacks fields may eventually become embedded into the stream bank.

Disadvantages

Jack fields have several disadvantages compared to other engineered shore protection approaches, among them are:

- Construction and installation is often complex and the system needs to be properly designed to be effective.
- Jack fields cannot be used on high velocity streams or where there are significant ice floes.
- Jack fields have a highly unnatural appearance which may be viewed by some as an eyesore.
- Jack fields may limit or disrupt access to the shoreline.

Similar Techniques

Alternatives include: rip-rap, revetments, coconut fiber rolls.

Green (Bio) Walls

Approach

Soft Hard

Construction Cost

Low High

Maintenance Cost

Low High

Adaptability

Low High

Description

A green or bio wall is a generic term used to describe hard sheer structures which are modified to provide ecological enhancement. Bulkheads, gabions, or keystone (block) walls frequently serve as the base for a green wall. The methods used to enhance these hard structures range from the incorporation of minimalistic vegetation, to variations in the form or composition of the structure itself. Examples include incorporating terraced or roughened edges, using alternate materials, or introducing undulations along the length of a structure. The purpose of these modifications is to improve both the aesthetic and ecological value of the structure, while providing the same high-level of protection afforded by the base structure. Green walls have been used increasingly in urban settings where a high level of protection is required and where space is limited.

Design and Construction

The design of green walls is extremely site specific. The base structure is designed using the methods applicable to that specific structure. The impact of introducing undulations, terraces, rough surfaces, and even vegetation frequently must be modeled due to the unique and often non-linear aspects of the structures. This modeling can be computational, however due to the many uncertainties involved, scale physical models are frequently most appropriate.

Detailed cost information on the bio wall technique was not found.

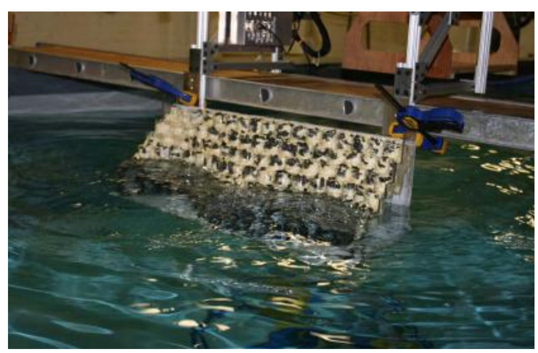


Figure 17: Laboratory study of wave run-up along a green wall (Herrington, et al., 2005).

Adaptability

Green walls have a very limited capacity to adapt to changing conditions, although they are typically designed to handle a wide range of conditions. If the base of the green wall is of a gabion- or keystone-type structure, adding elements to accommodate a rising sea level should be possible. If a bulkhead forms the backbone of a green wall, modification may be more difficult. Another key consideration that relates to the adaptability of green wall structures is the tolerance of any vegetation incorporated in the design to changing conditions. Many plants have a limited capacity to adapt to changing water levels, which may reduce the ecological benefits associated with a green wall over time. Similarly, when undulations or tide pools are created as a part of a bio wall structure, their effectiveness can be reduced as water levels change.

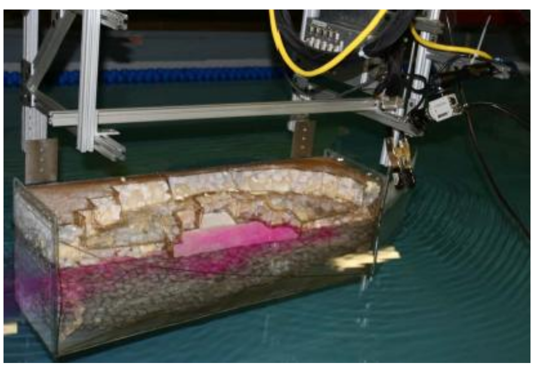


Figure 18: Laboratory study of circulation adjacent to a green wall (Herrington, et al., 2005).

Advantages

Green walls have several advantages over other engineered shore protection approaches, among them are:

- Green walls have the same structural integrity as traditional structures constructed of the same material; however they incorporate principles designed to maximize their ecological function.
- Green walls can be considered more natural looking than other shoreline hardening approaches.

Disadvantages

Green walls have several disadvantages compared to other engineered shore protection approaches, among them are:

- The hard sheer surface can reflect wave and current energy and increase scour at the toe.
- Green walls can be expensive to design, permit and implement.
- Green walls can alter/disrupt access to the shoreline.

Similar Techniques

Alternatives include: bulkheads, gabions, live crib walls.

Timber Cribbing

Approach

Soft Hard

Construction Cost

Low High

Maintenance Cost

Low High

Adaptability

Low High

Description

A timber crib is a 3 dimensional boxlike chamber constructed out of untreated log or timber, that is filled with alternating layers of rock and course gravel. Precast concrete or plastic structural members may replace the use of wood. The crib is placed perpendicular to the flow of the channel and can capture sediment if the flow is reduced by the cribbing. The crib serves a similar purpose to gabion wire; containing and utilizing smaller stones that would otherwise be washed away by the water. These structures are constructed at the base flow level, and are very effective in preventing bank erosion and retaining soil. Also known as crib walls, rock cribs or cribbing, timber cribbing is typically used in situations where the toe of a slope needs to be stabilized and where a low wall may be needed to reduce the steepness of a bank. They are normally used in small rivers or streams; however by adding anchors for additional support, they can be adapted for use in more extreme conditions. Timber cribbing is robust enough to withstand moderate to high currents and shear stresses. Timber cribbing is a convenient protection method when encroachment into the channel must be avoided. Historically, crib walls were a popular form of stream bank protection as heavy equipment and skilled labor was not required, for small, low-height applications.

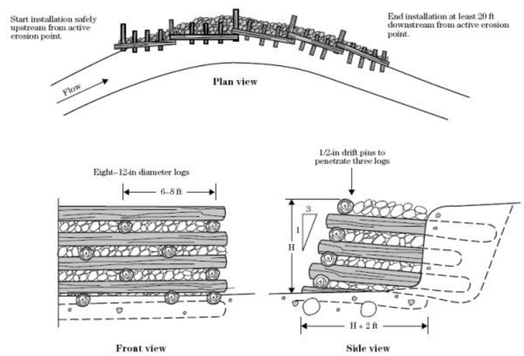


Figure 19: Typical Timber Cribbing Cross-Section and Plan View (National Engineering Handbook, August, 2007).

Design and Construction

Crib walls are susceptible to undermining and should not be used in areas where severe erosion has affected the channel bed. Toe protection can be used to counter these erosional forces; however if inadequate protection is provided, the entire structure can be destabilized.

Streams with narrow channels and high banks are indicative of the types of areas where crib walls may be inappropriate.

Crib walls are typically limited to low-moderate height applications, due to their inability to withstand large amounts of lateral earth pressure. This problem can be even more severe during periods of heavy rain, where the increased pressure can force the entire crib forward or even cause it to break apart. Once broken, the crib serves as a source of debris for the river and a safety hazard.

Crib walls can be an extremely effective collector of debris and soil in unidirectional flows. Large branches being transported by the flow can get stuck on the updrift side of the wall, causing further accumulation. As the accumulation of material continues, enough pressure can build up that the entire structure or sections can be uplifted and forced downdrift.

Crib wall construction will vary from project to project but there are a basic series of steps common to most installations. The base of the structure is constructed by excavating several feet below the ground elevation of the toe of the structure. The front of the excavated slope should be slightly higher than the back. Slopes of between 10H (Horizontal):1V (Vertical) and 6H:1V are common. The main footings should extend out into the river to prevent toe scour. The first layer of logs is typically placed approximately 5 feet apart, along the excavated surface, parallel to the sloping bank. The next layer is placed at a right angle to the first in a similar fashion, overhanging the back and front by several inches. This sequence is repeated until the full height of the structure is realized. It has been recommended that timber cribbing should range from 50 to 70% of the bank height, reaching a maximum of 7-8 feet not including the foundation (DCR, 2004). Each course is typically fastened into position using nails or reinforcing bars, and each layer is filled with rock and/or coarse gravel. Stepped front crib walls are common and can be constructed by stepping the front of each subsequent layer back 6 to 9 inches from the front of the previous.

Timber cribbing utilizes materials which are typically readily available. The frame of the structure is usually constructed of untreated timber or logs with diameters ranging from 4 to 8 inches. Eastern white cedar, red pine, jack pine and spruce are common. The backfill material is typically sourced from a local quarry and utilizes stone types and gradations that are plentiful in the area.

Maintenance for crib walls typically consists of monitoring the wall to check for excessive accumulations of debris or broken cribs. Removing the debris and repairing any broken cribs will help prolong the life of the structure.

Adaptability

After construction, it is difficult to modify a timber crib wall, with the exception of increasing its elevation. Excavating the top layer and adding additional sections is straightforward; however this may require an inspection of the lower layers to insure their stability. Adjusting in this manner is limited depending on the original height of the crib.

Advantages

Timber cribbing has several advantages over other engineered shore protection approaches, among them are:

- Timber cribbing can be used on banks that have steep slopes.
- Timber cribbing is constructed of readily available materials.
- Timber cribbing can withstand moderate – high velocities and shear stresses.
- Timber cribbing is considered by most to be more aesthetically pleasing than many traditional shoreline hardening approaches.

Disadvantages

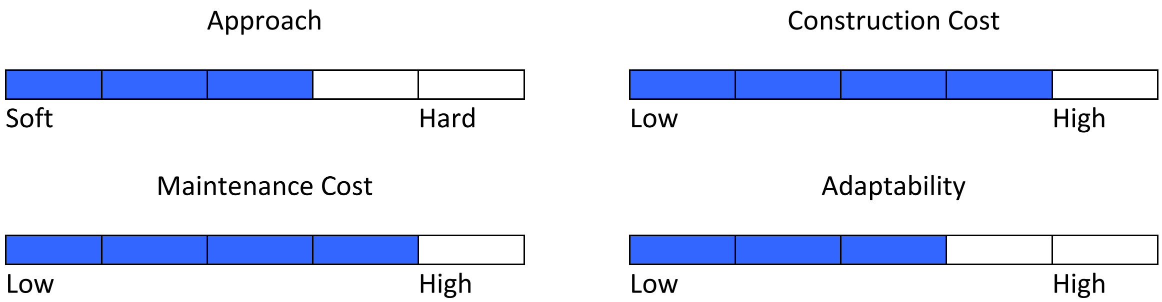
Timber cribbing has several disadvantages over other engineered shore protection approaches, among them are:

- Timber cribbing is not designed to resist large lateral earth stresses so the maximum height is limited.
- Moving ice can cause severe damage to timber cribbing.
- Accumulation of large debris can cause currents to push the entire structure and cause failure.
- Timber cribbing alters/disrupts access to the shoreline.

Similar Techniques

Alternatives include: green walls, bulkheads, gabions, and vegetated geogrids.

Live Crib Wall



Description

As discussed above, a crib wall is a 3 dimensional boxlike chamber typically constructed of untreated log or timber that is filled with alternating layers of rock, gravel, soil or other fill material. Live crib walls are typically constructed at the base flow level where they can be very effective in preventing bank erosion and retaining soil. Live crib walls integrate live branches into the traditional crib wall design which eventually take root inside the box and extend into the slope of the bank. The vegetation, once established, helps stabilize the structure while also creating habitat along the shoreline. The root system of the vegetation binds the structure into a single large mass.

Like crib walls, live crib walls are typically used in situations where the toe of a slope needs to be stabilized and where a low wall may be needed to reduce the steepness of a bank. They are normally used in small rivers or streams; however by adding anchors for additional support, they can be adapted for use in more extreme conditions.

Design and Construction

The materials used in the construction of a crib wall are typically readily available. The frame of the structure is usually constructed of untreated timber or logs with diameters ranging from 4” to 8” (eastern white cedar, red pine, jack pine or spruce are common). Small stones with diameters of between 1 and 4 inches are commonly used as a base layer, with locally sourced clean fill or soil used to fill each compartment. The vegetation incorporated into live crib walls are commonly branches 0.5 to 2 inches in diameter with willow, dogwood, and other woody species being typical.

Live crib walls are able to withstand reasonably high velocities and shear stresses. Construction proceeds as above for crib walls, however in a live crib wall, layers of branch cuttings and soil are interspersed between each layer of timber above the base flow level.

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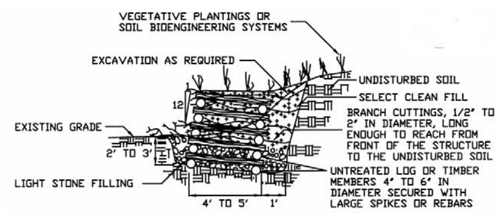


Figure 20: Typical live crib wall cross-section (NYS DEC, 2005).

Figure 21: Live crib wall installation (NYS SWCC, 2005).

The cost of installing a live crib wall is moderate to high compared to other shoreline stabilization methods. Costs can range from $100 to $400 per linear foot (Michael Kosiw, 2008). Live crib wall structures should be examined fairly frequently to make sure that the roots of the live cuttings are taking hold. Once the live cuttings are established, minimal maintenance is typically required.

Adaptability

After construction, it is difficult to modify a live crib wall, with the exception of increasing its elevation. Excavating the top layer and adding additional sections is straightforward; however this may require supplementing the initial plantings to re-stabilize the root system. If additional cells are added, the design should be rechecked to ensure that the modifications have not compromised the structural stability of the wall.

Advantages

Live crib walls have several advantages over other engineered shore protection approaches, among them are:

- Live crib walls can be used on banks that have very steep slopes.
- Live crib walls are constructed of readily available materials.
- Live crib walls can withstand relatively high velocities and shear stresses.
- Live crib walls are typically considered more aesthetically pleasing than many traditional shoreline hardening approaches.
- Live crib walls are better from an ecological standpoint than most shoreline hardening techniques.

Disadvantages

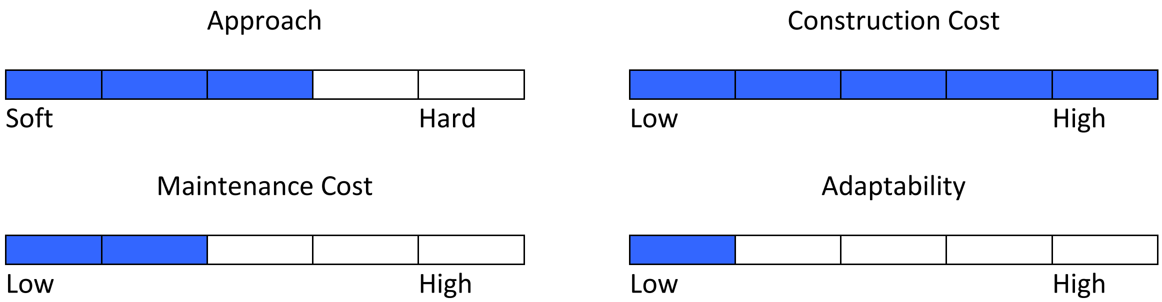
Live crib walls have several disadvantages compared to other engineered shore protection approaches, among them are:

- Live crib walls are not designed to resist large lateral earth stresses so the maximum height of the wall is limited.
- Moving ice can cause severe damage to live crib wall.
- Live crib walls alter/disrupt access to the shoreline.

Similar Techniques

Alternatives include: green walls, bulkheads, gabions, and vegetated geogrids.

Levees (Dikes)



Description

Levees or dikes are earthen embankments designed to furnish flood protection during periods of seasonal high water. As such these structures are designed to withstand the loading from water pressure for a period of days to weeks. Longer time periods will require alternative measures. Levees are frequently constructed on foundations that are less than ideal, using locally available fill. Floodwalls (vertical walls) are frequently constructed along with levees to increase the level of protection. Major modes of levee failure include overtopping, surface erosion, internal erosion, and sliding. Under strong currents and/or wave action, levee side slopes must often be protected using one of the other techniques discussed in this document.

Design and Construction

Basic steps in the design of a levee include detailed subsurface investigations of both the levee site and the borrow site to determine the characteristics of the foundation and fill material. Geometric parameters including crest height, crest width, and side slope are set based on factors such as expected flood crest elevation, soil stability, and practical considerations. Once cross-sections have been set, the design should be analyzed for seepage, slope stability, settlement, and surface use.

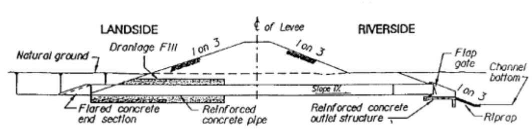


Figure 22: Typical levee cross-section (USACE, 2000).

Figure 23: Constructed levee (USACE, 2000).

Construction of a levee begins with clearing, grubbing, and if necessary, stripping the site. Any loose or soft areas should be removed to create a stable foundation. Once the site is prepared, fill material is added in lifts. Depending on the type of levee being constructed, compaction may be required between lifts. Once the desired geometry is achieved, surface protection can be added. Common choices include vegetation, rip-rap, and concrete.

Levee costs vary widely due to the significant variation in dimension and complexity of each project. After large flood events levees should be inspected to ensure their stability has not been compromised. Routine monitoring should also be carried out to ensure there is no slumping, wash out, or even vegetation growth that might compromise levee stability.

Adaptability

Due to their size and construction methods, modification of an existing levee is difficult. Floodwalls and other structural modifications can be added to increase flood protection if required.

Advantages

Levees have several advantages over other engineered shore protection approaches, among them are:

- Levees are one of the most frequently utilized methods of flood protection.
- When designed, constructed and maintained properly, levees have a long history of successfully combating flood waters.
- Levees can be constructed to match surrounding habitat.
- Levees do no restrict access to the shoreline.

Disadvantages

Levees have several disadvantages compared to other engineered shore protection approaches, among them are:

- Levees may require additional slope protection to stabilize.
- Levee failure can often be catastrophic.
- Levees can be extremely expensive due to the amount of earthwork that is involved.

Similar Techniques

Alternatives include: Levees are typically massive structures designed to combat major flooding. None of the other techniques discussed in this document fulfill the same role.

Geotextile Roll

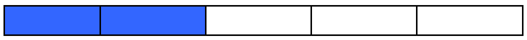
Approach

Soft Hard

Construction Cost

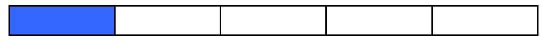
Low High

Maintenance Cost



Low High

Adaptability



Low High

Description

Geotextile rolls are sand filled tubes constructed of a geosynthetic membrane, which are placed on the shoreline or bank, parallel to the bank to prevent erosion. The net effect is a flexible, resilient structure, which relies on its own weight for stability. The size of the rolls can be varied depending on the erosional forcing. Geotextile rolls have even been used on ocean coasts where the primary destructive forces are related to shore perpendicular waves. The geotextile tubes are typically made of a high strength polyester or polypropylene, and are extremely resilient when filled. These tubes are placed along the bank and are frequently buried and/or planted so as to remain hidden. This provides a more natural aesthetic and enhances habitat value. Only when the erosion becomes extreme do the tubes become exposed and actively protect the shoreline. If the erosional pressures are transient, it is frequently possible to rebury the tubes to restore the natural aesthetic between storm events.

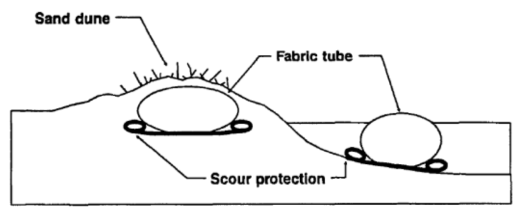


Figure 24: Typical geotextile roll slope protection (USAE WES, 1995).

Design and Construction

The selection of geotextile material for creating the roll is based on porosity and strength characteristics. The porosity is selected to match the particle size and permeability of the fill material, while the strength is selected such that the tube can withstand the high pressures experienced during the filling process. Fill material can consist of either onsite or dredged material, which is pumped into the tubes as a slurry through several injection ports. The water exits the roll through the porous fabric, while the sand remains behind. The injection ports are secured after pumping so that they are not torn and reopened. Once filled, the tubes have cross sections that are circular along the sides, and flat on top. As the tubes dewater, the final crest elevation can be lowered and it may be necessary to refill the tubes to retain the designed crest elevation. For stability, it is essential that the filled tubes have a high unit weight.

Figure 25: Geotextile roll being used as the core of a sand dune along the New Jersey coast. (Photo credit: Tom Herrington).

It is possible to stack several tubes together; however, this can lead to the development of scour holes directly adjacent to the structure. In order to protect against scour, a filter fabric apron can be installed with appropriate filtration characteristics.

Once installed, the filled geotextile tubes can be covered with sand or soil to form a dune or earthen mound. The newly constructed dune/bank can then be revegetated.

Construction costs will vary significantly depending on the local site conditions, including labor rates. Costs of between \$50/lf and \$200/lf have been reported (USACE, 1993).

Maintenance for geotextile roll stabilization projects is typically minimal. Exposed rolls should be checked for tears, and patched to prevent excessive loss of the fill material. Vegetation growth should be monitored to ensure that the roots of large plants do not destabilize the rolls.

Adaptability

Once placed, the geotextile rolls themselves are not readily adaptable. In addition, if the local conditions change such that bank erosion switches from episodic to chronic in nature, scour at the toe and on the flanks may cause the structure to fail.

Advantages

Geotextile rolls have several advantages over other engineered shore protection approaches, among them are:

- Geotextile rolls are flexible and can be fit to a curving bank.
- Geotextile rolls can be more cost effective than traditional hard structures.
- There are relatively few constraints on the dimensions of geotextile tubes for riverine applications.
- Geotextile rolls can be covered and revegetated to restore habitat and enhance aesthetics.
- Geotextile rolls do not limit access to the shoreline.

Disadvantages

Geotextile rolls have several disadvantages compared to other engineered shore protection approaches, among them are:

- Due to their tendency to roll, precautions must be taken to prevent scour at the base of the structure.
- Geotextile rolls filled with coarser material may experience premature and uneven settling.
- If left exposed, geotextile degradation and vandalism are a concern.
- Geotextile rolls are susceptible to puncture by ice and debris when exposed, particularly when underfilled.
- Geotextile roll structures are not adaptable.

Similar Techniques

Alternatives include: coconut fiber rolls, tree revetments

Vegetated Geogrids

Approach

Soft — Hard

Construction Cost

Low — High

Maintenance Cost

Low — High

Adaptability

Low — High

Description

A vegetated geogrid is a soil wall that is placed on a bank or shore that has been severely eroded. The wall is made up of successive soil lifts that are separated by and wrapped in a synthetic control fabric. Branch cuttings are then placed between each layer. The live branch cuttings serve several practical purposes. The cuttings act as a buffer to reduce wave energy and shear stress at the face of the wall. In addition, having the branch cuttings present before the completion of the wall enables the vegetation to grow as rapidly as possible. Finally, once established the branches serve to bind the geogrids together and provide a root structure behind the wall, attaching it more securely to the shore

Design and Construction

Vegetated geogrids are mainly used on smaller rivers or streams, and are designed to withstand maximum current velocities of 14 ft/s, and shear stresses of up to 8 lb/ft^2. The streambed needs to be stable at the construction location and all construction needs to be performed during times of low water.

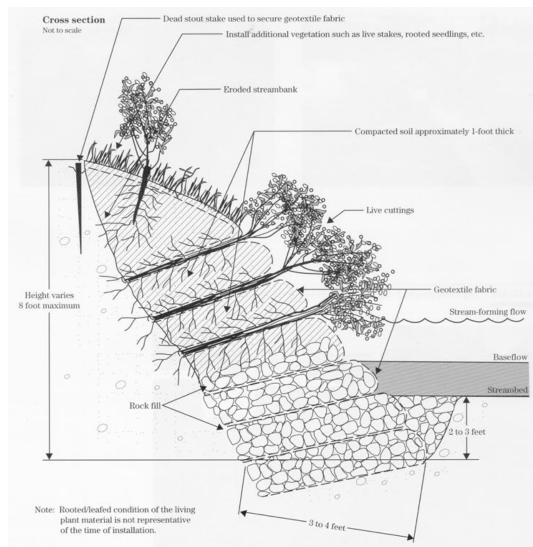


Figure 26: Typical vegetated geogrid (Iowa DNR, 2006).

Construction materials consist of branches (typically 0.5" to 2.5" in diameter - willow, dogwood, or other native woody plants), rock fill (with diameters ranging from 4" to 9"), soil and an erosion control fabric (synthetic polymer). Construction typically proceeds in a step-by-step fashion with each successive layer being built upon the previous. The base is constructed by excavating a 2 to 3 foot trench into the streambed that extends to the estimated scour depth. The trench is then filled up to the mean high water depth with rock, and wrapped in a control fabric. The first geogrid is constructed by filling the area with soil and rock; and then wrapping it. The first level of vegetation is placed on top of the first lift. Stakes or rebar are used to fix each layer of the geogrid to the one beneath it. The geogrid-vegetation pattern is then continued to the desired height, with each successive geogrid shorter than the previous, to create a slight slope. Once completed, soil is placed on top of the last geogrid and the fabric of the geogrid is staked to the bank. Grass and/or other vegetation can be planted on the surface to help anchor the structure. Vegetation can also be planted on the ends to prevent flanking.

The cost of a vegetated geogrid is moderate to high, with labor accounting for approximately 2/3 of the total project cost. It has been estimated that every linear foot of structure requires roughly one man hour of labor. Material costs range from $13 to $30 per linear foot with total costs of between $50 and $200 per linear foot reported (NSP, 2006).

The vegetation growth within a vegetated geogrid is an essential part of the protection it provides, therefore it is important that the branches become rooted and begin growing quickly. Regular monitoring, particularly immediately after construction, is essential to ensure that the vegetation is taking root. Once the vegetation is established however, the maintenance costs are greatly decreased.

Adaptability

Due to their layered or terraced nature, vegetated geogrids can be extended vertically with relative ease. The top layer can be excavated and additional geogrid-vegetation layers can be added up to the desired height. A limiting condition will occur, however, when the elevation of the land behind the structure becomes equivalent to the elevation of the structure itself. Backfilling to increase the elevation of the land behind the structure may be possible in these situations.

Advantages

Vegetated geogrids have several advantages over other engineered shore protection approaches, among them are:

- Vegetated geogrids can have very steep slopes, so they can be used on shores that drop off suddenly or in areas where the bank cannot be modified to create a gentle slope.
- Vegetated geogrids have a high aesthetic value compared to other shoreline hardening techniques and even other vegetated structures.
- Vegetated geogrids can withstand relatively high current velocities and shear stresses.
- Vegetated geogrids will become more stable as vegetation grows and matures

- Vegetated geogrids can improve the growing conditions for the native vegetation.
- Vegetated geogrids are typically considered more aesthetically pleasing than other shoreline hardening approaches.

Disadvantages

Vegetated geogrids have several disadvantages compared to other engineered shore protection approaches, among them are:

- Vegetated geogrids may limit shoreline access.
- Installation is complex and requires a significant amount of earthwork and heavy machinery.

Similar Techniques

Alternatives include: crib wall, live crib walls, revetments, joint planting bulkheads, green walls.

Live Stakes / Joint Planting

Approach

Soft — Hard

Construction Cost

Low — High

Maintenance Cost

Low — High

Adaptability

Low — High

Description

Joint planting consists of adding live stakes or vegetation into the open spaces, or joints, of an existing rip-rap or rock covered slope. Alternatively, the stakes can also be placed at the same time as the rock reinforcement. When the system of roots from the live stakes develops it creates a living root mat beneath the rocks, binding the soil and preventing washout of the soil and fine material, while also providing habitat.

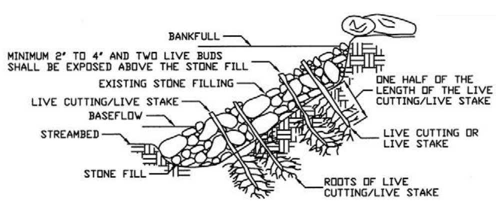


Figure 27: Typical joint planting (NYS DEC, 2005).

Design and Construction

Joint plantings are typically constructed in areas where a sloping rip-rap or rock revetment either exists or is planned. Live stakes/joint plantings have been shown to have a limited capacity to withstand wave action. This method has been shown to be most effective on rivers and streams with minimal flow fluctuations. Ideal sites should have a moderate slope and sufficient light for the vegetation to grow. Permissible shear stresses of 2.1 to 3.1 lb/ft^2 and flow velocities of 3 to 10 ft/sec are given for live willow stakes in Fischenrich (2001). The individual stakes typically consist of 2” to 3” diameter live stakes (willow or other woody plants).

Live stakes/joint planting is typically built on an existing or planned rock slope. The rocks should be appropriately sized to ensure their stability. The live stakes are placed perpendicular to the slope and tamped 2/3 of their length into the ground. A steel rod or hydraulic probe may be required to prepare the hole for the planting. The live stakes should be left with their tips slightly protruding from the surface of the rocks and placed in a random configuration. After construction, the live stakes need to be monitored regularly to ensure they take root and leaf-out. Beyond that there is typically little maintenance involved.

The capital cost of joint planting is low compared to other methods, particularly if the rock covered slope already exists. Prices normally range from $2 - $3/ per stake, with 2 to 4 stakes being placed every square yard (NSP, 2006). If additional site work is needed, these costs can rise to more than $35/ft^2.

Adaptability

Joint plantings can be added to existing structures or incorporated at the design stage. For this reason, as long as there is room within the structure, adding additional plantings to accommodate for variations in water level is reasonably straightforward. Since the plantings are typically sensitive to water level fluctuations, it is possible that rising sea levels will drown out live stakes placed too close to the waterline.

Advantages

Joint plantings have several advantages over other engineered shore protection approaches, among them are:

- Joint plantings can be installed rapidly if the rock covered slope already exists.
- Joint plantings can help reduce wave and current energy impacting the slope; however they are typically only capable of resisting small waves and slow currents.
- Joint plantings reinforce the underlying soil as they grow.
- The roots of the live stakes improve the drainage on slopes.
- Live stakes/joint planting is a low cost way to improve the ecological function of a rock slope.
- The plantings can help trap soil on the shoreline under the right conditions.
- Live stakes/joint planting are typically considered more aesthetically pleasing than other shoreline protection approaches.
- Live stakes/joint planting do not restrict access to the shoreline.

Disadvantages

Joint plantings have several disadvantages compared to other engineered shore protection approaches, among them are:

- Only a small amount of additional protection is initially offered by the stakes.
- Joint planting is typically a complementary, rather than a stand-alone shore protection approach.
- Joint planting is extremely vulnerable to scour from ice and debris.

Similar Techniques

Alternatives include: branch packing, live fascines, brush mattresses.

Brush Mattress

Approach

Soft — Hard

Construction Cost

Low — High

Maintenance Cost

Low — High

Adaptability

Low — High

Description

A brush mattress integrates live stakes, live fascines (rough bundle of brushwood used for strengthening an earthen structure), and branch cuttings to create a comprehensive shore protection system. The cover layer slows the stream velocity as it runs against the shore, and is capable of capturing sediment during flood conditions. The structure is typically supplemented with a rock base in order to prevent scouring. Materials of the mattress are held in place with wire, live stakes, and/or dead stout stakes. Once fully developed the mattress turns into a strong network of interlocking roots.

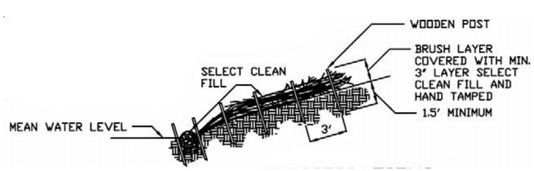


Figure 28: Brush mattress cross-section (NYS DEC, 2005).

Design and Construction

The important factors related to the design and construction of a brush mattress can be broken down into factors that impact vegetation growth, and those that are related to erodability. The important site considerations related to plant growth for a brush mattress project include the amount of sunlight exposure, the subsurface conditions and the local moisture levels. For a brush mattress to properly develop, the site must have enough moisture to support root growth during the growing season. On the other hand, most woody plants have a limited tolerance for water, which should not be exceeded. The amount of available sunlight must also be considered, particularly if light sensitive species such as willow and alder are used. Slope is an often overlooked factor that can be important because over-steep slopes can inhibit the growth of plants within the mattress. Finally, soil conditions are important because the roots must be able to penetrate the substrate.

There are also several factors related to erodability that must be considered as well. Fischenrich (2001) reported current velocity and shear stress thresholds of 4 ft/sec and 0.4 to 4.1 lb/ft^2 for a newly placed brush mattress and 12 ft/sec and 3.9 to 8.2 lb/ft^2 for an established project. Protection of the toe and flanks, of the structure are areas of additional concern that must be addressed during the design phase.

Figure 29: Brush mattress installation (USDA, 1996).

The construction of a brush mattress proceeds as follows. The side slopes should be graded to a maximum steepness of 3:1 to ensure vegetation takes hold. At the base of the slope, a trench should be excavated for the structure toe. Stout stakes can then be installed over the face of the sloped area, with branches placed in a layer over the surface of the bank, with the basal (bottom) ends in the trench. Wire is used to wrap one stake to the next and the stakes are tamped into the ground until the wire tightly secures the branches. Previously prepared live fascine bundles can then be installed in the trench over the basal ends. Dead stout stakes can be driven into the live fascines to secure them to the ground. Finally, all the spaces in the mattress are filled with clean fill, with the exception of the top surface which is left exposed.

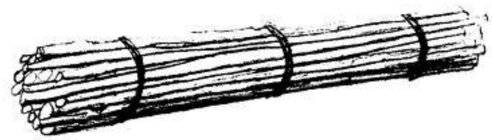


Figure 30: Live fascine bundle.

The cost of a brush mattress is heavily dependent on the local labor rates. A 10 ft^2 area of brush mattress can take from a .5-1.5 hours to construct. Construction costs for the dead stout stakes and the binding alone can range from $.40 to $.70/stake (Allen & Fischenich, 2001) A general figure that has been used in previous cost estimates, which includes labor and construction is between $7 and $12/ft^2 (DCR, 2004).

After construction the brush mattress should be examined frequently to make sure that the roots of the live stakes and fascines are taking hold. The level of maintenance required will depend on stream velocity, flood frequency, and sediment load. At a minimum brush mattresses should be inspected after the predominant flood season. More frequent inspections should be conducted during the first several growing seasons as the flow resistance doesn't reach its peak until the vegetation takes root.

Adaptability

Brush mattresses are not readily adaptable given the level of interconnectedness within the structure. Unlike terraced or layered structures, modification requires substantially more effort than simply stacking on an additional layer. Brush mattresses do have some inherent ability to adapt to slow changes in the environment through natural sedimentation and vegetation growth.

Advantages

Brush mattresses have several advantages over other engineered shore protection approaches, among them are:

- Brush mattresses provide the shoreline with immediate protection and their durability increases with time.
- Brush mattresses can be effective on relatively steep and fast flowing streams.
- Brush mattresses work in concert with and can promote the growth of native vegetation and add to the aesthetic appeal.
- Brush mattresses can serve as a habitat for birds, small animals, and insects.
- Brush mattresses do not alter/disrupt access to the shoreline.

Disadvantages

Brush mattresses have several disadvantages compared to other engineered shore protection approaches, among them are:

- A large amount of cuttings are required for construction.
- Installation is extremely labor intensive.
- Brush mattresses are particularly vulnerable to debris and ice until the vegetation becomes firmly rooted.
- Brush mattresses must be installed during the dormancy period of the live plants being used.
- As a living shoreline stabilization approach, specific conditions are required for the method to be successful.

Similar Techniques

Alternatives include: branch packing, live fascines, joint planting.

Branch Packing

Approach

Soft — Hard

Construction Cost

Low — High

Maintenance Cost

Low — High

Adaptability

Low — High

Description

The branch packing technique employs alternating layers of live branches and compacted soil to repair gaps or holes on stream bank slopes. The branch packing technique not only repairs missing sections of shoreline but also aids in the prevention of erosion and scouring. Branch packing should only be used at sites that have an area less than 4 feet deep and 5 feet wide that needs to be filled and supported (DCR, 2004). The application of the technique is typically limited to sites with side slopes greater than 2:1. Branch packing is not typically used to stabilize long stretches of shoreline.

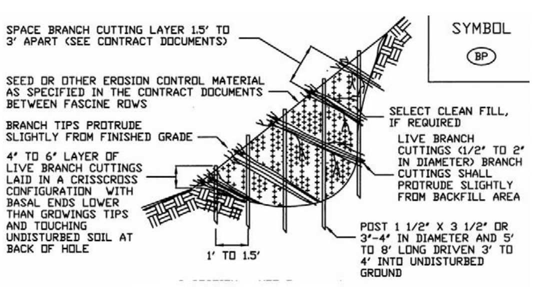


Figure 31: Typical branch packing cross-section (NYS DEC, 2005).

Design and Construction

Some of the important design considerations when applying the branch packing technique include: the size of the hole being filled, the steepness of the side slope, and the water level. As discussed above, the size of the hole and the bank slope will limit the effectiveness of the branch packing approach. Water level must be considered when the branches used are living plants. The ends of the plants must be able to reach the water, while not receiving so much water as to exceed their flood tolerance.

Figure 32: Shoreline stabilized with branch packing (USDA, 1996).

The branch packing approach utilizes a variety of materials, including: live stakes, live fascines, live branches, dormant post plantings, dead stout stakes, string, smooth wire, wooden stakes, and rebar. The construction sequence consists of driving wooden stakes vertically into the ground, then placing a 4 to 6 inch layer of living branches between the stakes, with their growing tips orientated towards the slope. Construction begins at the lowest point and proceeds up the bank. Subsequent layers of live branches and soil are added until the structure conforms to the existing slope.

Detailed information on the costs and maintenance requirements of the branch packing technique were not found.

Adaptability

The branch packing approach can be extended vertically under potential sea level rise scenarios; however, the overall fragility of the structure will make it highly susceptible to dislodgement under increasing flows and/or wave activity.

Advantages

Branch packing has many advantages over other engineered shore protection approaches, among them are:

- Branch packing is an inexpensive method of erosion prevention.
- The vegetation used in the branch packing approach grows quickly and offers immediate protection.
- As the plants grow, they become more efficient in reducing runoff and erosion.
- The branches can encourage sediment deposition along the shore.
- Branch packing is typically considered more aesthetically pleasing than other shoreline protection approaches.
- Branch packing does not disrupt access to the shoreline.

Disadvantages

Branch packing has several disadvantages compared to other engineered shore protection approaches, among them are:

- The branch packing technique is only effective at stabilizing small sections of shoreline.
- Unless the flow is diverted, branch packing is typically ineffective at sites that have been previously damaged by high velocity flow.
- Scouring can occur if branch packing is not flush with the existing bank.

Similar Techniques

Alternatives include: joint planting, live fascines, brush mattresses.

Live Fascines

Approach: Soft — Hard (rating 1 of 5)

Construction Cost: Low — High (rating 1 of 5)

Maintenance Cost: Low — High (rating 3 of 5)

Adaptability: Low — High (rating 3 of 5)

Description

Live fascines are composed of long bundles of branch cuttings that have been bound together. Once bound, they are placed, lengthwise, in shallow cylindrical trenches in rows along the bank. The live fascines are further supported by live and dead stakes. Adding live fascines to a stream bank can reduce erosion and sliding of the slope.

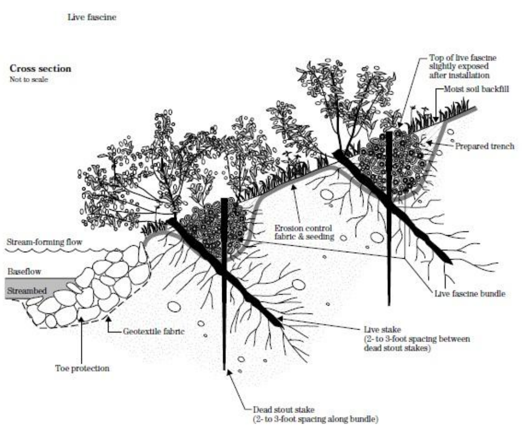


Figure 33: Typical live fascine cross-section (USDA, 1996).

The cuttings take root and sprout, so they must be placed on a bank which will keep the bundle wet throughout the growing season, but not exceed the plant's flood tolerance. Small to moderate perennial streams with a consistent water level are best suited for this type of stream bank stabilization project. Conditions at the site must be such that the roots can penetrate the earth, and reach the water table. As with most of the techniques involving live plants, the amount of exposure to sunlight and the type of soil at the site are also important.

Figure 34: Live fascine slope stabilization (Photo courtesy USDA - Robbin B. Sotir & Associates).

In the design of a live fascine project, the most important factor is the consideration of erosion at the toe and on the flanks of the installation. Water table elevation is also important as the live fascines must be able to access water during the growing season, yet not be so close that they remain submerged for long periods and die out. The type of vegetation utilized to form the live fascines will need to root easily. Young willow or shrub dogwood are options but plant choice will depend on the site conditions (USDA, 2000). Stability will be governed by stream flow conditions and shear stresses along the bank. Live fascines can withstand shear stresses of 1.25 to 3.1 lb/ft^2, and velocities of 6 to 8 ft/sec (Fischenrich, 2001).

Materials used to construct a live fascine bank stabilization project include: live branch cuttings, live pegs, dead stakes, mulch materials, twine, and backfill. Construction typically involves preparation of the live fascines and stakes prior to the commencement of the site work. Site work will typically involve the excavation of 1 foot wide by 1 foot deep trenches along the toe of the slope. A series of trenches will be excavated in rows along the entire bank. Long straw and/or annual grass can be planted between the rows for further erosion prevention. The bottom of the trenches should be layered with a geo-membrane or other erosion control fabric. The fascines are then placed in the trench, with live stakes placed on the downslope side of each fascine and dead stakes driven directly through the fascine.

The cost associated with a live fascine project is low to moderately expensive when compared to other engineered shore protection approaches. Material costs are generally low; however the approach is relatively labor intensive. Costs of between $10 and $40 per linear foot have been reported (NSP, 2006).

Once installed, live fascines provide immediate protection to the shore. The site should be examined after the first few floods, or at least twice a year, to ensure the project is performing up to expectations. In general, a live fascine project is considered successful if 70% of the plantings survive (filtrexx, 2009). The required maintenance will depend on stream velocity, flood frequency and other parameters. Any identified flanking or undercutting should be repaired immediately to ensure the continued stability of the project.

Adaptability

Live fascines are adaptable from the standpoint that they can always be extended up or down an existing slope to accommodate fluctuating water levels. However, dealing with die-off at the toe of the structure, and possibly the associated undermining and slumping, could prove difficult and costly. Live fascines also have a limited tolerance to waves and currents, so any increase in either will damage existing installations.

Advantages

Live fascines have several advantages over other engineered shore protection approaches, among them are:

- The approach does not cause a large amount of site disturbance.
- Once live fascines are installed, they provide immediate protection.
- Live fascines trap soil and facilitate drainage on the slope.
- Live fascines can enhance conditions for vegetation growth.
- Live fascines retain a natural appearance and are typically considered aesthetically pleasing.
- Live fascines allow access to the shoreline.

Disadvantages

Live fascines have several disadvantages compared to other engineered shore protection approaches, among them are:

- Live fascines are only effective on mildly sloping shallow shorelines.
- Live fascines are only effective for smaller streams.

Similar Techniques

Alternatives include: branch packing, joint planting, brush mattresses.

Coconut Fiber Rolls

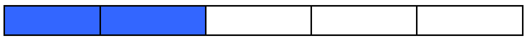
Approach

Soft Hard

Construction Cost

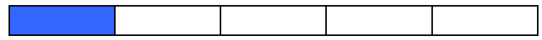
Low High

Maintenance Cost



Low High

Adaptability



Low High

Description

Coconut fiber (or coir) rolls are long, cylindrical structures, constructed from the fibers of a coconut. They are most commonly constructed with diameters on the order of 12 inches and lengths of between 18 and 24 inches. The rolls are typically held in place at the toe of a slope using stakes. Coconut fiber rolls are used to both prevent minor sloughing on the shore, and to impede shoreline erosion.

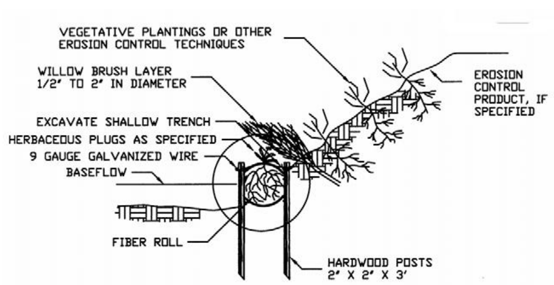


Figure 35: Typical coconut fiber roll installation (NYS DEC, 2005).

Design and Construction

Coconut fiber rolls are manufactured off-site and must be ordered prior to the commencement of site preparation. The rolls are normally placed at the toe of the slope at the stream-forming flow stage. Shear stresses related to the dominant flow and wave energy are the 2 dominant destabilizing forces which must be considered.

The first step in the construction process is the digging of a trench at the toe of the slope. The coconut fiber roll is then placed in the trench, with stakes utilized to stabilize it. Back fill is added upslope from the roll and vegetation is planted to provide additional protection. In some cases, vegetation is planted in to the roll itself.

Construction and material costs for the installation of coconut fiber logs has been estimated at $68/lf, on average, of which the cost for materials is approximately $11/lf (NSP, 2006).

Adaptability

The standard lifespan of a coconut fiber roll is 6 to ten years. The roll is flexible and can be formed to fit the curvature of the stream bank before placement. Once plants start growing within the fiber roll, the structure can become rooted into the soil. Once the roots take hold, the structure can no longer be easily relocated.

Figure 36: Close up of a coconut fiber roll (USDA, 1996).

Advantages

Coconut fiber rolls have several advantages over other engineered shore protection approaches, among them are:

- The coconut fiber rolls are flexible and can mold to the curvature of the stream bank.
- Coconut fiber rolls reinforce the stream bank without disturbing the existing habitat.
- Plant growth can develop in the fiber roll and the structure can become rooted into the system.
- Coconut fiber rolls are natural and eventually biodegrade.
- Coconut fiber rolls are typically considered more aesthetically pleasing than other types of engineered protection approaches.
- Coconut fiber rolls allow access to the shoreline.

Disadvantages

Coconut fiber rolls have several disadvantages compared to other engineered shore protection approaches, among them are:

- Coconut fiber rolls are susceptible to puncture by debris and/or ice.
- The rolls are manufactured and can be expensive.
- Coconut fiber rolls cannot be used at sites where flow velocities are high.

Similar Techniques

Alternatives include: geotextile rolls, tree revetments

Reed Clumps

Approach

Soft — Hard

Construction Cost

Low — High

Maintenance Cost

Low — High

Adaptability

Low — High

Description

Reed clumps are a natural shoreline erosion control methodology, frequently used to patch erosional hot spots. The technique involves placing individually wrapped root divisions in an excavated trench, then anchoring the system with stakes. The developed root mat stabilizes the soil by reinforcing the soil matrix, while at the same time removing excess moisture. Like many of the natural shore protection approaches, root clumps are dependent upon the natural growing conditions (light, water, etc.) for their establishment and survival. Typical species used in reed clump shoreline stabilization projects include arrowhead, cattail, and water iris.

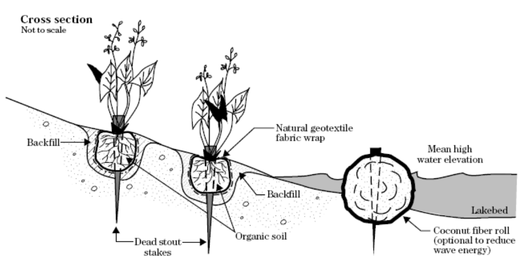


Figure 37: Typical reed clump project cross-section (USDA, 1996).

Design and Construction

There are few design guidelines outside of maximum shear stress limits to aid in the design of reed clump shoreline stabilization projects. Reed clumps have a shear stress tolerance of 0.21 lb/ft^2 (Browne, 2001).

Reed clumps typically range in diameter from 3 inches, up to 1 foot and can be prefabricated. The fabrication process consists of wrapping the individual clumps in a natural geotextile material and securing them with twine. The clumps can either be formed into rolls or placed directly in an excavated, geotextile fabric lined trench. The clumps are typically placed 12 to 18 inches apart, with soil used to backfill the trench. Dead stout stakes are used to secure the installation to the bank until the root system develops.

Reed clumps are inexpensive both in terms of material and labor cost. Detailed costs information on reed clumps was not found. Installation can proceed relatively quickly. Monitoring should be performed post construction to ensure that the vegetation becomes established. Maintenance is typically not required; however the relative simplicity and low cost of the approach makes replacing entire sections possible if necessary.

Figure 38: Close up of a reed clump shoreline stabilization project (MA CZM).

Adaptability

Reed clumps are generally considered a short term, temporary shore protection alternative. Because of the relatively low cost of materials and installation, the assumption is that an entire project can be replaced rapidly if required. Rising sea levels will cause die out of reed clumps placed close to the shoreline, however adding additional clumps higher up on the bank to compensate is straightforward.

Advantages

Reed clumps have several advantages over other engineered shore protection approaches, among them are:

- Reed clumps are flexible and can mold to the curvature of the stream bank.
- Reed clumps promote colonization by natural vegetation.
- Reed clumps can be installed quickly and economically.
- Reed clumps tend to accumulate sediment and strengthen with age.
- Individual clumps are not tied to one another so that if one dies out, it can be replaced without impacting the entire system.
- Reed clumps retain a natural appearance and are typically considered aesthetically pleasing.
- Reed clumps allow access to the shoreline.

Disadvantages

Reed clumps have several disadvantages compared to other engineered shore protection approaches, among them are:

- Reed clumps are susceptible to damage by waves, moderate currents, and debris and/or ice.
- Additional protection is frequently required while the root system develops.

Similar Techniques

Alternatives include: live fascines, branch packing, brush mattresses.

Dormant Post Planting

Approach

Soft — Hard

Construction Cost

Low — High

Maintenance Cost

Low — High

Adaptability

Low — High

Description

Dormant post planting refers to the technique of driving posts made from live, but dormant, medium- sized trees into the slope of a stream bank in a rectangular or triangular pattern to form a permeable barrier. The barrier works by slowing the flow in the stream during periods of high water, thereby limiting erosion and encouraging deposition along the shoreline. Once the roots of the posts are established the structure will also serve to stabilize the soil along the shore.

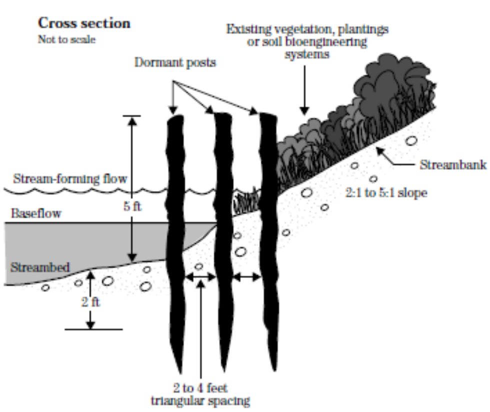


Figure 39: Typical cross-section of a dormant post planting project (USDA, 1996).

Design and Construction

One of the primary considerations when designing a dormant post planting shoreline stabilization project is groundwater level. Typically the ends of the posts need to have access to the water so that they will root. The remainder of the design process consists of choosing the number of rows of plantings desired, the configuration and placement of the plantings, and the selection of additional vegetation (if preferred). Typically, the length and diameter of the posts will be specified. Once an appropriate plant species is chosen, they are cut into 7 to 9 foot long pieces, and their ends are tapered for easy insertion into the soil. The posts are installed into the bank above the normal waterline, with half to 2/3 of their length being buried. An additional layer of posts may be placed in the bed, between mean low water and mean water, to limit erosion during low tide. The posts placed closest to the water should be capable of surviving long periods of time with their bases exposed to water. Typically a minimum of 2 rows of posts are planted in either a

HUDSON RIVER SUSTAINABLE SHORELINES

rectangular or triangular formation, with vegetation added post construction to further prevent slope erosion. Spacing between the posts is generally 2 to 4 feet. Stream curvature and stream velocity, will have the most significant impact on the success of a project.

Figure 40: Constructed dormant post planting project (Iowa DNR, 2006).

Dormant post planting is an inexpensive method for controlling erosion along stream banks. The cost per post ranges from $2 to $3, with stakes being placed 2 to 4 feet apart (NSP, 2006). Typically, a laborer can complete between 2.5 ft^2 and $13ft^2$ per hour. Posts that do not root should be removed or cut off near the bed to prevent them from becoming a hazard.

Adaptability

The dormant post planting approach is fairly adaptable. New posts and plantings can be added at any time.

Advantages

Dormant post planting has many advantages over other engineered shore protection approaches, among them are:

- Natural vegetation is an integral part of the approach.
- Natural methods are used to slow the flow of the stream.
- Sediment may be accumulated by the posts and plantings.
- Dormant posts do not restrict access to the shoreline.

Disadvantages

Dormant post planting has several disadvantages compared to other engineered shore protection approaches, among them are:

- Dormant post plantings are susceptible to damage by ice and/or debris.
- Dormant post planting has a limited range of applicability based on wave and stream flow conditions.
- Dormant posts are not typically considered aesthetically pleasing

Similar Techniques

Alternatives include: wave screens, jack fields, tree revetment.

Groins

Approach

Soft — Hard

Construction Cost

Low — High

Maintenance Cost

Low — High

Adaptability

Low — High

Description

Groins are finger shaped structures that project from the shoreline disrupting flows and transport occurring parallel to the shore. Groins (also referred to as groynes, spur dykes or wing dykes) have been used for centuries along shorelines to protect the bank and control channel meanders. Typically constructed in series, groins can be built perpendicular to the shoreline or angled either upstream or downstream, depending on the objective. Groins angled upstream or perpendicular to the flow are referred to as “deflecting” or “repelling” structures, as they deflect the current away from the bank. Groins angled downstream have the opposite effect, scouring areas close to the bank and maintaining a deep current close to shore. These structures are known as “attracting” groins. Typical angles of inclination are between 10° & 30° with respect to the bank. Depending on the application, the structures may either be permeable or impermeable, and are typically constructed of solid earth, timber, brush, branches, rocks, or some combination thereof.

Figure 41: Groin field along the Hudson (Image courtesy www.bing.com).

Groins function in 2 ways. First by slowing the current in the immediate vicinity of the bank, the erosional pressure is reduced. Second, as a consequence of the water velocity decreasing, suspended material falls out, creating a nearshore platform or buildup of sediment. This platform can have the added benefit that it acts as a buffer to oncoming waves, causing the energy to dissipate on the platform before reaching the shoreline. In estuaries, where flow reversals occur, angled structures can act as both deflecting and attracting structures depending on the direction of the tidal flow. Groins must be able to extend far enough into the water to catch the desired amount of sediment.

Design and Construction

When designing a groin; the dimensions, profile, spacing, active forces and the sizes of the structural members must all be considered. As mentioned in the previous section groins are typically constructed in groups. Depending on the application, the spacing between individual groins is generally on the order of 1 – 2.5 times the length of the individual groins. The groins should be rooted into the shore to prevent flanking during storms or flood conditions. Side slopes on river groin structures are typically between 2 and 3 (horizontal) to 1 (vertical).

In order for a groin to remain effective, it must be monitored and if necessary maintained. When designed and constructed correctly, maintenance on groins is typically minimal. However, if improperly designed, maintenance activities can range from the replacement of individual pieces or structural members to, in rare cases, the replacement of the entire structure. The cost of a groin stabilization project varies widely depending on the number and spacing of the groins, their geometry, and the material used to construct them. Estimates of between $1,200/lf and $5,000/lf have appeared in the literature (NCDENR, 2010).

Adaptability

Groins are not naturally adaptable, but may be modified manually by raising the crest elevation, extending the structure, or reinforcing weak sections. Although relatively straightforward, this procedure may be costly as heavy machinery will be required.

Advantages

Groins have several advantages over other engineered shore protection approaches, among them are:

- If sediment accumulates, the created nearshore flat serves as an additional shore protection feature.
- If a nearshore flat develops, it is often suitable for vegetation, and additional intertidal habitat may be created.
- Groins typically do not impede access to the water.

Disadvantages

Groins have several disadvantages compared to other engineered shore protection approaches, among them are:

- Groins may be viewed as an eyesore by some.
- Groins disrupt the natural currents and long shore sediment transport.
- Groins are susceptible to damage from ice and/or debris.
- Groin construction involves building out into the water way which may be prohibited by regulations designed to prevent infilling.

Similar Techniques

Alternatives may include: stream barbs.

Stream Barbs

Approach		Construction Cost	
Soft	Hard	Low	High

Maintenance Cost		Adaptability	
Low	High	Low	High

Description

Stream barbs are similar to groins and function in much the same way; however they tend to be lower in relief and less obtrusive. Stream barbs are constructed as low rock sills that project out from a stream bank and serve to redirect flow away from an eroding shoreline. Similar to groins, they are normally placed in groups of 3 or more and run parallel to each other.

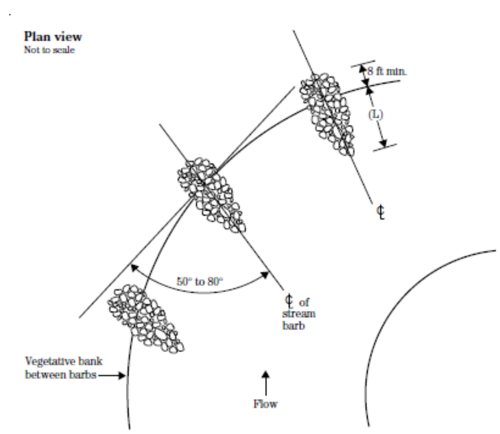


Figure 42: Plan view of a stream barb installation (USDA, 1996).

Design and Construction

Some of the important factors that need to be taken into consideration when designing a stream barb field are: the length, width, and height of the individual barbs, the spacing between the barbs, and the angle between the barbs and the upstream bank.

Figure 43: Field installation of stream barbs (USDA, 1996).

Stream barb construction typically begins at the shoreline and continues stream-ward. Typical stream barb dimensions are 2 feet high and not less than 8 to 10 feet wide (USDA, 2000). When installed in series, spacing between the barbs generally ranges from 4 to 5 times the length of the individual barbs. Common angles of inclination with respect to the upstream bank are between 50 and 80 degrees.

Due to their more modest size, stream barbs are generally cheaper to construct than groins. Average costs tend to be on the low side of those associated with groins, ranging anywhere from $300 to $12,000 per stream barb (DCR, 2004). In addition to the lower material costs associated with using smaller stones, labor costs are also reduced, due to a reduced reliance on heavy machinery.

Maintenance requirements for stream barbs tend to be minimal.

Adaptability

Similar to groins, stream barbs are fairly adaptable in that the elevation or lateral extent of the structure can be modified with relative ease. Also reinforcement through the addition of larger armor stone and/or the introduction of additional toe protection measures is relatively straightforward.

Advantages

Stream barbs have several advantages over other engineered shore protection approaches, among them are:

- Stream barbs can be more cost-effective and less intrusive than groins.
- Stream barbs can improve fish habitat.
- Stream barbs can be utilized in conjunction with other ecologically enhanced shoreline stabilization approaches.
- Stream barbs can trap sediment.
- Stream barb dimensions can be modified relatively easily.
- Stream barbs do not disrupt access to the shoreline.

Disadvantages

Stream barbs have several disadvantages compared to other engineered shore protection approaches, among them are:

- The applicability of stream barbs is limited to smaller streams.
- Although cheaper than groins, stream barbs can be expensive compared to many of the other techniques.
- The resulting jagged shoreline edge may not be acceptable from an aesthetic stand point.

Similar Techniques

Alternatives may include: groins.

Wave Screens

Approach

Soft — Hard

Construction Cost

Low — High

Maintenance Cost

Low — High

Adaptability

Low — High

Description

Wave screens are structures placed offshore with the primary purpose of reducing wave energy in their lee; however oriented perpendicular to the dominant flow direction(s), they can also be used to reduce current velocities. Wave screens, or permeable pile breakwaters, consist of a combination of horizontal, vertical, and/or diagonal slats affixed to rigid vertical and/or horizontal supports. Energy dissipation at a wave screen is primarily a function of the porosity of the structure, which is governed by the spacing of the slats. The permeability of the screens allows the structure to attenuate waves, while minimizing any negative environmental impacts.

Wave screens are predominantly constructed perpendicular to the dominant wave direction; however if the design calls for the structures to also reduce current energy, the design may be optimized such that the structures may be angled relative to the dominant wave and current conditions. In this case, care must be taken to ensure that navigation is not impacted by the structure.

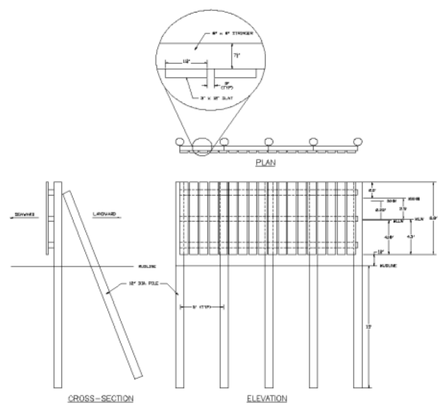


Figure 44: Typical wave screen cross-section (Herrington and Delorme, 2004).

Design and Construction

The design of wave screens will vary depending on site conditions. The performance of a wave screen is governed by the amount of wave energy which is transmitted through the structure. Typically, a transmission coefficient, k_t, which is defined as the ratio of the transmitted wave height to the incident wave height, is used to evaluate the effectiveness of a given structure. A value of

k_t = 1 indicates complete wave transmission (and therefore an ineffective structure) and a value of k_t = 0 indicates complete dissipation (or reflection). The percent reduction in wave energy behind a wave screen is given by:

$$E_{\%r} = \left(1 - \frac{H_t^2}{H_i^2}\right) x100$$

Where H_t is the transmitted wave height and H_i is the incident wave height.

Wave screens can be constructed of steel, concrete, or timber, although timber is most common. Construction consists of driving piles into the sea bed, then affixing a horizontal plate, or cap, and the required slats. Embedment of the support structure may involve significant effort depending on the subsurface conditions. The screens themselves can often be prefabricated off-site, shipped, and installed with minimal effort.

Compared to the other shoreline protection approaches, wave screens typically have a moderate cost associated with them. Wave screens typically require minimal maintenance unless the support structure itself is damaged by floating debris, ice, or wayward ships. More common maintenance consists of the replacement of individual slats which have become damaged. Under most conditions, a structure life of up to 20 years is possible.

Adaptability

Wave screens are fairly adaptable structures. The degree of energy dissipation can be modified relatively easily by changing the porosity of the structure through the addition or subtraction of slats. In addition, the wave screen structure itself can be raised or lowered by altering the way in which it is fixed to the support structure. Adding and/or removing support structures will, however, require more effort.

Advantages

Wave screens have several advantages over other engineered shore protection approaches, among them are:

- The slotted design reduces wave and/or current energy while still allowing for an exchange of water.
- Repair costs are typically minimal.
- The calm region in the lee of a wave screen may encourage sediment deposition and serve as habitat.
- Wave screens are durable structures that have minimal operation and maintenance costs.
- Wave screens have a minimal footprint.
- Wave screens do not impede access to the shoreline.
- Wave screens are submerged and only visible during low tide, resulting in minimal aestetic impact.

Disadvantages

Wave screens have several disadvantages compared to other engineered shore protection approaches, among them are:

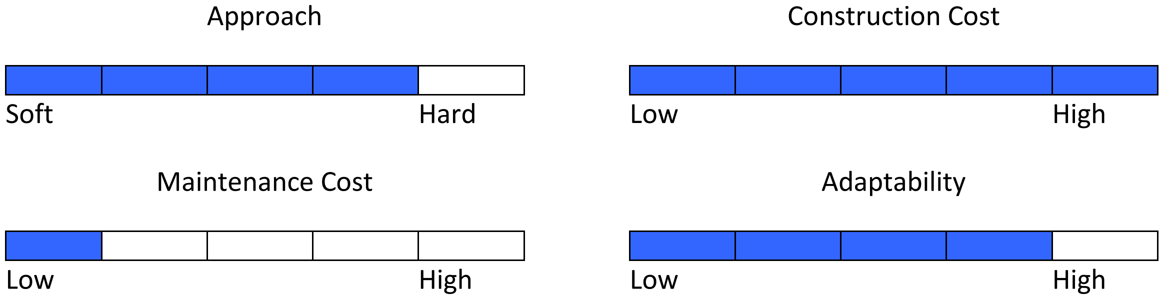
- Wave screens are susceptible to damage by ice and debris.

- Wave screens have higher design and construction costs than most of the soft approaches.
- The effectiveness of wave screens at reducing currents is not well documented.

Similar Techniques

Alternatives include: breakwaters, floating breakwaters, living breakwaters, sills.

Breakwater



Description

Breakwaters are shore parallel structures designed to reduce the amount of wave energy reaching the area behind them. This is achieved through a combination of dissipation, reflection and refraction of the incoming wave field. The area in which wave heights are reduced is called the shadow zone. Sediment is frequently deposited in the lee of a breakwater due to a combination of factors including calm water being more favorable for sedimentation, and wave refraction which results in a convergence of sediment transport.

Breakwaters along sheltered shorelines tend to be much smaller than those along open coasts. Typical construction materials include rubble, concrete, and wood, although recently, living organisms such as oysters and mussels have been utilized to create living breakwaters (see separate section). Breakwaters may be shore attached, or stand alone and can either be continuous or segmented.

Design and Construction

Breakwater design consists of determining the stable armor unit size, as well as defining the structure geometry. Armor stone is typically selected using a formula such as the Hudson formula (see *Revetments*), which relates the stone size to the incident wave height. Critical areas where scour and flanking are likely to occur may require additional design consideration. Factors such as limiting wave run-up, overtopping, reflection, and cost will influence structure geometry.

Breakwater construction requires a solid base to prevent settlement, therefore subsurface conditions should be checked and supplementary measures employed to ensure a solid foundation. A filter fabric is typically used to limit scour and prevent the washout of fine material from beneath the structure. Gravel layers may be placed on top of the filter layer to form the core of the structure. Along sheltered shorelines a single or double layer of armor stones would be placed over the base layer(s) to provide the ultimate resistance to the dominant wave and current forces.

Breakwaters on open coasts tend to be rather expensive when compared to other shoreline stabilization techniques, due to the larger stone sizes required and the cost to transport and install them. In sheltered waters, this cost is reduced substantially due to the smaller stone sizes required and the relative ease of placement in shallower water. When designed correctly, breakwaters require minimal maintenance and can function safely even after one or more armor unit has been shifted. Regular inspections should be scheduled in order to ensure structural integrity.

Adaptability

Breakwaters are typically substantial structures with a limited capacity to adapt to a changing environment. Displacement of individual armor units typically does not result in structural failure; however it may result in a loss of effectiveness. Similarly, rising water levels may result in increased overtopping and wave transmission. Increasing the crest elevation through the addition of material to reduce overtopping and transmission is typically possible, but expensive.

Advantages

Breakwaters have several advantages over other engineered shore protection approaches, among them are:

- Breakwaters can be designed to withstand significant wave activity.
- Breakwaters can generally sustain minor damage and remain effective.
- Breakwaters do not interrupt the natural shoreline, and frequently create aquatic habitat.
- Maintenance requirements are minimal and structures are robust.

Disadvantages

Breakwaters have several disadvantages compared to other engineered shore protection approaches, among them are:

- Breakwaters can be expensive compared to other shoreline stabilization techniques.
- Breakwaters are subject to settling, scour and flanking.
- Since they are constructed some distance from the shoreline breakwaters may pose a hazard to navigation.
- Breakwaters are constructed offshore and typically have a fairly large footprint, which may disturb existing benthic vegetation.
- Breakwaters have an unnatural appearance and may not be considered aesthetically pleasing.

Similar Techniques

Alternatives include: wave screens, floating breakwaters, living breakwaters, sills.

Floating Breakwater

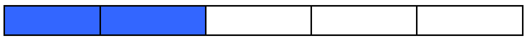
Approach

Soft Hard

Construction Cost

Low High

Maintenance Cost



Low High

Adaptability

Low High

Description

A floating breakwater is a special type of breakwater that floats within the water column, but performs the same function as a traditional breakwater. Floating breakwaters are typically shore parallel structures (or more accurately, wave perpendicular structures) that protect the shoreline by reducing the amount of wave energy in the shadow zone created between it and the shoreline. On open coasts, sediment often accumulates within this low energy region.

Floating breakwaters can and have been constructed from many different types of buoyant materials including tires, logs, timber, hollow concrete modules, and heavy duty plastic. Floating breakwaters must be securely anchored to the bottom to withstand the often substantial wave and current induced forces.

Design and Construction

There are several important parameters which must be set during the design of a floating breakwater. The length and width of the structure must be determined along with its free board (crest elevation above the water line), its distance offshore and the corresponding water depth. All of these parameters play a role in determining the degree of wave energy reduction behind the structure. This in turn will determine the impact on the shoreline behind the structure. A second important consideration is the way in which the breakwater will be fixed to the bottom. Waves and currents can induce significant forces; therefore the anchoring mechanism must be robust.

Floating breakwaters vary in cost depending on the type of material used in construction. A variety of proprietary designs exist; however readily available material (tires, logs, etc) can also be used.

Maintenance requirements for floating breakwaters are typically modest. As is the case for most shore protection structures, inspections should be performed after major storms to ensure the structure is still securely anchored, and to clear any accumulated debris.

Adaptability

Floating breakwaters can readily adapt to water level changes; however their effectiveness may be reduced as the local water depth increases. Depending on the structure design, it may be possible to tune the structure by modifying the tension in the anchoring mechanism to achieve the desired wave height reduction.

Advantages

Floating breakwaters have several advantages over other engineered shore protection approaches, among them are:

- Floating breakwaters can be constructed from many different types of materials.
- Floating breakwaters can be used where the water is too deep for fixed breakwaters.
- Floating breakwaters have a minimal impact on water exchange since they do not extend to the bottom.
- Floating breakwaters can be effective at sites with large tidal ranges.
- Floating breakwaters do not disrupt access to the shoreline.

Disadvantages

Floating breakwaters have several disadvantages compared to other engineered shore protection approaches, among them are:

- Floating breakwaters are less effective against long period (> 5 sec) waves.
- Floating breakwaters may be considered aesthetically unappealing.
- Debris can collect along floating breakwaters requiring periodic maintenance and removal.
- Floating breakwaters require more maintenance than fixed breakwaters.
- Sediment accumulation behind a floating breakwater can result in down drift erosion.
- Heavy construction equipment is necessary for construction.
- Floating breakwaters may be considered an eyesore to some.

Similar Techniques

Alternatives include: living reef breakwaters, breakwaters, sills, wave screens.

Living Reef Breakwater

Approach

Soft — Hard

Construction Cost

Low — High

Maintenance Cost

Low — High

Adaptability

Low — High

Description

Recently, living reef breakwaters have become a popular choice for protecting shorelines in sheltered areas. These submerged aquatic habitats are most common in the southern United States and functionally work in a similar manner to constructed breakwaters or sills. In the northeast, living breakwaters are typically constructed by using oysters or mussels as the dominant species. Both species can grow rapidly near estuarine river mouths and in near shore areas. Many of the natural beds have disappeared either through natural or anthropogenic causes, so current projects typically begin in a controlled environment. Once an adequate substrate is provided, the larvae of the species naturally seek out a hard surface to settle upon. Over time as generations of the species continue to grow large reef structures are formed. As they develop, the living reefs serve as critical aquatic habitat while also acting as a natural breakwater. Frequently deposition occurs and vegetation takes root in the quiescent areas created behind the reefs.

Figure 45: Established oyster reef (Chesapeake Bay Program).

Design and Construction

Since the technique is relatively new, and relies predominantly on natural processes, limited design guidance exists in the literature. One of the most important considerations is water quality. Both oyster and mussel reef systems require specific conditions in order for the species to thrive and become self-sustaining. Regulatory issues must be carefully considered. One recent project in New Jersey was terminated after it was determined that the illegal harvesting of oysters used to create a breakwater in impaired waters posed a threat to the New Jersey seafood industry.

Construction of living reef breakwaters typically consists of "jump starting" the growth by providing a suitable substrate for new oysters and mussels to colonize. Once the process takes hold, nature takes over and the reef can be allowed to develop naturally.

Detailed cost information on living reef breakwaters was not found.

Figure 46: Established mussel reef (Partnership for the Delaware Estuary).

Adaptability

Living reef breakwaters have some capacity to adapt to changing conditions; however they are particularly sensitive to changes in water quality. As long as parameters such as water temperature, salinity, and turbidity, remain within the range required by the constituent species, living reefs can adapt naturally to slow changes in water level through natural growth/migration. If the changes are rapid however, they may outpace the ability of the natural system to respond.

Advantages

Living reef breakwaters have several advantages over other engineered shore protection approaches, among them are:

- Living reef breakwaters serve important habitat functions.
- Living reef breakwaters can encourage natural deposition and vegetation growth.
- Living reef breakwaters can improve water quality by filtering out toxins.
- Living reef breakwaters allow access to the shoreline.
- Living reef breakwaters are typically considered to be aesthetically pleasing.

Disadvantages

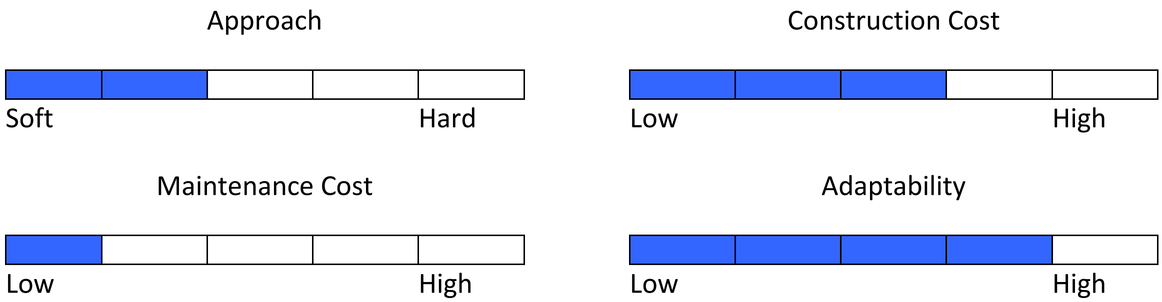
Living reef breakwaters have several disadvantages compared to other engineered shore protection approaches, among them are:

- Living reef breakwaters are susceptible to damage by debris and/or ice.
- Living reef breakwaters are extremely sensitive to changes in water quality.
- Regulatory requirements for living reef breakwaters can be strict.

Similar Techniques

Alternatives include: floating breakwaters, breakwaters, sills.

Sills



Description

Sills are low elevation structures that are placed in the water parallel to the shoreline. Similar in function to a breakwater, sills help reduce wave energy and bank erosion. The calm area generated behind a sill allows sand and sediment to build up between the structure and the shoreline, ultimately raising the elevation of the bottom creating a perched beach. In some cases the area between the sill and the shoreline is prefilled to hasten the development of a perched beach or is planted to create a marsh. The resulting perched beach or marsh combined with the sill structure causes waves to break farther away from the shore and dissipate some of their energy before reaching the eroding shoreline.

Design and Construction

Sills can either be placed above or below the mean water line. Increasing the sill height can result in significantly more protection, but at the expense of reducing the overtopping which is important for water exchange. Lower crest heights also make accessing deeper water easier for wildlife; however they may also create a navigation hazard unless marked properly. Sills are typically constructed in areas with small-moderate tidal ranges such that position of the crest with respect to the waterline remains relatively constant. Sills can be constructed of many different types of materials; however rock is most common. Stone size, sill placement and geometry, are all governed by the desired wave height reduction and shoreline profile behind the structure.

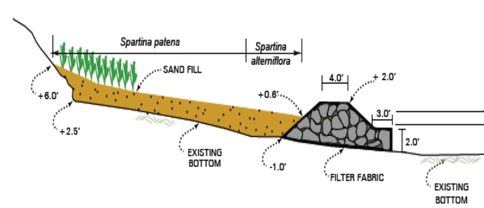


Figure 47: Typical sill/perched beach cross-section (Jefferson Paterson Park & Museum).

Figure 48: Sill and marsh shore protection project. (Jefferson Paterson Park & Museum).

Adaptability

Sills are more readily adaptable than many other structures. Because smaller stone sizes and a less exacting profile are required for sills, modifying the structure is relatively straightforward. In terms of natural adaptability, if sedimentation occurs behind the sill, and vegetation takes hold, the sill/perched beach system will have some capacity to respond naturally to slow changes in the environment.

Advantages

Sills have several advantages over other engineered shore protection approaches, among them are:

- The shoreline retains many of its natural characteristics.
- Sills can be submerged and therefore do not affect the view of the stream bank.
- Sills can be constructed from a range of different materials, depending on what is locally available.
- Once a sill is constructed, vegetation to create a marsh can be planted between the structure and the shoreline, further increasing its ecological function.
- Sills are readily adaptable.
- Sills do not impede access to the shoreline.

Disadvantages

Sills have several disadvantages compared to other engineered shore protection approaches, among them are:

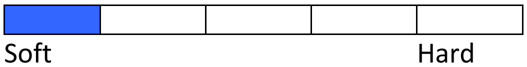
- Sills can produce dangerous slopes and abrupt changes in depth.
- If sediment and sand is trapped behind the sill, erosion can result on downdrift shorelines.
- Sills are susceptible to damage by ice and/or debris.
- Submerged sills can represent a navigation hazard.
- Submerged sills may impact nearshore submerged aquatic vegetation beds.
- Sills are typically limited to sites with a small-moderate tidal range.

Similar Techniques

Alternatives may include: breakwaters, floating breakwaters, living breakwaters, wave screens.

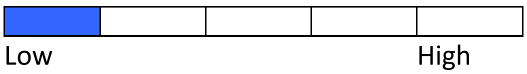
Artificial Vegetation

Approach

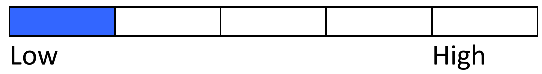


Construction Cost

Maintenance Cost



Adaptability



Description

Artificial vegetation is a shoreline stabilization approach that attempts to mimic the beneficial impact of natural submerged aquatic vegetation. The artificial vegetation can be installed on river beds and in flood plains to reduce wave and current energy, and to trap sediment. Artificial vegetation is often used in place of natural vegetation in areas where the growing conditions are unfavorable. Plastic materials such as polypropylene are used to create the individual fronds, which are typically installed in strips. A mesh made of material such as iron reinforcing rods is used to secure the fronds to the bed. The polypropylene strips float freely but provide frictional resistance to the flow, slowing currents and dissipating wave energy. If the energy is reduced enough, suspended sediment falls out of the water column, raising the local bed elevation.

Design and Construction

Projects are designed based on the objective of dissipating wave and current energy. As an example, a project was constructed in 1991, to stabilize a shipwreck and trap sediment at a site off the coast of Australia. Artificial seagrass mats were installed in a configuration that called for 24 strips, each 1.6 cm wide by 90 cm, 120 cm or 150 cm long. The resulting mats were weighed down by railway iron, and a total of 42 mats were deployed. The approximate cost of the project was $100,000.

Figure 49: Installation and subsequent sediment trapping by artificial seagrass mats in Australia (Keough, 2010).

Historically, artificial vegetation projects constructed in high energy environments have been plagued by an inability to withstand the destructive forces. As a result individual fronds and even entire mats have been washed away. As mats become torn, they lose their effectiveness in trapping sediments, and may need to be repaired or replaced.

Detailed cost information on artificial vegetation installation and maintenance was not found.

Adaptability

Once installed, artificial vegetation mats can be moved, rearranged, or removed relatively easily. As sea levels rise, increased water depths may begin to limit the effectiveness of the mats. Since the mats are entirely man made, they have no ability to adapt to the changing conditions.

Advantages

Artificial vegetation has many advantages over other engineered shore protection approaches, among them are:

- Artificial vegetation can serve as refuge for aquatic species.
- Artificial vegetation is easy and cost effective to install.
- Artificial vegetation can be used in waters incapable of supporting natural vegetation.
- Artificial vegetation protects the bank from erosion due to waves and currents.
- Artificial vegetation is submerged and has a minimal impact on the aesthetics of a site.
- Artificial vegetation does not restrict access to the shoreline.

Disadvantages

Artificial vegetation has several disadvantages compared to other engineered shore protection approaches, among them are:

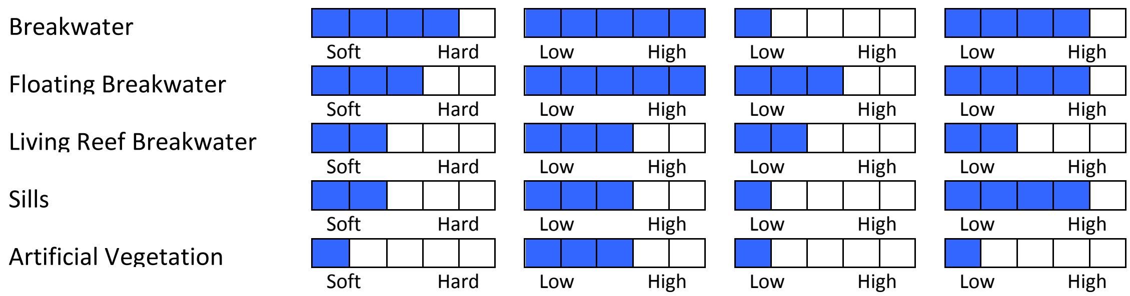
- Applications are limited to low energy environments.
- Damaged installations may wash up on shorelines or out to sea and become a hazard.
- Artificial vegetation is susceptible to damage from ice and debris flows.

Similar Techniques

Alternatives include: natural vegetation, living breakwaters, floating breakwaters, wave screens.

Summary

	Approach (Soft – Hard)	Construction Cost (Low – High)	Maintenance Cost (Low – High)	Adaptability (Low – High)
Bulkhead	■■■■■	■■■□□	■□□□□	■□□□□
Gabions	■■■■□	■■■□□	■■■□□	■■■■□
Revetments	■■■■□	■■■■■	■■□□□	■■■■□
Rootwad Revetment	■■■□□	■■■■□	■■■□□	■■□□□
Tree Revetment	■■■□□	■■■□□	■■■□□	■■□□□
Rip-rap	■■■□□	■■□□□	■□□□□	■■■■■
Jack Fields	■■■□□	■■■□□	■■□□□	■■■□□
Green Walls	■■■■□	■■■■□	■■□□□	■□□□□
Timber Cribbing	■■■■□	■■■□□	■■■□□	■■■□□
Live Crib Walls	■■■□□	■■■■□	■■■■□	■■■□□
Levees	■■■□□	■■■■■	■■□□□	■□□□□
Geotextile Roll	■■■□□	■■■□□	■■□□□	■□□□□
Vegetated Geogrid	■■■□□	■■■■□	■■■□□	■■■□□
Live Stake	■■□□□	■□□□□	■■■□□	■■■■□
Brush Mattress	■□□□□	■□□□□	■■■□□	■■■□□
Branch Packing	■□□□□	■□□□□	■■□□□	■■■□□
Live Fascines	■□□□□	■□□□□	■■■□□	■■■□□
Coconut Fiber Rolls	■□□□□	■□□□□	■■□□□	■□□□□
Reed Clumps	■□□□□	■□□□□	■■■□□	■■■■□
Dormant Post Planting	■■□□□	■■□□□	■■■□□	■■■□□
Groins	■■■■□	■■■■□	■■□□□	■■■□□
Stream Barbs	■■■□□	■■■□□	■■□□□	■■■□□
Wave Screens	■■■□□	■■■□□	■■□□□	■■■■□


Breakwater
Floating Breakwater
Living Reef Breakwater
Sills
Artificial Vegetation
Soft
Hard
Low
High

Glossary of Terms

Artificial Vegetation - Artificial vegetation works identically to natural vegetation by decreasing wave/current energy at the shoreline, reducing erosional pressure, and encouraging sediment deposition. Unlike natural vegetation, artificial vegetation can be used in most areas, regardless of water quality/growth conditions.

Bio/Green Walls - Walls or barriers that incorporate living plants or stakes into their design. This term is used to refer to a collection of approaches, all of which attempt to soften a traditionally hard edge through the introduction of ecologically friendly modifications.

Bulkhead – Traditionally, the most common shoreline hardening technique used to protect vulnerable and eroding shorelines. Used at the base of bluffs or steep shorelines, bulkheads are vertical walls which prevent the loss of soil and the further erosion of the shore.

Branch Packing - Branch packing consists of segments of compacted back fill separated by layers of live branches. This approach is a relatively inexpensive technique used to fill in missing areas of the shoreline, which also provides a succession of barriers to prevent further erosion and scouring.

Breakwater - A breakwater is a structure that is built within a water body to reduce wave energy and erosion in its lee. Types include rubble mound breakwaters, floating breakwaters, and living breakwaters.

Brush Layering - Brush layering consists of placing branch cuttings along a sloped shoreline to serve as a covering and protection against erosion. Brush layering may also stabilize the shoreline by capturing sediment.

Brush Mattress - A brush mattress is a combination of live stakes, live fascines, and branch cuttings that form a protective cover on an eroding shoreline that acts to protect the shoreline against oncoming waves, capture sediment during floods, and enhance habitat for vegetation.

Coconut Fiber Rolls - Coconut fiber rolls are long cylindrical structures composed of coconut husks that are laid parallel to the shore. These structures are intended to help prevent minor slides while encouraging sediment deposition and plant growth.

Crib walls, rock cribs or cribbing - Box-like arrangement of interlocking logs, timbers, precast concrete or plastic structural members are used to form a "crib", which is then filled with broken rock.

Dormant Post Planting - Dormant post are installed into an eroded bank at or above the waterline. Rootable vegetative material is added to form a permeable revetment along the shoreline.

Gabions - Gabions are wire mesh containers that can be used to form retaining walls, sea walls, channel linings or revetments. The containers are generally filled with cobbles or crushed rock and stacked to form flexible, permeable, monolithic structures. Gabions are particularly useful when the stones that must be used would normally be too small to be used without being washed away.

Geotextile Rolls – Cylindrical sand filled geotextile tubes which are placed along the shoreline to reduce erosion. The rolls may either be exposed, or designed such that they remain hidden within the dune/bank only becoming "active" during storms.

Groins - Groins are fingerlike shaped barriers that are built perpendicular or at an angle to the shoreline that have the effect of creating pockets of reduced currents. These lower currents have the two-fold effect of reducing the erosional pressure on the shoreline, while also encouraging sediment deposition.

Jacks / Jack Fields - Jacks are individual structures constructed out of wood, concrete or steel, which are placed in rows called jack fields parallel to the shoreline. They serve to prevent erosion by trapping debris and sediment.

Live Crib Wall - A live crib wall is a 3-dimensional, box-like chamber that is constructed out of untreated log or timber and is placed at the streams base flow level. The interior of the structure has alternating layers of soil and/or fill material and live branches that are meant to root themselves inside the box and eventually extend into the slope of the bank.

Live Fascines - Live fascines are cylindrical bundles of branch cuttings that are placed in trenches on sloping shorelines with the purpose of dissipating wave energy at the shoreline. The Latin term for "bundle of sticks" is fascine.

Live Stakes / Joint Planting - Joint planting consists of adding live stakes or vegetation into open spaces or joints in an already existing or to be constructed rip-rap, or rock covered slope. As the stakes mature, they create a living root mat beneath the structure that binds the soil and prevents additional soil erosion.

Living Breakwater - A breakwater constructed of living (or once living) organisms such as oysters or mussels that reduce shoreline erosion by dissipating incident wave energy.

Living Shorelines – A general term utilized to encompass many of the techniques discussed in this document. Living shorelines generally include some living element, i.e. plants, however they can also include materials such as rock, downed trees, etc.

Log and Rootwad Revetment – A natural revetment constructed of logs, rootwads, boulders and other natural materials that once established serves both as a habitat for insects and water organisms and as a shoreline stabilization structure.

Perched Beaches - A perched beach is when section of shoreline is artificial filled in with natural sediments. Typically a sill is built to retain the fill material above the natural bottom.

Reed Clumps - Reed clumps are individually wrapped root systems that are placed in trenches and staked down on the water's edge. These individual plant systems create a root mat that reinforces and retains soil at the shoreline.

Revetments - Revetments are shore attached structures built to protect natural sloping shorelines against wave energy and erosion. Revetments use large rocks (or other materials) on the front of a dune or stream bank to dissipate wave and/or current energy to prevent further recession of the backshore.

Rip Rap - A rip rap slope functions similar to a revetment; however they are constructed from small rocks, cobble and gravel, instead of large stones. Rip rap structures armor the shoreline by providing a base layer, which is stable under normal stream flow conditions.

Sills – Low-profile, shore parallel mounds placed offshore with the purpose of retaining sediment and elevating the nearshore profile. Sills can be constructed of natural (stone, soil, etc) or synthetic (geotextile rolls) materials and are typically used as part of a perched beach system.

Soil Bioengineering - Soil bioengineering is a generic term used to describe the processes by which living plant materials are used as a structural component to harden the shoreline against erosion.

Stream Barbs - Stream barbs are low sitting rock piles that protrude out from the shore and are constructed to redirect the flow of a stream away from the eroding shores. Stream barbs function similarly to river groins; however are typically more modest in nature.

Timber cribbing - Box-like arrangement of interlocking logs or timbers are used to form a "crib", which is then filled with broken rock.

Tree Revetment - A tree revetment is an engineered slope with trees planted along the shoreline in such a manner as to function like a revetment. Tree revetments are typically very efficient in capturing soil, protecting the shore, and creating a natural habitat.

Wattling - Wattling refers to the process by which sticks, twigs and/or branches are twisted or intertwined to form an interwoven structure or fabric. The resulting mat can be placed and anchored to the shoreface to prevent further erosion.

Wave Screens - Wave screens are offshore structures designed to reduce wave (primarily) and current energy at the shoreline. Typically placed perpendicular to the dominant wave direction, these structures consist of horizontal, vertical and diagonal slats affixed to structural support members. The amount of energy dissipation is directly related to the porosity of the structure.

Vegetated Geogrid - A vegetated geogrid is a terraced wall consisting of alternating horizontal layers of soil wrapped in synthetic fabric and live branch cuttings. The live branch cuttings serve to both reduce the wave energy and shear stress on the wall and bind the geogrid together, as the vegetation matures.

Vegetative Planting - Vegetative planting refers to the establishment of eelgrass or other subaqueous vegetation near the shoreline. The vegetation naturally dissipates wave and current energy, reducing the erosional stress on the shoreline, and encouraging sediment deposition.

Vegetated Rock Gabions - Vegetated rock gabions are rock gabions that have had vegetation incorporated into their design. Live branches are placed between each layer of gabions and root inside the baskets as well as in the soil behind the structure, greatly increasing their structural integrity, and softening the edge.

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