A Property Owner’s Guide

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LOW COST SHORE PROTECTION

…A Property Owner's Guide

AN INTRODUCTION TO SHORELINE EROSION

This report is intended for property owners whose land is located on sheltered waters protected from direct action of open ocean waves. As a reader, you may be personally concerned about some aspect of shore protection because your house or cottage is threatened by continued erosion or a sandy beach you once enjoyed has disappeared. Whatever your personal circumstances, it is probably small comfort to know that your plight is shared by many others.

In trying to solve your problem, you may have sought the advice of others or observed the means they have used to combat erosion problems. Or, you may have been approached by a local firm trying to sell either construction services or some shore protection device. While such resources may sometimes achieve satisfactory results, you and a majority of others are probably reading this because you have been unable to solve your problems and have suffered substantial capital losses in the process. If such is the case, then this report is for you.

LOW COST SHORE PROTECTION

In distinguishing between "low cost" and "cheap", one should remember that practically any method of shore protection, if properly implemented, is expensive. While no specific price range applicable to all places, or valid for any length of time, can be defined, for our purposes low cost protection includes those methods within the financial means of most landowners and commensurate with the value of their property. While personal financial resources and the costs of the methods described in this report vary significantly, landowners who are serious about protecting their property should be able to find a suitable (and affordable) solution.

ORIENTATION AND OVERVIEW

Shorelines are areas of unending conflict among the natural forces in wind, water, and land. Atmospheric disturbances generate winds, which in turn cause waves that move through the, water until breaking at the shore with a great release of energy. If the shore is composed of loose sediments such as sands, gravels, or silts, there are washed in the direction of the waves' advance. If replaced by an equal quantity of beach material moving from other areas, the shore remains stable, a condition described as "dynamic equilibrium"; constant movement but with no change of volume. However, if less material replaces what has been washed away, the volume of material in the region decreases and the shore erodes, leading to the loss of beaches, recession of bluffs, or other dramatic landscape changes at the water's edge.

In fact, shorelines have undergone change since time immemorial. Man, with his drive to control the shore for his own ends, often loses sight of this essential fact. The results have been catastrophic for many property owners, both private and public. The situation is not hopeless, however. A variety of alternatives are available to property owners. Most of them require careful judgment and often-considerable investment to correctly implement. Therefore, it is important to understand the principal forces at work before acting. By considering the shoreline processes in your general area, rather than the immediate problem at your property, you develop a broader perspective that enables you to make a more informed decision.

This report has four main objectives: to acquaint you with the actual shoreline processes at work; to explain available alternatives; to review the entire decision process leading to an appropriate choice from among available options; and to identify sources of additional help.

Discussion is limited to sheltered waters where low cost, owner-implemented shore protection can be successful. Application to open coast sites experiencing the full force of oceanic waves is not intended, and those who do so should realize the considerable chances for failure. *Applications of low cost methods to* open *coast sites are definitely not recommended.*

The U. S. Army Corps of Engineers has produced this report as a public service. While the methods described herein have been successfully utilized to slow or arrest erosion problems, no method is successful in all cases. Therefore, the government cannot guarantee that any method described in this report will be successful in your case.

SHORELINE PROCESSES

The first step in solving an erosion problem is understanding the processes and forces at work. Without such basic knowledge, any solutions are likely to be misguided and inappropriate. The following sections present basic information about shoreline processes as a foundation for subsequent discussion of specific alternatives.

Wave Action

While waves are always present on the open coast, they are not continuous in sheltered waters. Nonetheless, they are still the major cause of erosion in these areas. Understanding how wave action influences shoreline processes requires familiarity with several basic characteristics of waves, including height, period, and length (Figure 1). Wave height is the vertical distance between the wave crest and trough. Wave period is the time (in seconds) it takes two successive wave crests to pass a stationary point, and wavelength is the distance between successive crests.

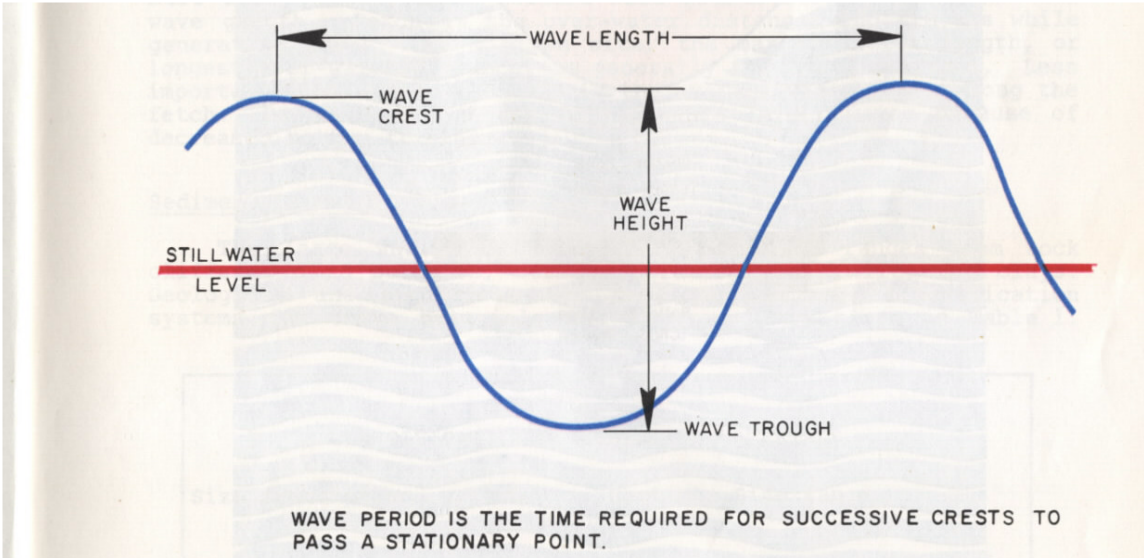


Figure 1 Characteristics of Waves

As a wave moves through deep water (depths greater than one-half the wavelength), these basic characteristics do not change. When a wave approaches shallower water near the shore, the period remains constant, the forward speed and wavelength decrease, and the height slightly increases. The wave begins to "feel the bottom", and its profile steepens as its gently rolling shape sharpens to a series of pointed crests with intervening flat troughs. When the wave height is about 80 percent of the water depth, the wave can no longer steepen and it is forced to break. For example, a 5-foot high wave breaks in a water depth of about 6.5 feet.

Important wave properties are demonstrated when a train (series) of regular waves meets a solid barrier, such as an offshore breakwater (Figure 2). Wave diffraction occurs when the waves pass the barrier, and wave energy is transferred along the crests to the quiet area in the shadow of the structure. Diffraction causes waves to form in the shadow zone that are smaller than waves in the adjacent unprotected zones.

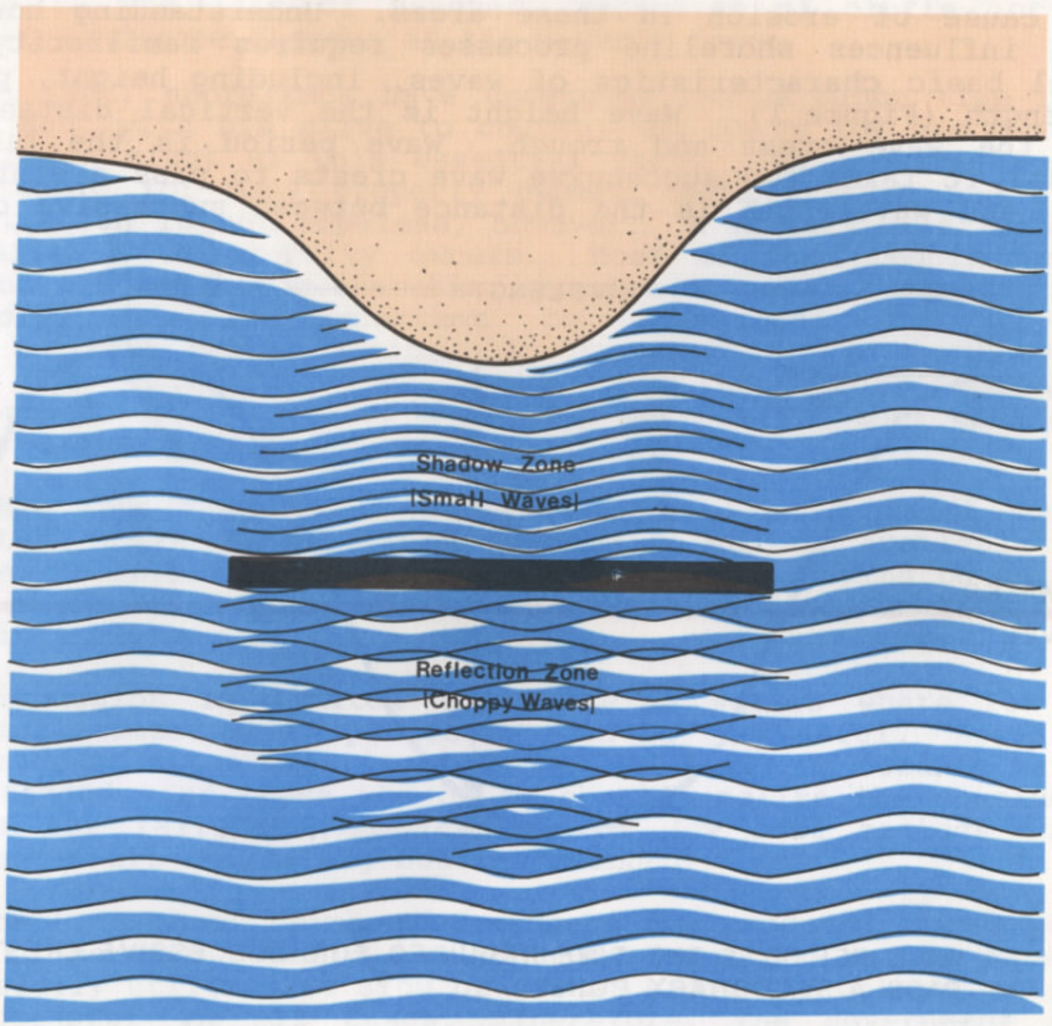


Figure 2 Wave Diffraction and Reflection

Wave reflection occurs on the offshore side of the breakwater. While waves passing the structure are diffracted, the portions striking the breakwater are reflected like a billiard ball from a cushion. If the structure is a smooth vertical wall, the reflection is nearly perfect, and if the wave crests are parallel with the breakwater, the reflected and incoming waves will reinforce each other to form standing waves, which are twice as high as the incoming waves and may cause considerable scouring of the bottom. If the waves approach at an angle, no standing waves will form, but the resulting water surface will be confused and choppy because the reflected waves will cross the path of the incoming waves. This could also contribute to erosion and scouring of the bottom.

The final important wave characteristic is evident when waves break either on a beach or structure. The uprush of water after breaking is called runup and it expends the wave's remaining energy. The runup height depends on the roughness and steepness of the structure or beach and the characteristics of the wave. Increased roughness reduces runup.

The actual process of wave generation depends on several important factors, the most prominent being wind, although pleasure craft and large vessels also cause significant wave activity in the form of wakes. The height of wind-driven waves depends on the wind speed, duration, fetch length, and water depth. Wind speed is obviously important, but duration (length of time the wind blows) must also be considered because wind action must be sustained for wave growth. Fetch is the over-water distance wind travels while generating waves. At a given site, the maximum fetch length, or longest over-water distance, is generally the most important. Less important, but still critical, is the average water depth along the fetch. Deeper water allows for somewhat larger waves because of decreased bottom friction.

Sediment Transport

The large variety of shoreline materials ranges from rock cliffs down to boulders, cobbles, gravel, sand, silt, and clays. Geologists and engineers have developed several classification systems for these materials and an example is given in Table 1.

Table 1

CLASSIFICATION OF SHORELINE MATERIALS

Size Description	Particle Size Range	
	(Inches)	(mm)
Boulder	greater than 10	greater than 256
Cobble	10 - 3	256 – 76
Gravel	3 - 0.18	76 -4.8
Sand	0.18 - 0.003	4.8 -0.07
Silt	0.003 - 0.00015	0.07 -0.004
Clay	smaller than 0.00015	smaller than 0.004

Rock characterizes cliff shorelines, such as the northern California shore. Boulders are often present at the base of such cliffs because of rock fracturing and weathering. Cobbles and gravels are prevalent beach materials in the Pacific Northwest, Alaska, and the Great Lakes area. Sand, the most common shoreline material, is found in virtually all coastal areas. Silts and clays generally occur on bluff shorelines or marshes, such as along the Great Lakes and various bays.

Littoral (shoreline) materials are derived from the deterioration and erosion of coastal bluffs and cliffs, the weathering of rock materials found inland and transported to the shore by rivers and streams, the disintegration of shells, coral or algae to form carbonate materials, and the production of organic material (generally peat) by coastal marshes and wetlands.

Failure or erosion of a bluff causes material to be deposited at the base. Waves sort this material and carry the fine-grained silts and clays far offshore where they settle to the bottom. The original deposit is eventually reduced to sand and gravel fractions, which form a beach. Eventually, if no other littoral material is carried to the site by waves, even the sand and fine gravel will disappear down the coast or offshore, leaving only coarse gravel behind. However, a new supply of material may be deposited on the beach by a fresh failure of the bluff, and the process begins again. In many cases, therefore, littoral materials comprising beaches are often derived from erosion of the shoreline itself.

Rivers and streams that carry sediments eroded from mountains, forests, and fields are a second source of littoral materials, particularly during heavy rains. This material is usually not coarser than sand because gravel and cobbles are not easily transported by most streams. Once the material arrives at the shore, the wave-sorting process begins; the sand particles move to the beaches while silts and clays move offshore.

Coral reefs, shells, and other plant or animal matter are a third material source. They gradually break and weather into carbonate sands, which are, for instance, the primary component of beaches south of Palm Beach, Florida. Swamps, marshes, and coastal wetlands produce peats and other organic matter. Too light to remain in place under continued wave action, they are ultimately washed offshore unless stabilized.

These littoral materials are transported along the shore by waves (Figure 3). As waves approach the shore, they move to progressively shallower water where they bend or refract until finally breaking at an angle to the beach. The broken wave creates considerable turbulence, lifting bottom materials into suspension and carrying them up the beach slope in the general direction of wave approach. A short distance up the beach, the motion reverses direction back down the beach slope. In this case, the downrush does not follow the path of the advancing wave but instead, moves down the slope in response to gravity. The next wave again carries the material upslope, repeating the process, so that each advancing wave and the resulting downrush move material along the beach. This is the downdrift direction. As long as waves approach from the same direction, the alongshore transport direction remains the same.

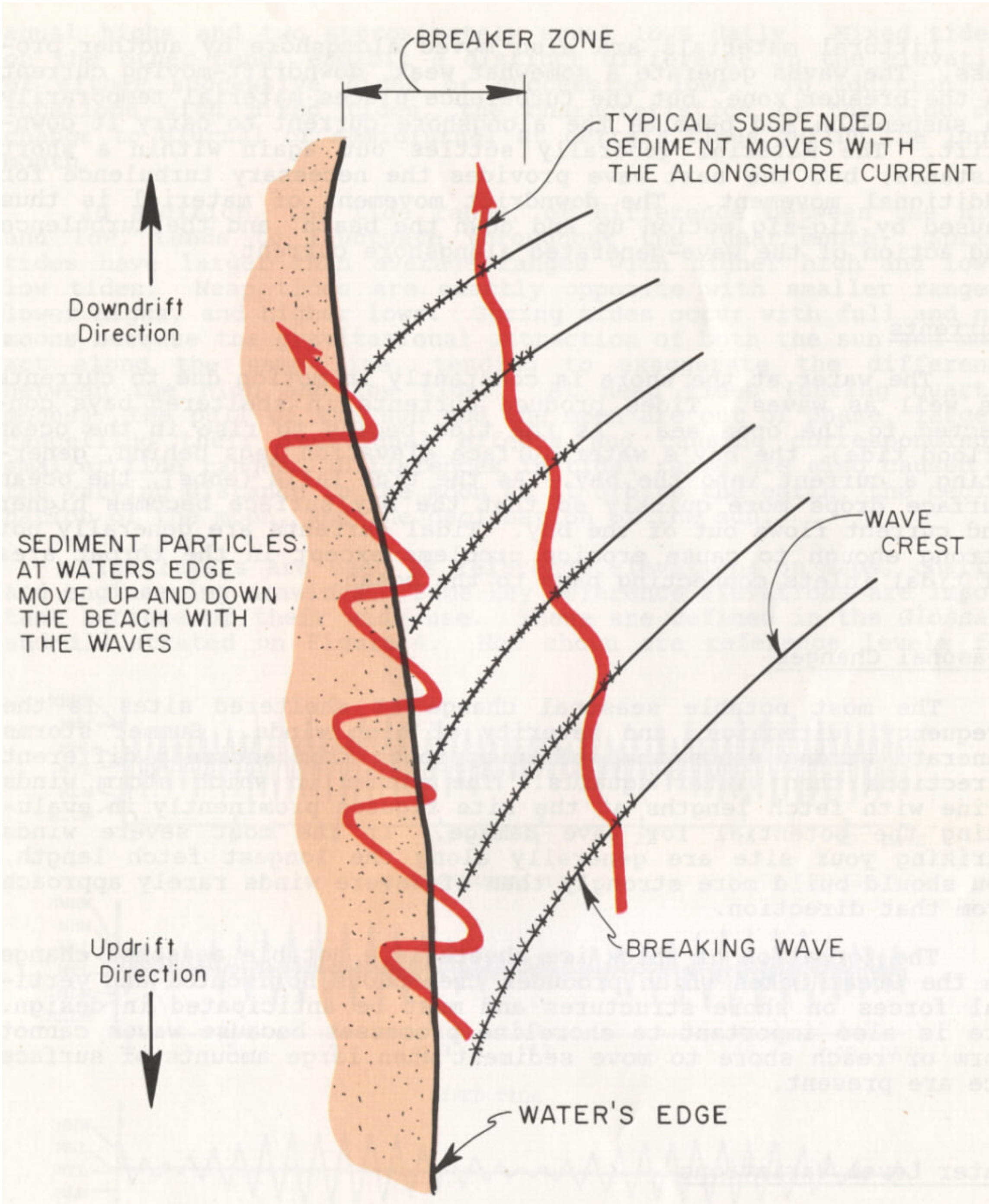


Figure 3 Alongshore Sediment Transport

Littoral materials are also moved alongshore by another process. The waves generate a somewhat weak, downdrift-moving current in the breaker zone, but the turbulence places material temporarily in suspension and permits the alongshore current to carry it downdrift. The material generally settles out again within a short distance, but the next wave provides the necessary turbulence for additional movement. The downdrift movement of material is thus caused by zig-zig motion up and down the beach, and the turbulence and action of the wave-generated alongshore current.

Currents

The water at the shore is constantly in motion due to currents as well as waves. Tides produce currents in sheltered bays connected to the open sea. As the tide begins to rise in the ocean (flood tide), the bay's water surface elevation lags behind, generating a current into the bay. As the tide falls (ebbs), the ocean surface drops more quickly so that the bay surface becomes higher and current flows out of the bay. Tidal currents are generally not strong enough to cause erosion problems except -in the throat area of tidal inlets connecting bays to the ocean.

Seasonal Changes

The most notable seasonal change at sheltered sites is the frequency, direction, and severity of high winds. Summer storms generate strong winds that often approach from entirely different directions than winter squalls. The manner in which storm winds align with fetch lengths at the site figures prominently in evaluating the potential for wave damage. I f the most severe winds striking your site are generally along the longest fetch length, you should build more strongly than if severe winds rarely approach from that direction.

The formation of thick ice sheets is a notable seasonal change on the Great Lakes which produces tremendous horizontal and vertical forces on shore structures and must be anticipated in design. Ice is also important to shoreline processes because waves cannot form or reach shore to move sediment when large amounts of surface ice are present.

Water Level Variations

The stillwater level, or the water level with no waves present, changes because of astronomical tides, storms, and periodic lake level variations.

Tides are generated in ocean basins by the gravitational attraction between the earth, moon, and sun, and are classified as diurnal, semidiurnal, or mixed. Diurnal tides have only one high and low each day, while semidiurnal tides have two approximately equal highs and two approximately equal lows daily. Mixed tides, on the other hand, exhibit a distinct difference in the elevation of either successive highs or successive lows. In addition, at locations with mixed tides, the characteristics of the tide may change to diurnal or semidiurnal at certain times during the lunar month.

In addition, the tide range, or difference between the high and low, tends to fluctuate throughout the lunar month. Spring tides have larger than average ranges with higher high and lower low tides. Neap tides are exactly opposite with smaller ranges, lower highs, and higher lows. Spring tides occur with full and new moons because the gravitational attraction of both the sun and moon act along the same line, tending to exaggerate the difference between the high and low tides. At neap tides (during quarter moons), the pull of the sun and the moon are out of phase, largely canceling their individual effects and causing correspondingly smaller tide ranges. Differences in tidal range are also caused by the varying distances to the moon as it orbits the earth, the declination of the moon, and the declination of the sun.

Tide levels are used as reference elevations on maps, charts, and engineering drawings. Some key reference elevations are important because of their wide use. These are defined in the *Glossary* and illustrated on Figure 4. Not shown are reference levels for the Great Lakes where all water levels are ultimately referenced to the International Great Lakes Datum (IGLD) (see *Glossary).* Each lake, however, has a designated chart datum [Low Water Datum (LWD)] based on the IGLD. Depths and water levels are commonly given as feet above or below the chart datum for that lake.

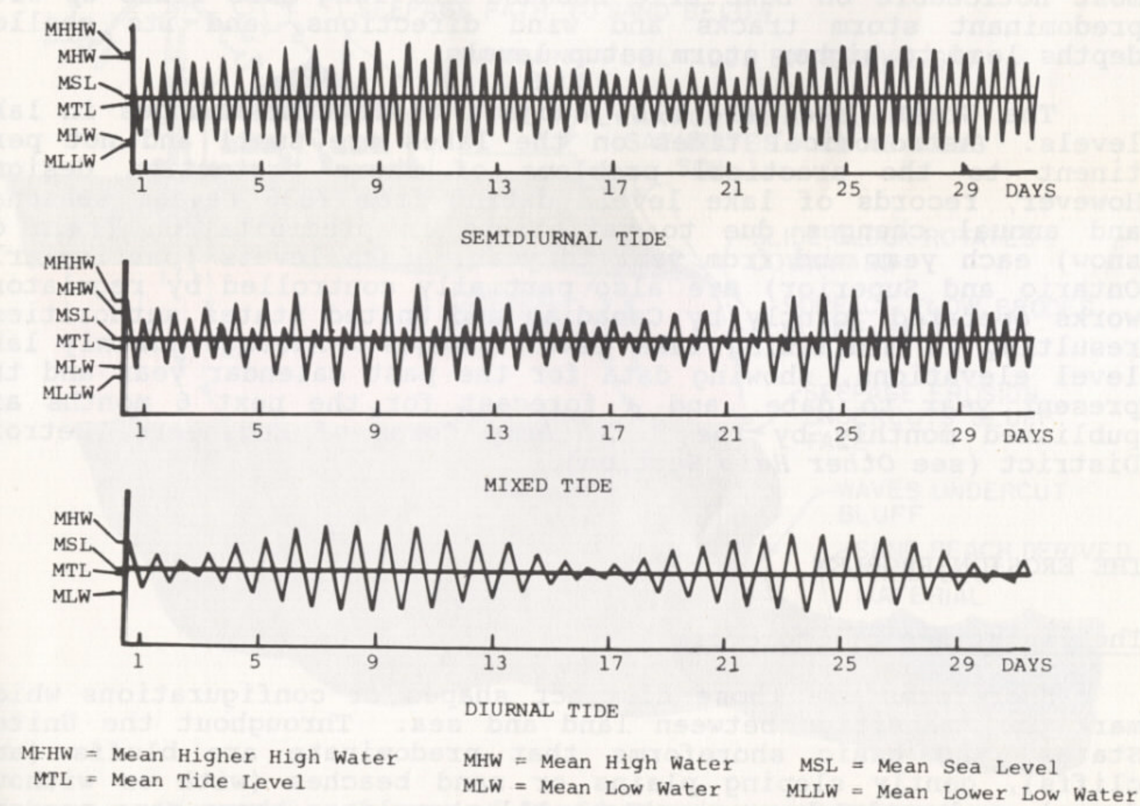


Figure 4 Tidal Reference Elevations

Storms tend to increase the Stillwater level because of atmospheric pressure differences, high winds, and the effects of large breaking waves. Atmospheric pressure differences across a large water body can commonly cause one- or two-foot rises in the water level in the lower pressure area. The stress on the water's surface from high storm winds also tends to drive the water on shore to above normal levels (storm setup) until balanced by the tendency for the water to f low back to a lower level. Finally, these same high winds generate large storm waves. As these break, they tend to pile the water on shore higher, raising the stillwater level further.

Enclosed water bodies (such as the Great Lakes) can also respond to storm forces by seiching. This occurs when storm winds force the water surface higher at the downwind end of the lake. As the storm passes, this pent-up water is released, causing it to move toward the opposite end of the lake, resulting in oscillations as in a bathtub. This back and forth movement (seiching) will noticeably continue for several cycles. Seiching effects are most noticeable on Lake Erie because its long axis lines up with predominant storm tracks and wind directions, and its shallow depths lead to higher storm setup levels.

The Great Lakes are also subject to regular changes in lake levels. Astronomical tides on the lakes are small and not pertinent to the practical problems of shore protection design. However, records of lake levels dating from 1836 reveal seasonal and annual changes due to variations in precipitation (rain or snow) each year and from year to year. Lake levels (particularly Ontario and Superior) are also partially controlled by regulatory works operated jointly by Canadian and United States authorities, resulting in minimizing lake level changes. Average monthly lake level elevations, showing data for the past calendar year and the present year to date, and a forecast for the next 6 months are published monthly by the U. S. Army Corps of Engineers, Detroit District (see *Other Help* Section).

THE EROSION PROBLEM

The Importance of Shoreform

Shoreforms are those distinct shapes or configurations, which mark the transition between land and sea. Throughout the United States, the basic shoreforms that predominate are bluffs (and cliffs), gently sloping plains or sand beaches (with or without dunes), and wetlands or marshes. All shorelines share some predominant feature with at least one of these shoreforms. Of course, a shoreline may combine two or even all three of these forms. For instance, a shoreline may be a high bluff with a sand beach at the base, or a gently sloping plain fronted by a marsh. In that case, one must consider the interaction of these features with the erosive forces and then single out the most important for further study.

Bluff and Cliff Shorelines. *Cliff* shorelines consist primarily of relatively resistant rock. On the other hand, *bluff* shorelines are composed of such sediments as clays, sands, and gravels, or erodible rock. Cliffs rarely suffer severe or sudden erosion but undergo slow, steady retreat under wave action over a long period. Such shorelines cannot be protected at a low cost because available alternatives would not be as durable as the rock forming the cliff.

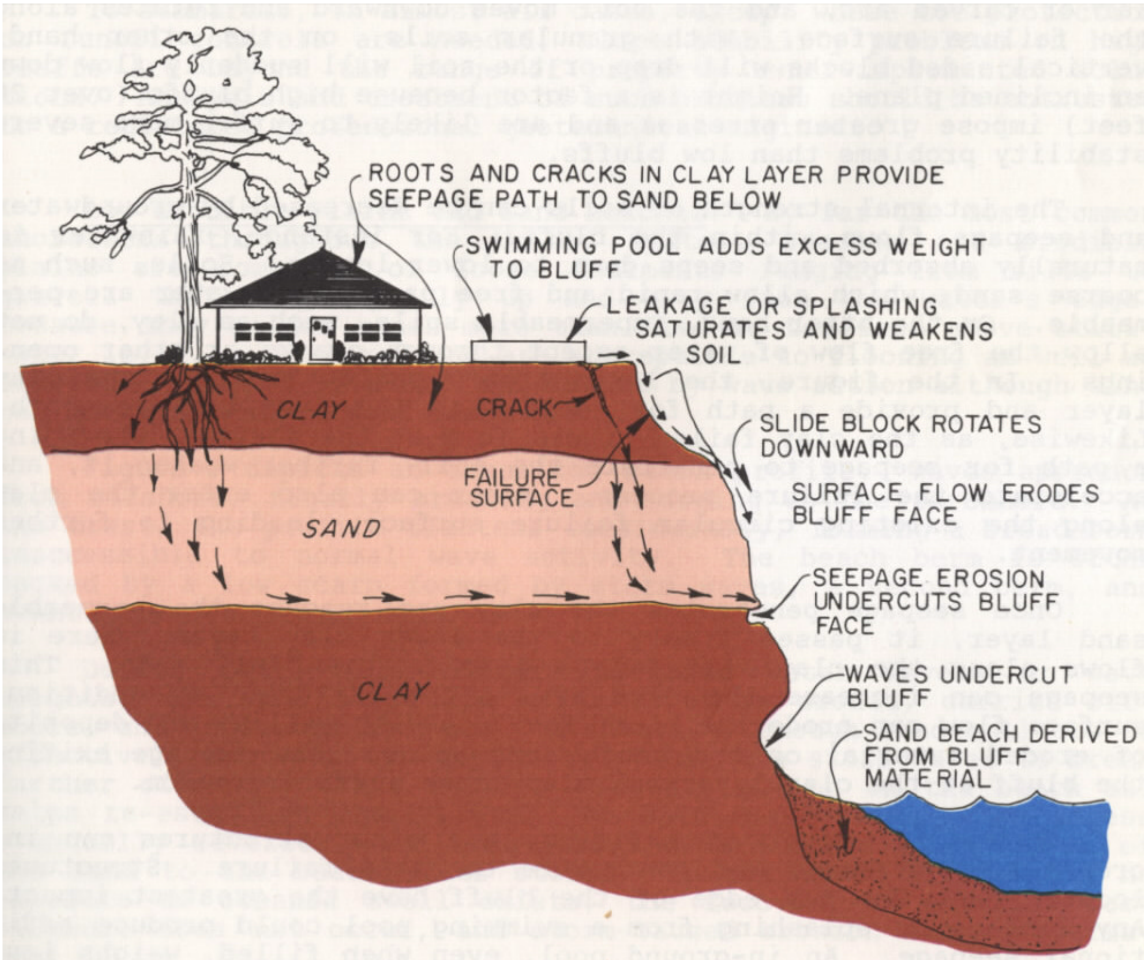


Figure 5 Causes of Bluff Erosion and Retreat

Erosion problems are most common along bluff shorelines where a variety of forces and processes act together (Figure 5). The most prevalent causes of bluff erosion and recession are scour at the toe (base) by waves and instability of the bluff materials themselves. Because slope stability problems are difficult to analyze correctly without expertise in geotechnical engineering, they are beyond the scope of this report. A brief discussion of factors affecting slope stability and how to recognize potential problems is presented below. If you believe your property is endangered by a slope stability problem, you should contact a registered professional geotechnical engineer.

As the figure illustrates, a typical bluff often consists of different soils deposited in distinct layers, such as clay, sand, silt, or glacial till. (Glacial till contains a mixture of particle sizes and is common throughout the Great Lakes region.) These soils do not permanently stand at a vertical face, but form an angled slope that varies with the soil and groundwater conditions. This slope forms following a series of failures whose nature depends on whether the soil is cohesive (clay) or granular (sand, silt, gravel, etc.). Cohesive soils generally slide along a circular or curved arc, and the soil moves downward and rotates along the failure surface. With granular soils, on the other hand, vertical sided blocks will drop or the soil will suddenly flow down an inclined plane. Height is a factor because high bluffs (over 20 feet) impose greater stresses and are likely to suffer more severe stability problems than low bluffs.

The internal strength of soils can be decreased by groundwater and seepage flows within the bluff. For instance, rainwater is naturally absorbed and seeps down to lower levels. Soils, such as coarse sand, which allow rapid and free passage of water are permeable. On the other hand, impermeable soils, such as clay, do not allow the free flow of water except through cracks or other openings. In the figure, the large tree's roots penetrate the clay layer and provide a path for seepage to the sand layer beneath. Likewise, as the clay fails, cracks form at the surface, providing a path for seepage to penetrate the soil, further weaken it, and accelerate the failure process. Water can also enter the clay along the existing circular failure surface, leading to further movement.

Once seepage penetrates the clay and reaches the permeable sand layer, it passes freely to the lower clay layer, where it flows along the clay's surface and exits the bluff face. This seepage can increase the risk of a slope failure. In addition, surface flow can erode the bluff face, causing gullies and deposits of eroded material on the beach area below. The seepage exiting the bluff at the clay layer can also cause surface erosion.

The added weight of buildings and other structures can increase soil stresses and contribute to slope failure. Structures located near the top edge of the bluff have the greatest impact. Any leakage or splashing from a swimming pool could produce additional seepage. An in-ground pool, even when filled, weighs less than the soil it replaces and, therefore, would not adversely affect stability, provided no leakage exists and splashing is minimized.

The other major cause of bluff shoreline problems is wave action at the toe. Figure 5 shows a beach formed from fallen materials. As described earlier, waves sort this material, moving clays and silts offshore while leaving sands and gravels for the beach. However during severe wave activity, waves can reach the bluff itself and erode or undercut the toe. Only a short time may be needed under such conditions for the entire bluff face to fail.

The slope of the offshore bottom is important to wave action on a bluff. If the offshore slopes are steep, deep water is closer to shore, more severe wave activity is possible, and maintenance of a protective beach is more difficult. Flat offshore slopes, on the other hand, result in shallower water near the shoreline, which inhibits heavy wave action at the bluff and provides for potentially better protective beaches.

To summarize, in almost all cases, except where toe protection or runoff controls are needed, slope stability problems on high bluffs are beyond the range of property owner-implemented solutions. Analysis and treatment of such problems should be entrusted to a registered professional geotechnical engineer.

<u>Low Erodible Plains and Sand Beaches</u>. By far the most common shoreforms throughout the United States, beaches and erodible plains are composed of loose sediments ranging from silts to gravels that slope gently up and away from the water's edge. Because they seldom reach more than five to ten feet above stillwater level, such shorelines are susceptible to flooding as well as erosion. Erosion problems are caused by wave action although wind can be important in some cases.

Figure 6 depicts an idealized beach profile. Waves approach from offshore, finally breaking and surging up the foreshore. At the crest, the profile flattens considerably, forming a broad berm unaccessible to normal wave activity. The beach berm is often backed by a low scarp formed by storm waves, a second berm, and eventually a bluff or dune.

During periods of either increased water levels or wave heights, the sand above low water level is eroded, carried offshore, and deposited in a bar. Eventually, enough sand collects to effectively decrease the depths and cause the storm waves to break farther offshore. This reduces the wave action on the beach and helps re-establish equilibrium. At open coast sites, the process eventually reverses, and long-period swells again return most of the sand to the beach after storms. At sheltered sites where no exposure to oceanic swell exists, the recovery of material lost offshore does not occur, and storm-caused erosion becomes permanent.

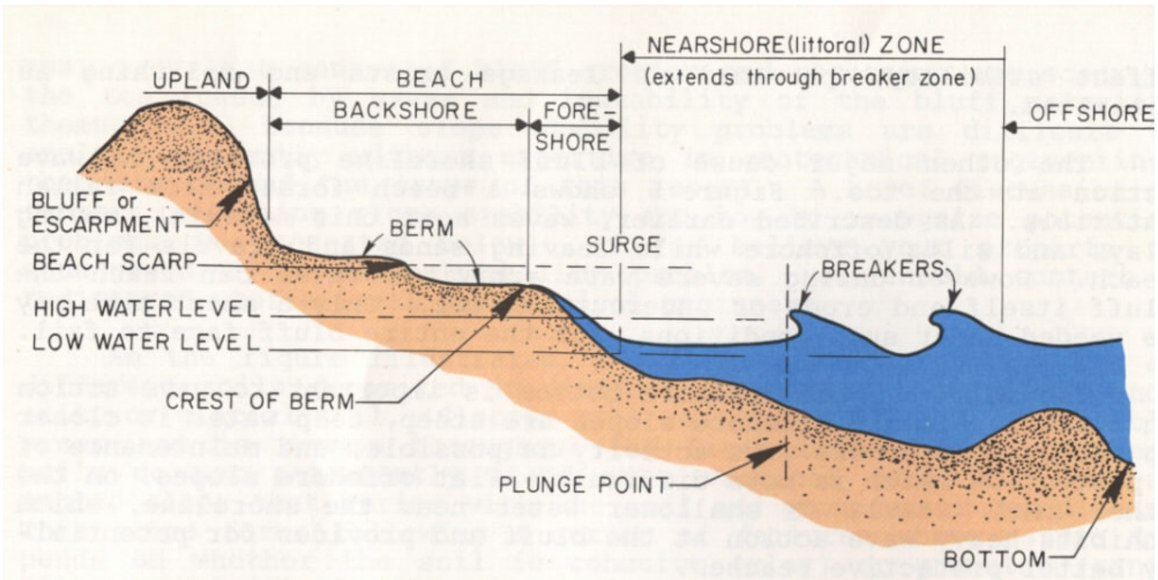


Figure 6 An Idealized Beach Profile [U.S. Army Corps of Engineers (1977a)]

Wetlands. Wetlands usually occur in combination with sand beaches or low erodible plains. Construction in a wetland will generally require a federal, state, and possibly, a local permit (These will be described later.) Under federal regulations, we lands are defined as:

> "Those areas that are inundated or saturated by surface groundwater at a frequency and duration sufficient to support and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated so conditions. Wetlands generally include swamps, marshes, bog and similar areas" [U. S. Arm Corps of Engineers (1977b)]

Marsh plants are primarily herbaceous (lacking woody stems), such as grasses, sedges, and rushes. The species present depend o location and whether the marsh is low (regularly flooded) or high (irregularly flooded).

Until recently, marshes were regularly drained and filled for new development or agriculture. They are now recognized as vita links in the food chain of the aquatic community and for their capacity to absorb water-borne pollutants. However, more importantly, they provide shore protection by absorbing the energy o approaching waves and trapping sediment carried along by currents

The shore protection qualities of marshes are particularly important when they provide a buffer zone in front of a sandy beach or other area vulnerable to erosion. While not providing full protection, they effectively diminish wave energy and allow for less massive and costly back protection.

The Causes of Erosion

Wave Action. This is the most obvious cause of erosion.

Littoral Material Supply. Waves keep the littoral materials constantly moving downdrift. As long as equal quantities of material are transported from the updrift direction, the shoreline remains stable. when the updrift supply exceeds the amount moving downdrift, the shoreline accretes (material accumulates). However, when the updrift supply is deficient, the shoreline retreats.

Much of the littoral material supplied to shorelines results from updrift erosion. Therefore, if large amounts of updrift shoreline are suddenly protected, material is lost to the littoral system. This decreases the supply to the downdrift shores, resulting in erosion problems unless they are also protected.

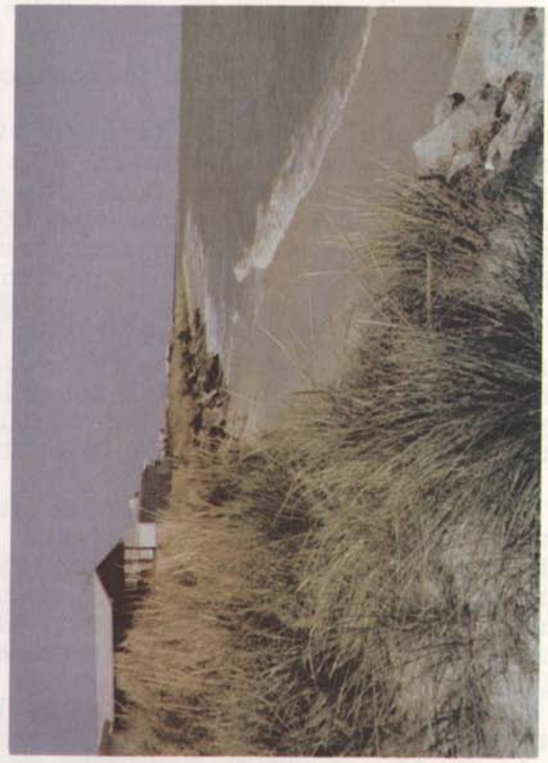
Determining the transport direction is necessary in some cases but usually difficult because of variation in wave directions throughout the year. Summer winds (and waves) may be primarily from one direction, while winter storm winds may come from an entirely different quadrant. When winds and waves change direction, the transport direction also changes (transport reversal).

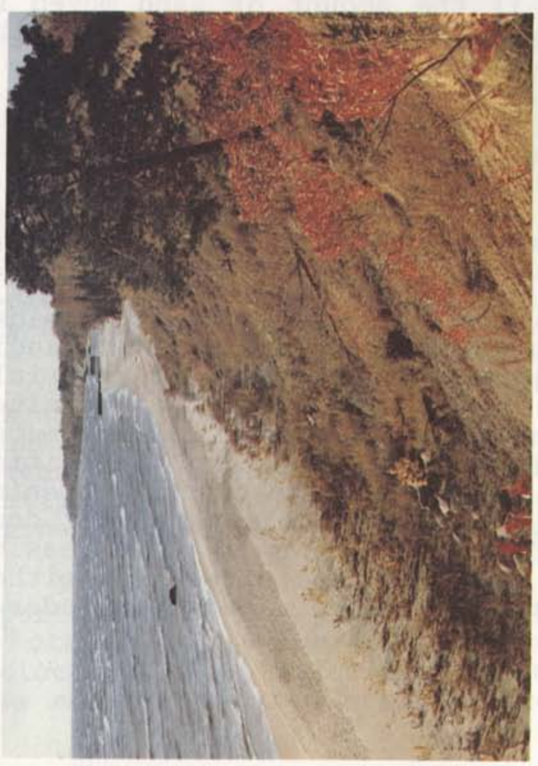
The gross transport rate is the total amount of sand that annually moves past a point in either direction. The net transport rate is the quantity moved in one direction minus that moved in the opposite direction. For example, if the amount of sand moved in one direction in one year was equal to the amount moved in the other direction, the net transport rate would be zero.

Wind. Wind is a problem where large volumes of sand may be transported by prevailing breezes to form dunes. This seldom occurs along sheltered shorelines.

The Effects of Erosion

The most obvious and noticeable effect of erosion is the loss of shorefront property. Less apparent are the increases in sedimentation caused by erosion in adjoining areas since all materials eroded from the shoreline at one point are eventually deposited elsewhere. If this were an individual’s beach, the additional material would be welcomed. However, it is more likely that deposition would occur in deeper water, such as a navigation channel crossing or closely paralleling the shoreline. You should carefully consider, therefore, all possible effects of increasing or decreasing sediment movement by your actions. Significant effects of either kind will probably make it impossible to obtain required federal and state permits.





AVAILABLE OPTIONS FOR CONSIDERATION

There are three basic alternatives in response to an erosion problem: do nothing, relocate endangered structures, or take positive action to halt it. The latter includes devices to armor the shoreline, intercept or diminish wave energy before it reaches shore, or retain bluffs against sliding.

NO ACTION

The no action alternative is used by engineers to help evaluate different courses of action. When confronted with an erosion problem, the first reaction is to take immediate action. What is not realized, at first, is the expense of even low cost solutions. Therefore, it is advisable to estimate the losses involved in doing nothing, particularly if only undeveloped land or relatively inexpensive structures are threatened. Also, erosion may be caused by temporary factors (e.g., unusually high Great Lakes levels). In such cases, it may be advisable to wait for the erosion rate to slow before taking any action.

RELOCATION

In most cases, however, some action is required. Before investing in shore protection, physical relocation of your house or other structure should be considered. If this simply involves moving the house back on the same property, an experienced professional engineer should be retained to evaluate the required setback. Moving a house involves a considerable investment which could be lost if the house is not moved back far enough.

If you have lived in one place for a long time (25 years or more) and have observed a steady shoreline retreat over the period, you can compute an average annual erosion rate by dividing the total retreat by the number of years observed. For instance, if the shoreline gradually receded 300 feet in 30 years, you can estimate the average erosion rate at about 10 feet/year. Therefore, if you moved your house back 100 feet, you would add 10 years of life to the structure at the present erosion rate. If no erosion occurred for years but then the shoreline suddenly retreated 300 feet in 5 years, however, a setback would be both risky and inadvisable.

Even with gradual erosion, the rate could increase suddenly and eclipse a setback in a short period of time. Therefore, an element of risk is involved in any setback. Relocation should be considered, however, particularly if the house can be moved to a new site.

BULKHEADS AND SEAWALLS

"Bulkheads" and "seawalls" are terms often used interchangeably in referring to shore protection structures. Bulkheads are retaining walls, however, whose primary purpose is to hold or prevent sliding of the soil. While they also provide protection from wave action, severe wave action is usually beyond their capacity. Seawalls, on the other hand, are massive structures used to protect backshore areas from heavy wave action. Their size generally places them beyond the range of low cost shore protection. They are also not generally needed in sheltered waters where large waves do not occur, except possibly in the Great Lakes.

Bulkheads may be employed to protect eroding bluffs by retaining soil at the toe, thereby increasing stability, or by protecting the toe from erosion and undercutting. Bulkheads are also used for reclamation projects where a fill is needed at a position in advance of the existing shore. Finally, bulkheads are used for wharves and other navigational structures where greater water depth is needed directly at the shore (Figure 7).

Construction of a bulkhead does not insure stability of a bluff. If a bulkhead is placed at the toe of a high bluff steepened by erosion to the point of incipient failure, the bluff above the bulkhead may slide, burying or moving the structure toward the water. To increase the chances of success, the bulkhead should be placed away from the bluff toe, and if possible, the bluff should be graded to a flatter, more stable slope.

Bulkheads may be either thin structures penetrating deep into the ground (e.g., sheet piling) or massive structures resting on the surface (e.g., sand- and cement-filled bags). Simple sheet pile bulkheads require adequate ground penetration to retain soil. They are generally used only where low bulkheads are required. When higher structures are required, an anchoring system must be added to the basic sheet pile section. Stacked bag structures do not require heavy pile driving equipment and are appropriate where subsurface conditions hinder pile penetration. However, they need firm foundation soils to adequately support their weight. Because they do not normally penetrate the soil, they often cannot prevent slides where failure occurs beneath the surface. This generally limits their effectiveness to sites where the backfill is relatively low.

Bulkheads protect only the land immediately behind them and offer no protection to adjacent areas up and down-coast or to the fronting beach. In fact, their vertical faces may reflect wave energy, causing increased scour in front of the structure. if downdrift beaches were previously nourished by the erosion of land now protected, that land will erode even more quickly. . If a beach is to be retained adjacent to a bulkhead, additional structures, such as groins or breakwaters, may be required.

Detailed information about specific bulkhead configurations is contained in *APPENDIX A.*

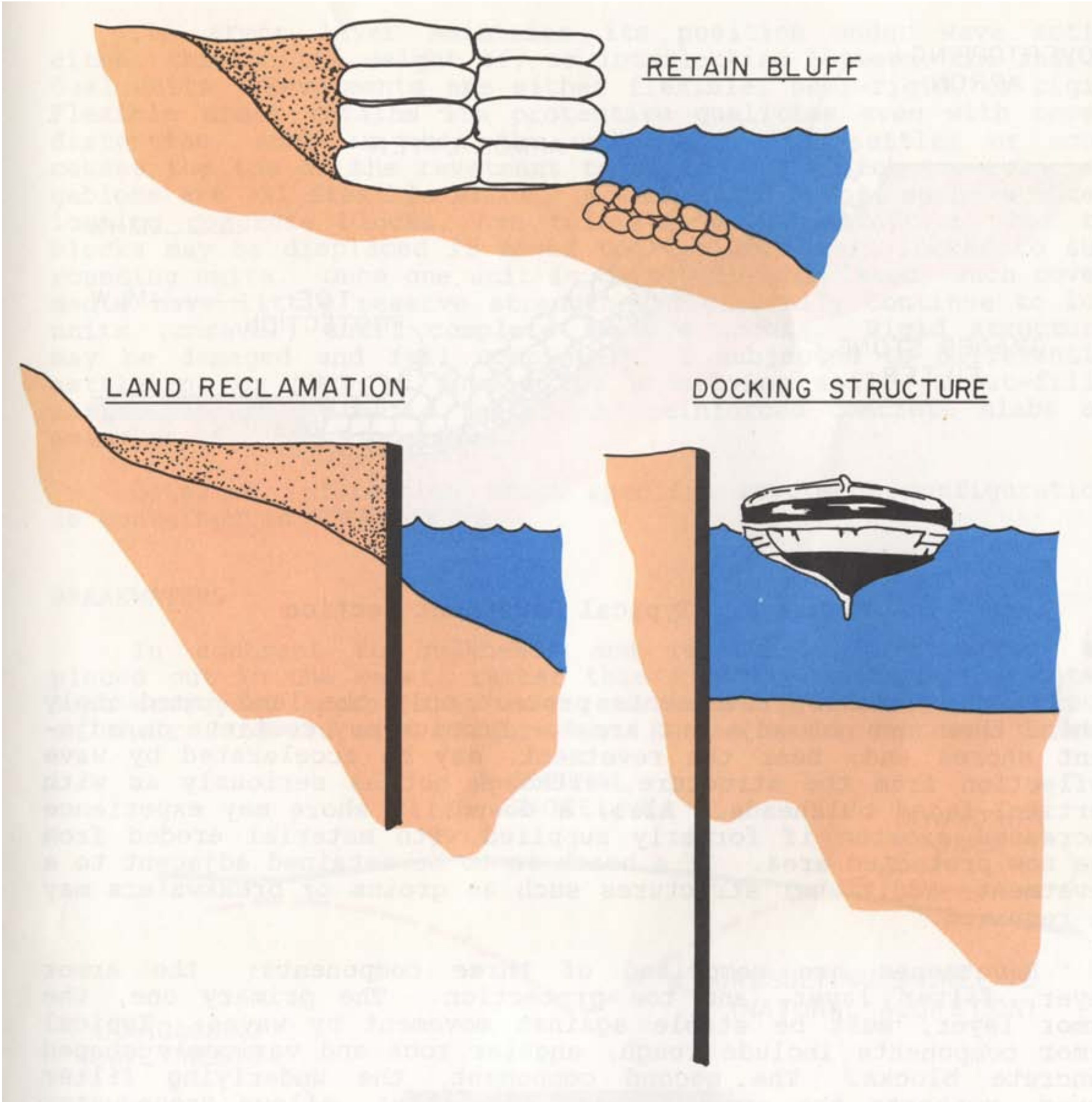


Figure 7 Uses of Bulkheads

REVETMENTS

A revetment is a heavy facing (armor) on a slope to protect it and the adjacent upland against wave scour (Figure 8). Revetments depend on the soil beneath them for support and should, therefore, be built only on stable shores or bank slopes. Slopes steeper than 1 on 1.5 (1.0 vertical on 1.5 horizontal) are unsuitable for revetments unless flattened. Fill material, when required to achieve a uniform slope, must be properly compacted.

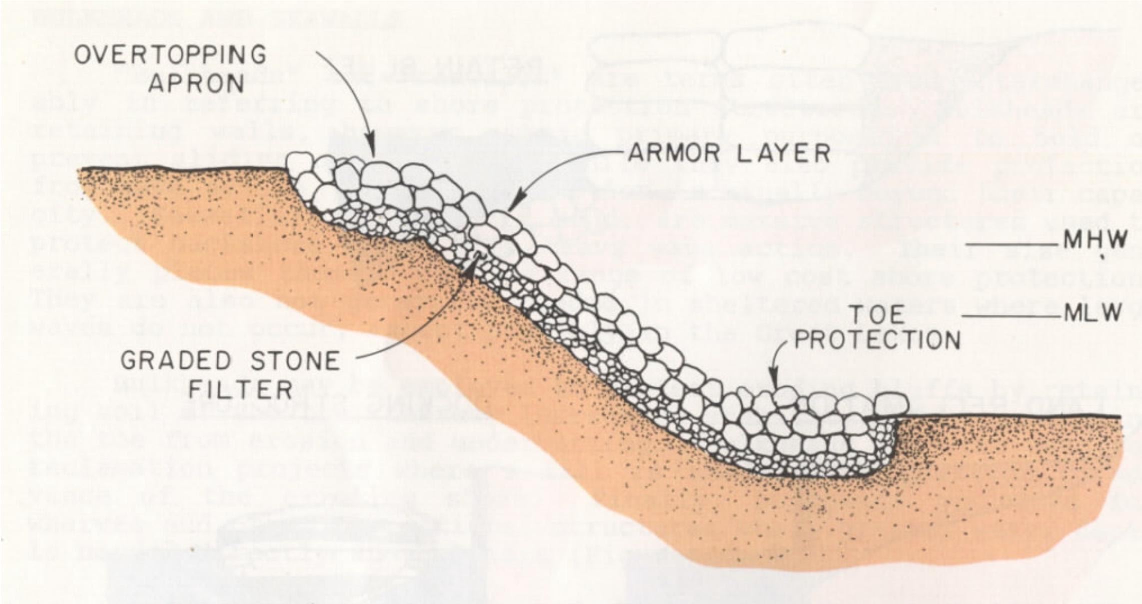


Figure 8 Typical Revetment Section

Like bulkheads, revetments protect only the land immediately behind them and not adjacent areas. Erosion may continue on adjacent shores and, near the revetment, may be accelerated by wave reflection from the structure, although not as seriously as with vertical-faced bulkheads. Also, a downdrift shore may experience increased erosion if formerly supplied with material eroded from the now protected area. If a beach is to be retained adjacent to a revetment, additional structures such as groins or breakwaters may be required.

Revetments are comprised of three components: the armor layer, filter layer, and toe protection. The primary one, the armor layer, must be stable against movement by waves. Typical armor components include rough, angular rock and variously shaped concrete blocks. The second component, the underlying filter layer, supports the armor against settlement, allows groundwater drainage through he structure, and prevents the soil beneath from being washed through the armor layer by waves or groundwater seepage. The third component, toe protection, prevents settlement or removal of the revetment's seaward edge.

Overtopping by green water (not white spray), which may erode the top of the revetment, can be limited by a structure height greater than the expected runup height or by protecting the land at the top of the revetment with an overtopping apron. Flanking, a potential problem with revetments, can be prevented by tying each end into adjacent shore protection structures or the existing bank. If the bank later retreats, the ends must periodically be extended to maintain contact.

The armor layer maintains its position under wave action either through the weight of, or interlocking between, the individual units. Revetments are either flexible, semi-rigid, or rigid. Flexible armor retains its protective qualities even with severe distortion, such as when the underlying soil settles or scour causes the toe of the revetment to sink. Quarrystone, riprap, and gabions are all flexible armor. A semi-rigid armor, such as interlocking concrete blocks, can tolerate minor distortion, but the blocks may be displaced if moved too far to remain locked to surrounding units. Once one unit is completely displaced, such revetments have little reserve strength and generally continue to lose units (unravel) until complete failure occurs. Rigid structures may be damaged and fail completely if subjected to differential settlement or loss of support by underlying soil. Grout-filled mattresses of synthetic fabric and reinforced concrete slabs are examples of rigid structures.

Detailed information about specific revetment configurations is contained in *APPENDIX B.*

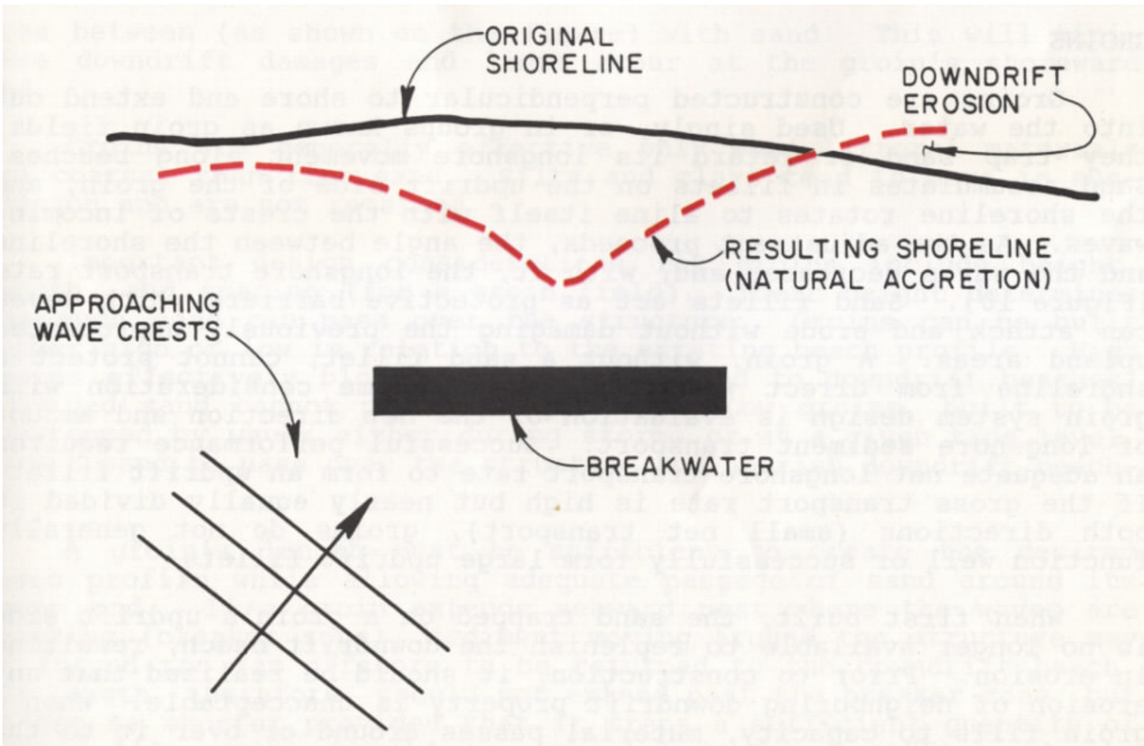


Figure 9 Plan View of a Breakwater

BREAKWATERS

In contrast to bulkheads and revetments, breakwaters are placed out in the water, rather than directly on shore, to intercept energy of approaching waves and form a low-energy shadow zone on their landward side (Figure 9). Even a small decrease in wave height reduces the ability of waves to transport sediment. Sand moving along the shore, therefore, is trapped behind the structure and accumulates. In the meantime, downdrift beaches are deprived of their normal sand supply and may suffer significant erosion. For this reason, the area behind any such structure should be partially filled (to perhaps 50 to 75 percent capacity) with sand after construction to insure an uninterrupted supply of sand to downdrift beaches.

Breakwaters are either fixed or floating. The effectiveness of fixed breakwaters depends on their height and porosity (amount of voids), distance from shore, length parallel to shore, and spacing (where there is more than one structure).

Floating breakwaters are constructed of buoyant materials, such as logs, hollow concrete boxes, and scrap rubber tires. The latter are most popular because of their ready, no-cost availability and durability. Floating breakwaters are generally effective in sheltered waters where short-period (less than

5 seconds), wind-generated waves dissipate while passing a floating structure. Such waves have short wavelengths that may be less than the structure width.

APPENDIX C contains information about specific breakwater configurations.

GROINS

Groins are constructed perpendicular to shore and extend out into the water. Used singly, or in groups known as groin fields, they trap sand or retard its longshore movement along beaches. Sand accumulates in fillets on the updrift side of the groin, and the shoreline rotates to align itself with the crests of incoming waves. As the adjustment proceeds, the angle between the shoreline and the waves decreases and, with it, the longshore transport rate (Figure 10). Sand fillets act as protective barriers which waves can attack and erode without damaging the previously unprotected upland areas. A groin, without a sand fillet, cannot protect a shoreline from direct wave attack. A prime consideration with groin system design is evaluation of the net direction and amount of longshore sediment transport. Successful performance requires an adequate net longshore transport rate to form an updrift fillet. If the gross transport rate is high but nearly equally divided in both directions (small net transport), groins do not generally function well or successfully form large updrift fillets.

When first built, the sand trapped on a groin's updrift side is no longer available to replenish the downdrift beach, resulting in erosion. Prior to construction, it should be realized that any erosion of neighboring downdrift property is unacceptable. When a groin fills to capacity, material passes around or over it to the downdrift shore, but at a slower rate than before the groin was built. An alternative is to build more than one groin and fill the area between (as shown on the figure) with sand. This will minimize downdrift damages and limit scour at the groin's shoreward end.

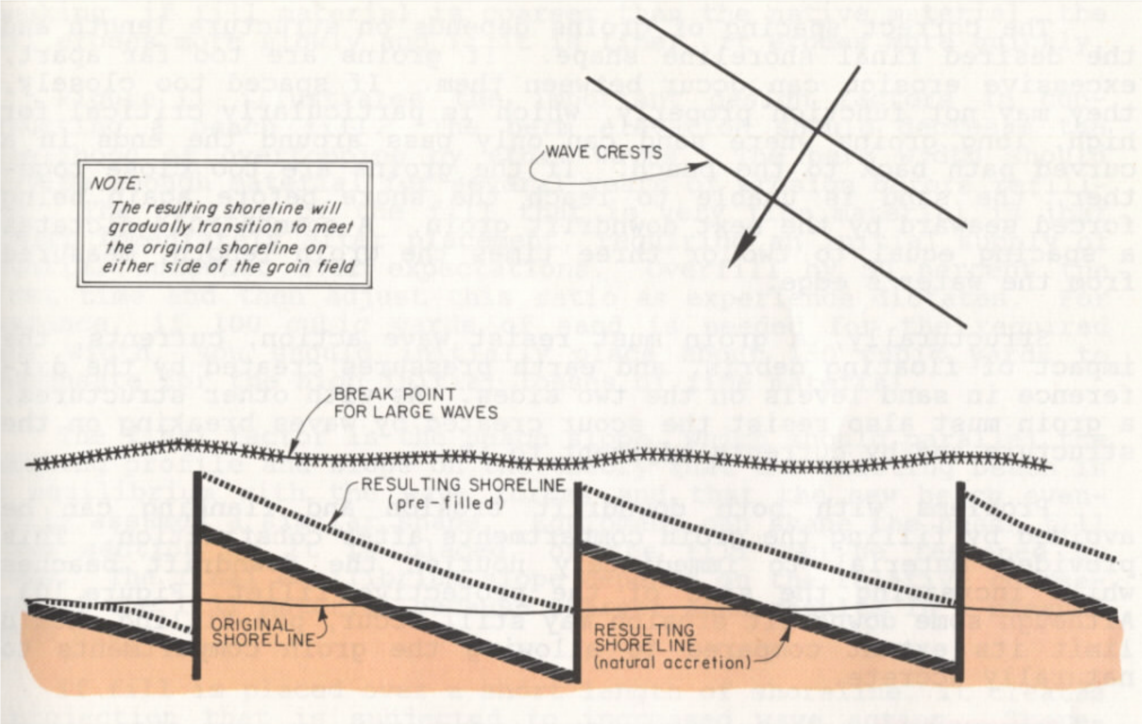


Figure 10 Effects of Groins

Groins are generally effective only when littoral materials are coarser than fine sand. Silts and clays tend to move in suspension and are not retained.

Important design considerations for groins include height, length, and spacing (for a groin field). Their height determines how much sand can pass over the structure. Groins can be built either high or low in relation to the existing beach profile. High groins effectively block the supply of sand to downdrift beaches, provided sand cannot pass through them. Low groins, built to be overtopped by waves either during storms or at a given tide level, permit sand to pass over the structure and nourish downdrift beaches.

A groin's length must be sufficient to create the desired beach profile while allowing adequate passage of sand around its outer end. If a groin extends seaward past where the waves are breaking (breaker zone), sediment moving around the structure may be forced too far offshore to be returned to the downdrift beach. Its length, therefore, should not extend past the breaker zone, but it can be shorter provided that it traps a sufficient quantity of sand. All groins should be extended landward sufficiently to prevent their detachment from shore (flanking) if severe erosion occurs.

The correct spacing of groins depends on structure length and the desired final shoreline shape. If groins are too far apart, excessive erosion can occur between them. If spaced too closely, they may not function properly, which is particularly critical for high, long groins where sand can only pass around the ends in a curved path back to the beach. If the groins are too close together, the sand is unable to reach the shore before again being forced seaward by the next downdrift groin. A common rule dictates a spacing equal to two or three times the groin length, measured from the water's edge.

Structurally, a groin must resist wave action, currents, the impact of floating debris, and earth pressures created by the difference in sand levels on the two sides. As with other structures, a groin must also resist the scour created by waves breaking on the structure and by currents adjacent to it.

Problems with both downdrift erosion and flanking can be avoided by filling the groin compartments after construction. This provides material to immediately nourish the downdrift beaches while increasing the size of the protective fillet (Figure 10). Although some downdrift erosion may still occur, pre-filling should limit its extent compared to allowing the groin compartments to naturally accrete.

APPENDIX D contains specific information on possible groin configurations.

BEACH FILLS

Beach fills are quantities of sand placed on the shoreline by mechanical means, such as dredging and pumping from offshore deposits or overland hauling and dumping by trucks. The resulting beach provides some protection to the area behind it and also serves as a valuable recreational resource.

The beach fill functions as an eroding buffer zone. As large waves strike it, sand is carried offshore and deposited in a bar. As the bar grows, it causes incoming waves to break farther offshore. The useful life of such a beach, which depends on how quickly it erodes, can be completely eliminated in a short period of time by a rapid succession of severe storms. The owner must expect, therefore, to periodically add more fill as erosion continues. Beach fills generally have a relatively low initial cost but a periodic maintenance cost of adding new fill (periodic nourishment).

The rate at which new fill must be added depends on the relative coarseness of the fill material in relation to the native beach material. Ideally, fill and native beach materials should **be** perfectly matched, but this is virtually impossible. Generally speaking, if fill material is coarser than the native material, the fill erodes more slowly and if it is finer, it erodes more quickly.

Figure 11 illustrates the important design factors in constructing a beach fill. The berm elevation should decrease the likelihood of overtopping by storm waves. The berm width should provide,enough material for several years of erosion before refilling. The portion of the fill that is very fine material is lost almost immediately after placement, requiring an initial supply of material somewhat over expectations. Overfill by 50 percent the first time and then adjust this ratio as experience dictates. For instance, if 100 cubic yards of sand is needed for the required berm width, you should initially place about 150 cubic yards to compensate for the high initial losses of fine material.

The final factor is the beach slope, which should parallel the existing profile and slope on the theory that the existing beach is in equilibrium with the wave forces and that the new beach eventually assumes a similar shape. Equipment can shape the beach fill cross section as it is placed, or the fill can be reshaped by waves. The final equilibrium slope depends on the relative coarseness of the fill material because coarser sand results in a steeper beach slope.

If fill is placed over a short length of shoreline, it creates a projection that is subjected to increased wave action. Therefore, it is generally preferable to make the transition to the existing shoreline over a longer distance, which may require cooperation from other landowners. If this is impractical, protective structures, such as groins, may be required to retain the fill.

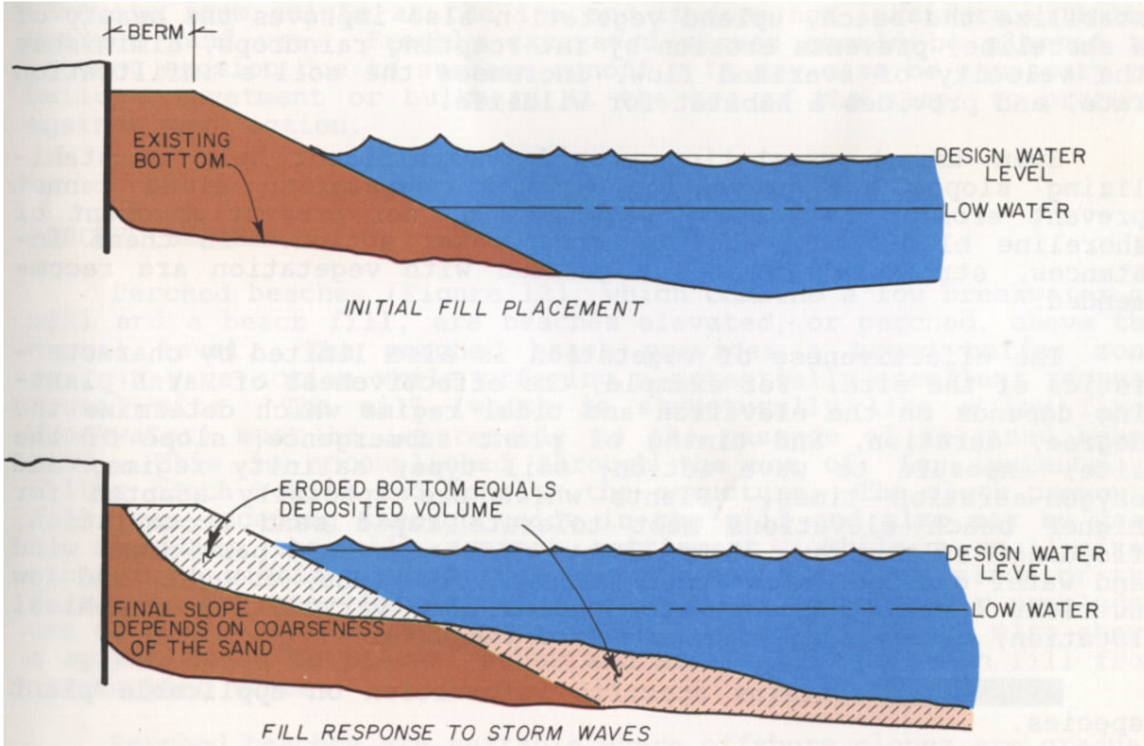


Figure 11 Beach Fill

VEGETATION

A planting program to establish desired species of vegetation is an inexpensive approach to shoreline protection. Depending on where stabilization is desired, species from two or three general groups should be selected to insure adequate growth.

Species of grasses, sedges, and rushes occur in marshes of moderate- to low-energy shorelines that are periodically flooded by brackish water. Once extensive and widely distributed, marsh areas were viewed in the past as useless and were subjected to filling and diking. However, their destruction has lessened as their importance in the ecosystem and to shoreline protection has been realized.

Upland species (shrubs and trees but particularly grasses) are especially adapted to growing in the low-nutrient, low-moisture environment of the higher beach elevations, where they are subject to abrasion by windblown sand particles. Used to trap sand and stabilize the beach, upland vegetation also improves the beauty of a shoreline, prevents erosion by intercepting raindrops, diminishes the velocity of overland flow, increases the soils infiltration rate, and provides a habitat for wildlife.

Even though vegetation provides significant help in stabilizing slopes and preventing erosion, vegetation alone cannot prevent erosion from heavy wave action, nor prevent movement of shoreline bluffs activated by groundwater action. In these instances, structural devices augmented with vegetation are recommended.

The effectiveness of vegetation is also limited by characteristics of the site. For example, the effectiveness of marsh planting depends on the elevation and tidal regime which determine the degree, duration, and timing of plant submergence; slope of the site; exposure to wave action; soil type; salinity regime; and oxygen-aeration times. Plants which are specially adapted for higher beach elevations must tolerate rapid sand accumulation, flooding, salt spray, abrasion by wind-borne sand particles, wind and water erosion, wide temperature fluctuations, drought, and low nutrient levels. Appropriate species also vary with geographical location, climate, and distance from the water.

APPENDIX E contains specific information on applicable plant species

INFILTRATION AND DRAINAGE CONTROLS

Infiltration and drainage controls are often needed for stability along high bluff shorelines. Although many factors lead to slope stability problems, groundwater is one of the most important. The majority of slope failures and landslides occur during or after periods of heavy rainfall or increased groundwater elevations. Infiltration controls prevent water from entering the ground, while drainage controls remove water already present in the soil or on the surface.

Since water entering surface cracks can lead to further instability, the cracks should be filled with compacted, impermeable soil (preferably clay) as they develop. Surface runoff should also be diverted from critical areas of the bluff by either drainage ditches or swales.

The treatment of subsurface drainage problems is complex. Where such problems exist, a geotechnical engineer should be consulted.

SLOPE FLATTENING

A bluff slope may be flattened to enhance its stability when adequate room exists at the top and it does not interfere with the desired land use. Freshly excavated slopes should be planted to prevent erosion due to surface runoff. It may also be necessary to build a revetment or bulkhead at the toe of the slope to protect against wave action.

PERCHED BEACHES

Perched beaches (Figure 12), which combine a low breakwater or sill and a beach fill, are beaches elevated, or perched, above the normal level. The perched beach provides a broad buffer zone against wave action while offering a potentially excellent recreational site. The sill (which is structurally like a low fixed breakwater) must be impermeable to the passage of retained beach sand. This is accomplished through the use of, for instance, a filter cloth behind and beneath the structure. The cloth prevents fill from escaping through voids in the sill and also may be used to stabilize the sill against settlement. While a small-sized stone core within a rock sill could also be used in place of the filter cloth, the limited height of such sills generally precludes use of multi-layered structures of this kind. Figure 12 also shows a splash apron to prevent scour and erosion of the beach fill from overtopping waves.

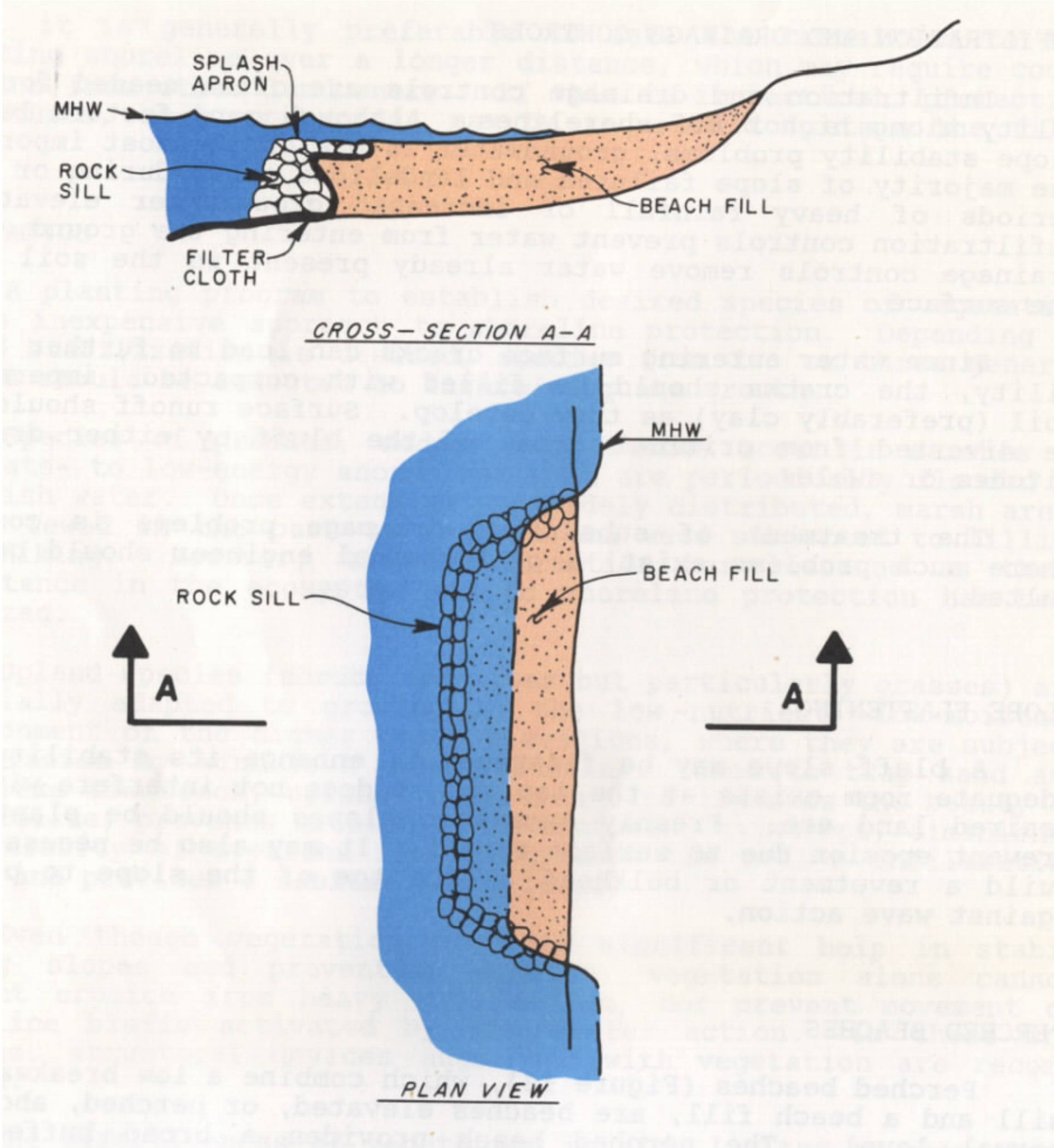


Figure 12 Perched Beach

Perched beaches are suitable where offshore slopes are gradual enough for location of the sill at a reasonable distance from shore in shallow water. Sheet piling will usually provide the best containment for the fill but it presents a hazard due to the sudden step of f to deeper water. Rubble sills are not as hazardous, but retention of the fill will require the use of a filter. All submerged sill materials are potentially hazardous to boaters.

APPENDIX F contains information on specific materials that can be used for sill construction.

STRUCTURES AND FILLS

In addition to perched beaches, fills can also be incorporated in groin systems and with breakwaters. In fact, auxiliary fills are almost mandatory in most cases because when such structures fill by natural accretion, serious erosion problems almost surely occur downdrift.

STRUCTURES AND VEGETATION

While vegetation is one means of controlling shoreline erosion, its most serious deficiency is its restriction to areas of limited fetch because it cannot establish itself in heavy wave environments. Vegetation can be used in areas experiencing considerably heavier wave activity, however, if it is placed in the shelter of a structure such as a breakwater. The use of a temporary structure is particularly appealing because it protects the plants while they become established and it can be removed later when the plants mature.

GUIDING PRINCIPLES FOR DESIGN

With so many options available, a decision may seem difficult. The following section on functional design should provide assistance toward a wise choice. At the end of the *FUNCTIONAL DESIGN* section, there are summary decision tables, followed by the *STRUCTURAL DESIGN* section with important guidelines for planning structures to withstand the forces expected at the site. Finally, *THE CONSTRUCTION STAGE* section gives important precautions during actual implementation.

FUNCTIONAL DESIGN

Shoreform Compatibility

Certain approaches are better suited to particular shoreline configurations than others. It is important to choose a method appropriate to the dominant shoreform at your site.

Bluff Shorelines. The *no action* alternative can be appropriate since it does not disrupt the natural shoreline processes and requires no investment for protective structures. However, the property may eventually be totally destroyed by erosion. While relocation also does not disrupt shoreline processes and permanently eliminates any threat to buildings if done properly, it also requires special equipment and skills and can cost as much as or more than a protective structure. *Bulkheads* are ideally suited either for full-height retention of low bluffs or as toe protection for high bluffs. They can be constructed of readily available materials, are easily repaired if damaged, and are particularly useful with steep offshore slopes. They can, however, induce toe scour and loss of remaining beach material from the force of reflected waves. They also have high initial costs and some require special pile driving equipment which may have difficulty reaching the work site. Revetments are sometimes effective in bluff situations. Low bluffs that can be regraded to a stable slope may be effectively protected by revetments. Revetments can protect the toes of high bluffs, either alone or in conjunction with another device. *Breakwaters* reduce wave energy reaching the bluff but do not provide positive protection to the toe. They may build or maintain a sand beach which provides some protection by buffering against normal waves but would be ineffective against storm waves. They require an adequate sand supply and gentle offshore slopes. *Groins* provide only a buffer by building or holding a beach. Since they require a natural sand supply, they would generally not work in a clay or silt bluff area unless sand were imported. *Beach fills* provide only dissipation of normal wave action and would not be effective during severe storms. Vegetation provides little protection until well established and, even then, does not positively protect against large storm waves. *Drainage controls* are mandatory if groundwater and seepage adversely affect slope stability. They provide no toe protection against wave action and can be expensive. Also, they are difficult to properly design and require the assistance of a qualified engineer. *Slope flattening* provides a permanent solution for slope stability problems but does not provide protection against continued wave action. It also requires adequate setback room at the top of the bluff for the slope. *Perched beaches* would protect the bluff from normal wave action but would not provide positive toe protection during storms. *A combination approach* can be the best solution. For instance, drainage controls should be used as needed, possibly with slope flattening as well. Toe protection could be provided with a revetment along with a fronting sand beach for additional protection (provided offshore slopes are mild). Vegetation planted on the regraded slope would prevent erosion from runoff and also help to stabilize a beach fill.

Sand Beaches or Low Plains. The *no action* and relocation alternatives are applicable. Bulkheads are generally inappropriate unless an elevated feature, such as a promenade or parking lot, is needed. Vertical bulkheads induce toe scour and wave reflections, and could cause a total loss of the beach fronting the bulkhead. *Revetments* are suited for protecting features directly behind the beach since they absorb wave energy and are flexible if settlement occurs. However, they have an adverse aesthetic effect on the beach, and can limit use or access to the shore. Their use by a single landowner is generally a problem because they are subject to flanking. *Breakwaters* are also well suited because they trap and hold sand moving both alongshore and on- or offshore. However, they can cause extensive downdrift erosion damages and they are expensive to build. *Groins* can effectively build beaches on their updrift sides but can also cause accelerated downdrift erosion. Their functional behavior is complex and difficult to predict. *Beach fills* retain the natural form and character of the beach and enhance its recreational potential. Local sources of suitable sand are not always available, however, and fills do require periodic renourishment. Vegetation, effective in low wave-energy situations, has low initial costs and enhances natural appearance. Unfortunately, foot and vehicular traffic damage plantings. *Drainage controls* and *slope flattening* are not applicable to beach shorelines. *Perched beaches* are ideally suited as they increase the available beach area. *Combination methods* are often excellent, such as a perched beach that is further stabilized with vegetation.

Wetlands. Erosion control structures built near wetlands should be placed at a low bluff or beach behind the marsh. For protection of the marsh itself, vegetation is the only appropriate alternative. To assist establishment bf plantings, however, small temporary breakwaters may be required. *Beach fills or perched beaches* may also be used to provide a suitable substrate for planting in some areas.

Applicability to Shoreline Uses

Some methods lend themselves more readily than others to particular shoreline uses. It is important to choose a method that performs its function without interfering with planned shoreline uses - *No action* obviously does not enhance use of the shoreline, although continued erosion may have an adverse impact. Relocation involves similar considerations. *Bulkheads* create an access problem unless stairs are provided. Vertical structures also cause wave reflections that can erode the remaining beach. Bulkheads are necessary when a water depth for boating activities is needed at the shore. *Revetments* of randomly placed, rough stone definitely hinder access to the beach. Smooth structures, such as concrete blocks, cause less difficulty for walkers. *Breakwaters* provide an area sheltered from waves but also can hinder circulation and cause water quality problems. Beaches built behind breakwaters have enhanced recreational potential. Rough stone structures provide an improved habitat for certain fish species but may be hazardous to climbers. High structures may also obstruct the view of the water and have an undesirable aesthetic effect. Groins may hinder travel along the beach, but any sand trapped updrift from groins improves beach conditions. *Beach fills* enhance recreational uses of the shore. Vegetation improves the wildlife habitat but hinders other uses of the beach because traffic through the plantings must be restricted. *Drainage controls* have little impact on shoreline uses. *Slope flattening* reduces available land at the shore. *Perched beaches* provide increased beach area for recreation. Rubble sills can serve as a habitat for certain fin and shellfish species. The sudden step off sheet pile sills can be hazardous to bathers. Submerged sills can also hinder access for boaters and could pose a potential hazard.

Conditions in the General Area

Conditions in your area can strongly influence selection of an alternative. One of the most important considerations is the possible effects on downdrift properties. Accretion devices (breakwaters and groins) trap sand moving along the beach and starve the downdrift shoreline. If this causes damages to a neighbor, the area behind the breakwater or updrift from the groin must be filled so that no additional sand is trapped, littoral material bypasses the structure, and no further damages occur downdrift. You should also consider neighbors updrift from you who may build such structures and potentially damage your property.

Composition of the shoreline is also important. Accretion devices do not function in areas with very little sand because they cannot sufficiently calm the water to permit settlement of silts and clays. Slope and soil composition are also important for determining appropriate plant species.

Climatic and other environmental conditions must also be considered. Vegetation obviously must be planted where the climate permits survival and growth. Water salinity is also critical for many species which can only tolerate a narrow band of salinity changes. Salinity and climate are also important for structural materials. Warm salt water more easily corrodes steel and other metals than cold f resh water. Warm salt water is also the habitat of marine borers that attack submerged timber structures. on the other hand, fresh water lakes freeze in the winter, subjecting structures to large forces and abrasion from ice sheets. In some areas this may require more sturdy construction than would be required for resisting wave action at the site.

Summary

The factors relating each available alternative to shoreform and shoreline use are summarized on Tables 2 and 3.

Table 2

METHODS APPLICABLE TO VARIOUS SHOREFORMS

Alternative*	High Bluffs	Low Bluffs	Beaches	Wetlands
No Action	Rarely	Rarely	Rarely	Rarely
Relocation	Sometimes	Sometimes	Sometimes	Sometimes
Bulkheads	Usually	Almost always	Sometimes	Rarely
Revetments	Sometimes	Almost always	Almost always	Rarely
Breakwaters	Rarely	Rarely	Almost always	Sometimes
Groins	Almost never	Almost never	Almost always	Almost never
Beach Fills	Almost never	Almost never	Almost always	Rarely
Vegetation	Almost never	Almost never	Sometimes	Almost always
Infiltration and Drainage Control	Almost always	Usually	Almost never	Almost never
Slope Flattening	Rarely	Usually	Almost never	Almost never
Perched Beaches	Rarely	Rarely	Almost always	Sometimes

Applicability is for the alternative used alone in the given situation. Combination devices are not included.

Table 3

COMPATIBILITY OF ALTERNATIVES WITH SHORELINE USES

Alternative	Strolling	Bathing	Fishing	Boating
No Action	Sometimes	Sometimes	Usually	Usually
Relocation	Sometimes	Sometimes	Sometimes	Sometimes
Bulkheads	Usually	Sometimes	Almost always	Almost always
Revetments	Usually	Sometimes	Usually	Usually
Breakwaters	Almost always	Almost always	Almost always	Usually
Groins	Usually	Almost always	Almost always	usually
Beach Fills	Almost always	Almost always	Usually	Almost always
Vegetation	Almost never	Almost never	Almost always	Rarely
Infiltration and Drainage Controls	Almost always	Almost always	Almost always	Almost always
Slope Flattening	Almost always	Almost always	Almost always	Almost always
Perched Beaches	Almost always	Almost always	Almost always	Usually

STRUCTURAL DESIGN

If the chosen alternative involves construction of a shore protection device, several key problems must be resolved before an adequate structural design is completed. The first step is evaluation of the potential water level and design wave height at the site to determine how strong the device must be to withstand wave forces. Other considerations include toe protection, filtering, flank protection, structural height, environmental factors, and availability of materials.

Water Levels

A design water level must be determined before the wave height used to design structures can be found. In tidal waters, the elevation of the spring or diurnal tide (see Tide Tables under the heading "Water Levels", in the *OTHER HELP* section) is an appropriate starting point for low cost protection. An increment should be added to account for storm setup effects. Local experience should dictate, but values of two or three feet are probably reasonable for the storm setup.

On the Great Lakes, the Monthly Bulletin of Great Lakes Levels (see a7iso, *OTHER HELP* Section) summarizes past and projected water *levels*. For each lake, a curve is given for the long-term average lake level (1900 to the present) (see Figure 13). A suggested design water level is the greater of (a) the water level midway between the long-term average and the recorded maximum average monthly water level, or (b) the highest monthly water level that has occurred during the preceding year. For instance, on Lake Michigan, the highest average water levels occur in July when they are about +2.0 feet above chart datum (576.8 feet) [Low Water Datum (LWD) is +576.8 feet IGLD for Lake Mighigan]. The maximum observed monthly water level for July on Lake Michigan was observed in 1974 at +4.2 feet. A water level midway between them is +3.1 feet. The maximum observed monthly water level during the previous year was +3.0 feet, so the chosen water level should be the greater of the two, or +3.1 feet (579.9 feet). Storm setup values should be added to obtain a final water level. Figure 14 contains suggested values superimposed on a map of the Great Lakes. The design water level, therefore, will be the sum of the water level found in the previous step and the storm setup value from Figure 14.

Wave Heights

Waves at a site are generated either by wind action or moving vessels. At most locations, however, wind action is more critical for design. The first step in evaluating the wave height is to measure (on a calm day) the water depth about 50 feet from the low water line or lakeshore and then determine the lake or tide level at the time of measurement (from Tide Tables or Monthly Bulletin of Lake Levels for the Great Lakes). Next, add to the measured depth the difference between the design water level and the level at the time of observation and multiply by 0.8 to find the maximum design breaking wave height. For instance, at a site on Lake Erie, if the measured depth is 3.5 feet when the lake level is 571.0 feet and the design lake level is 572.5 feet, the design depth is 3.5 + (572.5 - 571.0) or 5.0 feet. The maximum design breaking wave at the site is then 5.0 x 0.8 or 4 feet.

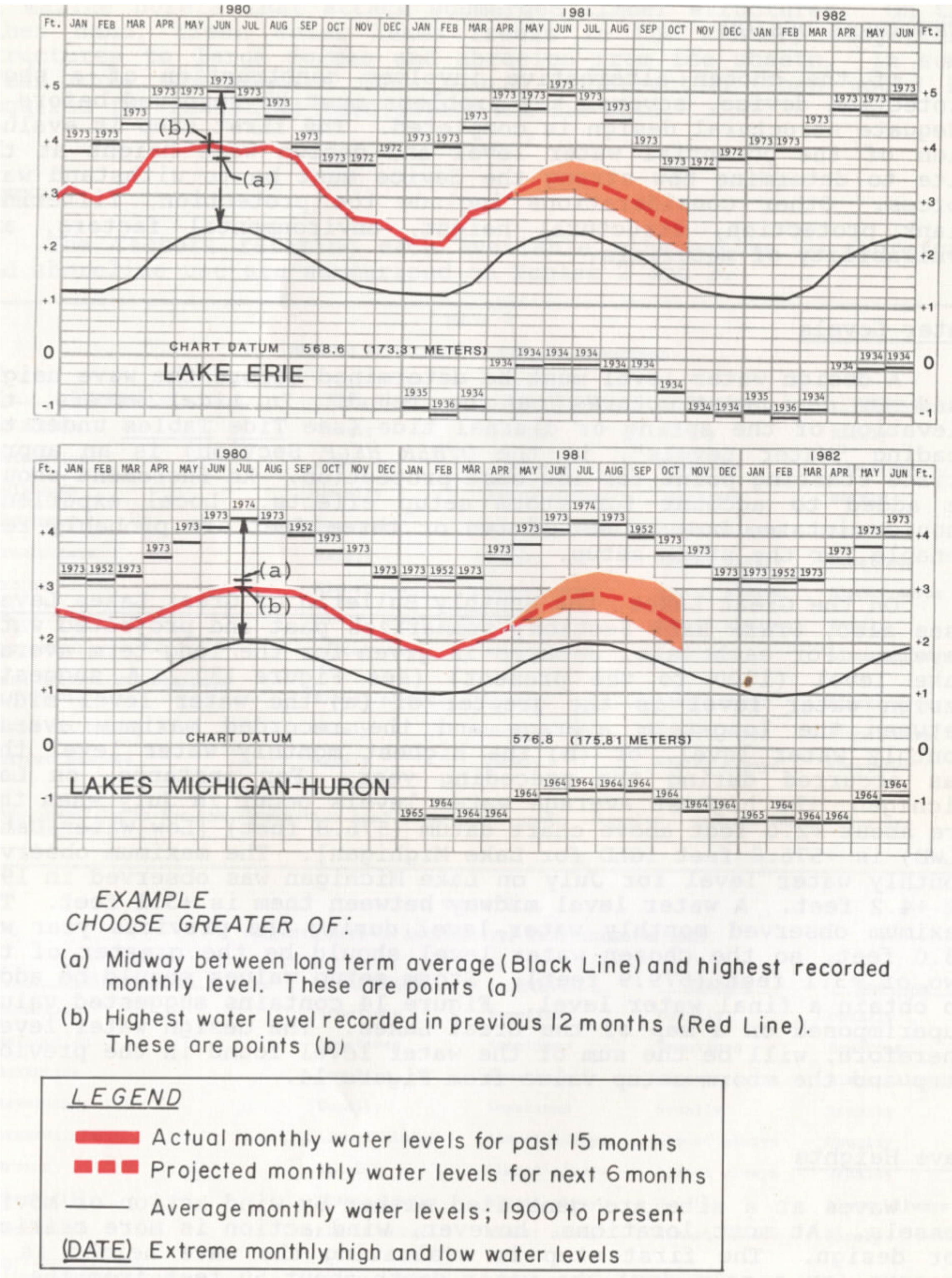


Figure 13 Design Lake Levels
[After U.S. Army Corps of Engineers (1981a)]

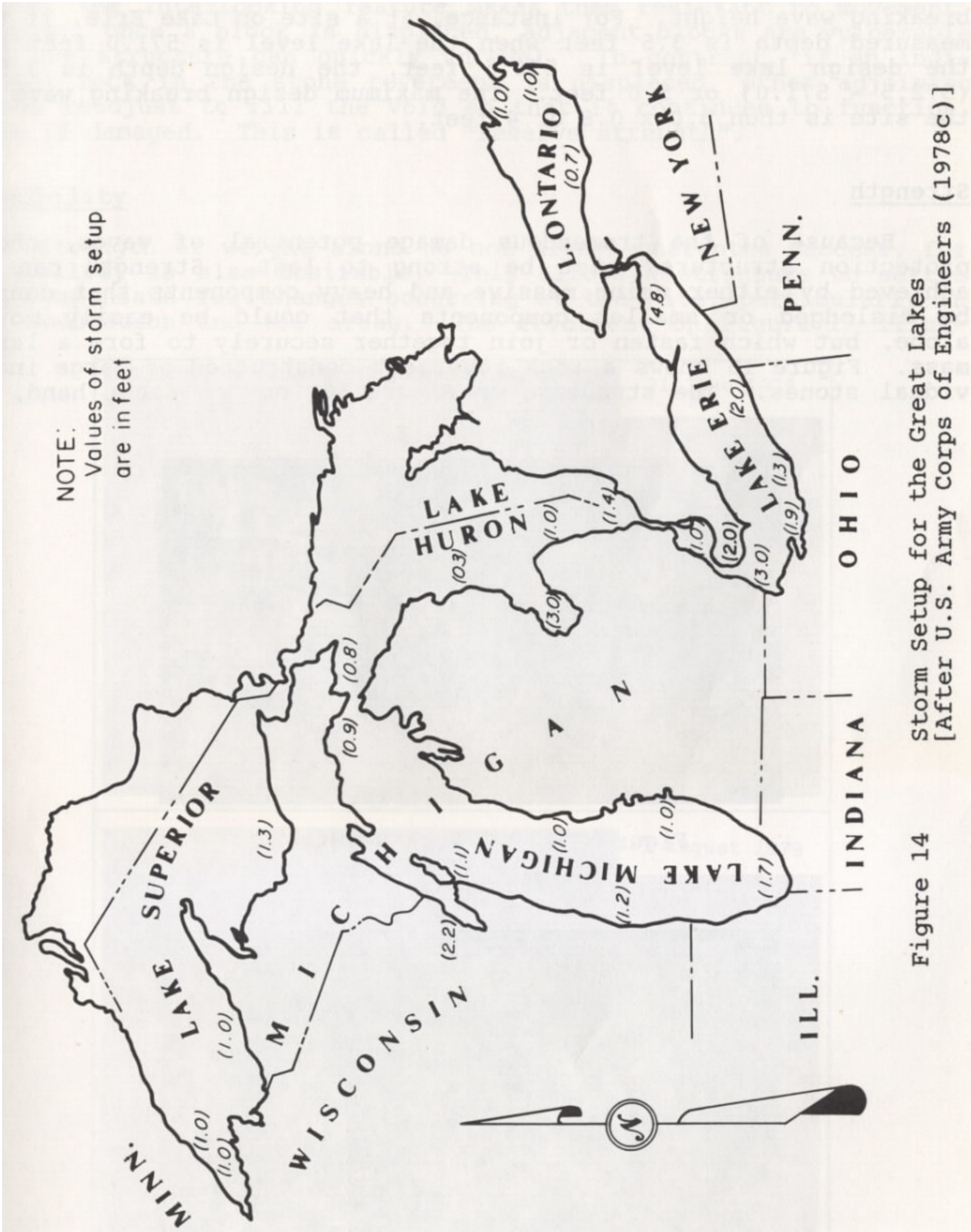


Figure 14   Storm Setup for the Great Lakes
[After U.S. Army Corps of Engineers (1978c)]

Strength

Because of the tremendous damage potential of waves, shore protection structures must be strong to last. Strength can be achieved by either using massive and heavy components that cannot be dislodged or smaller components that could be easily moved alone, but which fasten or join together securely to form a large mass. Figure 15 shows a rock revetment constructed of large individual stones. The structure on Figure 16, on the other hand, is constructed of small concrete blocks that interlock when placed. The small blocks would be easily moved by large waves but, when in place, the interlocking feature makes them resistant to movement. However, once a block is displaced, adjacent blocks are vulnerable and the structure can quickly unravel. In contrast, if an individual rock in the stone revetment is displaced, other adjoining rocks readjust to fill the void so that it continues to function, even if damaged. This is called "reserve strength".

Figure 15 Rock Revetment

Figure 16 Concrete Block Revetment

Flexibility

Strength or weight alone do not always guarantee success, for flexibility is also desirable. This allows a structure to settle and compensate for changes occurring at the site, particularly in the foundation and toe areas. The revetment on Figure 17 illustrates this point. While the massive individual concrete slabs had adequate weight to resist movement, the structure failed for several reasons, including lack of flexibility. That is, it could not adjust to erosion occurring around the ends and throu4h cracks between the slabs.

Figure 17 Concrete Slab Revetment

<u>Toe Protection</u>

The absence of proper toe protection also contributed to the failure depicted in Figure 17. Toe protection is supplemental armoring of the beach surface in front of the structure, which prevents waves from scouring and undercutting it. A typical example of toe protection is shown in Figure 18. The bulkhead on the left has no protection, has suffered toe scour, and could eventually fail. The bulkhead on the right has properly designed toe protection and is not experiencing similar problems. As a rule, toe protection should be provided unless the structures are embedded enough to withstand scour equal to at least one design wave height.

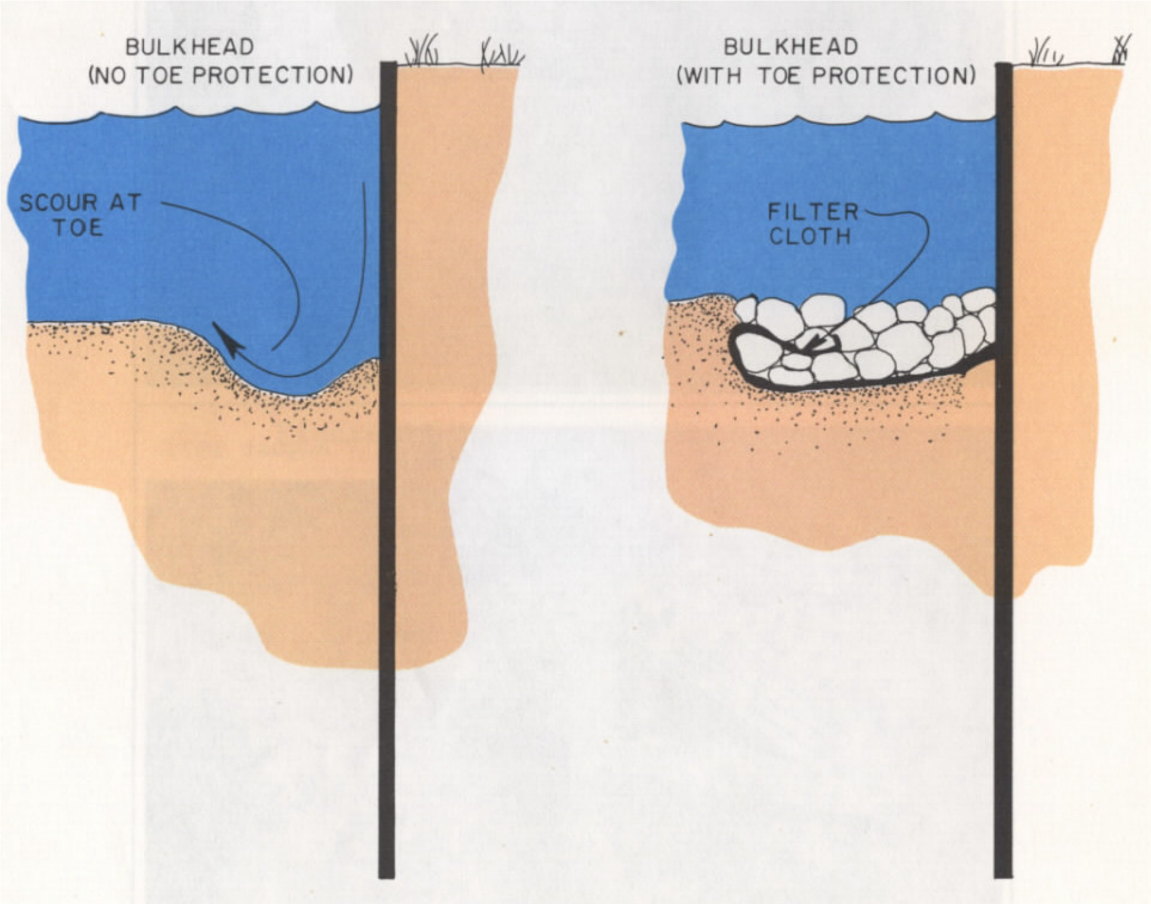


Figure 18 Typical Examples of Toe Protection

Filtering

In the example of the concrete slab revetment (Figure 17), inadequate filtering also contributed to failure. Although one of the most important design details, filtering is probably the most neglected and hence leads to more failures than any other cause. In Figure 19, large rocks have been placed on an eroding slope without an adequate filter. As waves break on the slope, much of the water seeps into the soil and flows back to the water level. As it exits the slope behind the rocks, the water carries minute soil particles with it. Since the spaces between the rocks are so much larger than the coarsest soil particles, they pass practically unhindered through the revetment. To make matters worse, high velocity jets of water from waves also penetrate spaces and stir up the underlying sediments. The bank then erodes from behind the rocks as they settle into the slope.

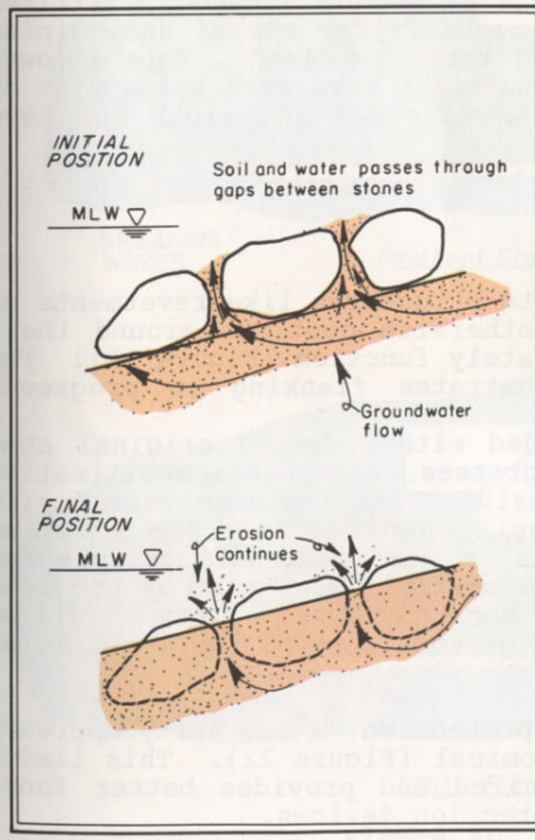


Figure 19
Inadequate Or No Filtering

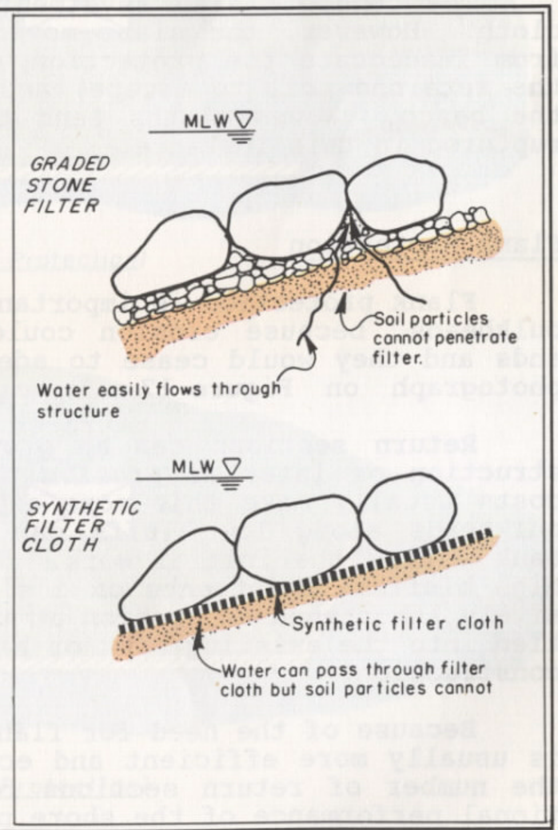


Figure 20
Proper Filter Design

With a properly designed filter, (Figure 20) some soil particles are coarser than the finest holes in the overlying stone. As the flow of water begins, fine soil particles are washed out and flows through lost (piping), but the coarser ones work their way into openings of the overlying stone filter layer and block them. This process continues until essentially all of the holes are blocked by soil particles. Water continues to pass through, but soil cannot, halting the erosion. However, it is imperative that water be able to pass through the structure. If there are no water passages, as with solid concrete, high water pressures will develop behind the structure and topple or displace it, unless it is specifically designed as a dam.

Filtering can be provided through use of graded stone or gravel in a range of sizes, or through woven or nonwoven synthetic filter cloths. Woven cloths, manufactured with high strength nylon or other synthetic fibers, provide a uniform mesh with a consistent opening size which can be matched to the soil characteristics. Non-woven cloths, manufactured from masses of somewhat randomly oriented fibers bonded together by chemicals, heat, or pressure, come in various standard thicknesses. Unlike woven cloths, however, they lack uniform-sized openings, their principal advantage being lower cost.

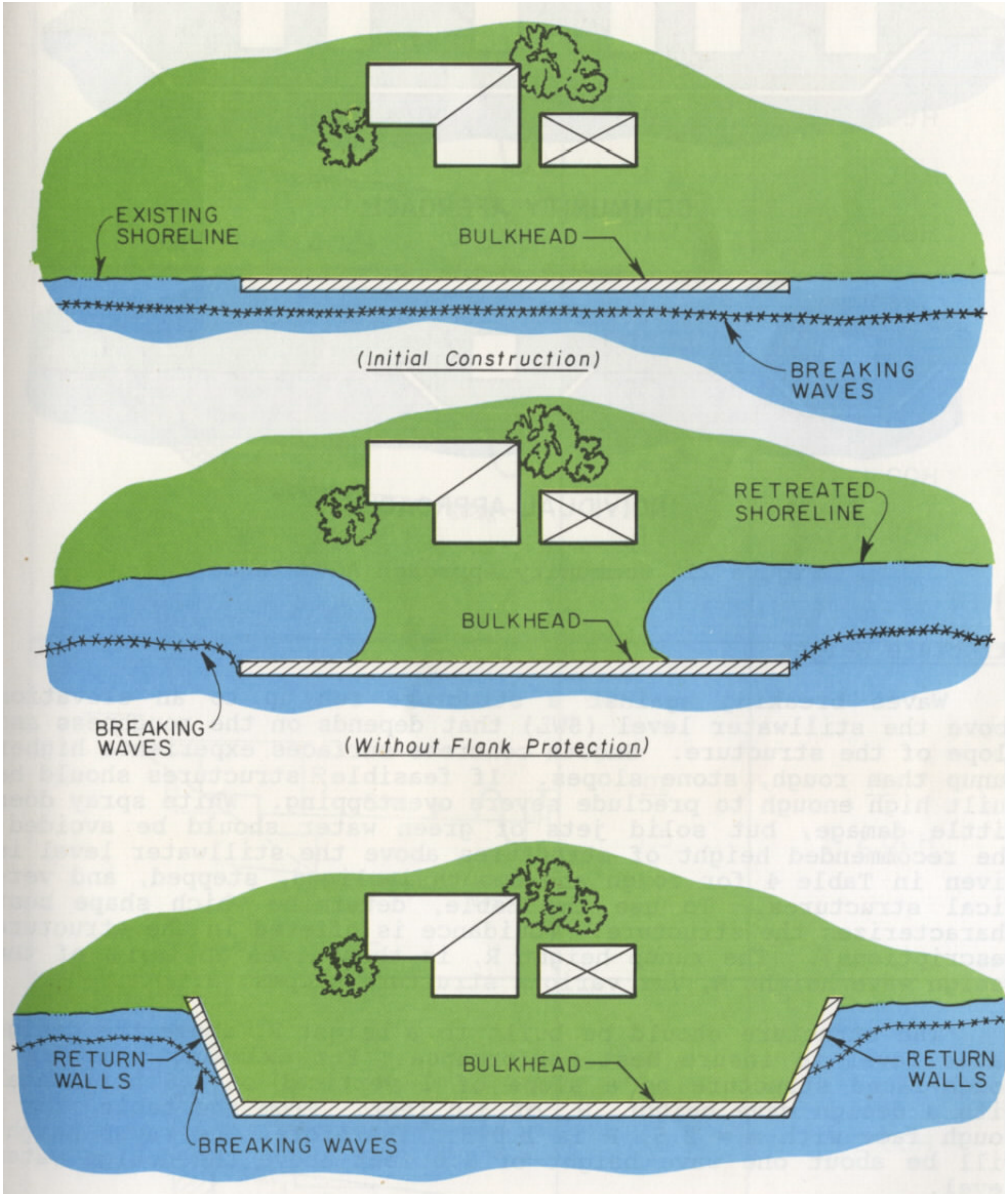
The concrete slab revetment was backed by a non-woven filter cloth. However, the slabs moved, probably because of undermining from inadequate toe protection, and tore the cloth. This allowed the retained soil to escape, and the slabs were soon lying flat on the beach. Woven cloths tend to be stronger and might not have ruptured in this instance.

Flank Protection

Flank protection is important to structures like revetments or bulkheads, because erosion could otherwise continue around their ends and they would cease to adequately function (Figure 21). The photograph on Figure 17 also illustrates flanking in progress.

Return sections can be provided either during original construction or later as erosion progresses, although remobilization costs usually make this more expensive. For instance, sheet pile bulkheads along low bluffs can easily be tied into the existing bank during the initial work. This is generally not possible for high bluffs. Revetments on a slope nearly always must be progressively lengthened as erosion at the ends continues. They should be tied into the existing bank or high ground, however, during initial construction.

Because of the need for flank protection, a community approach is usually more efficient and economical (Figure 22). This limits the number of return sections required and provides better functional performance of the shore protection devices.



(With Flank Protection)

Figure 21 Flank Protection

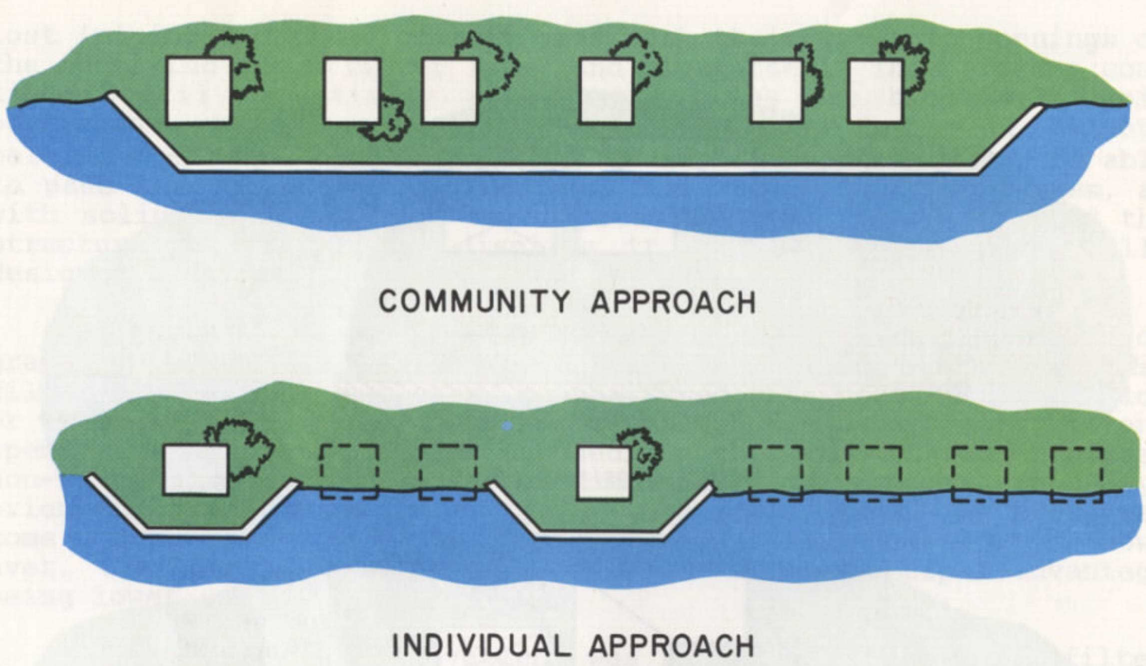


Figure 22 Community Approach Advantages

Structure Height

Waves breaking against a structure run up to an elevation above the Stillwater level (SWL) that depends on the roughness and slope of the structure. Smooth concrete surfaces experience higher runup than rough, stone slopes. If feasible, structures should be built high enough to preclude severe overtopping. White spray does little damage, but solid jets of green water should be avoided. The recommended height of structures above the Stillwater level is given in Table 4 for rough and smooth inclined, stepped, and vertical structures. To use the table, determine which shape best characterizes the structure. (Guidance is offered in the structure descriptions). The runup height R, is then given in terms of the design wave height H, for various structure slopes, m.

The structure should be built to a height R, above the design water level to insure best performance. For example, consider a rough-faced structure on a slope of 1 vertical on 2.5 horizontal with a design wave height, H, of 3.0 feet. From the table, for a rough face with m = 2.5, R is 1.0 H. Therefore, the runup height will be about one wave height or 3.0 feet above the design water level.

If it is impractical or undesirable to build the structures to the recommended height, a splash apron should be provided at the top. Generally constructed of rock, it prevents the ground behind from being eroded, and thus eventually undermining that portion of the structure.

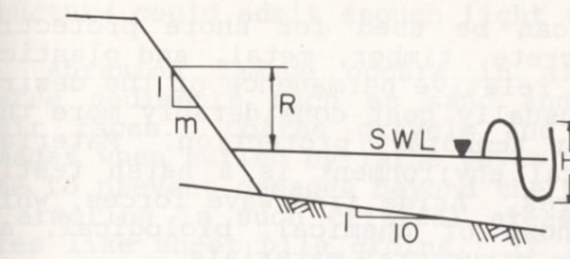
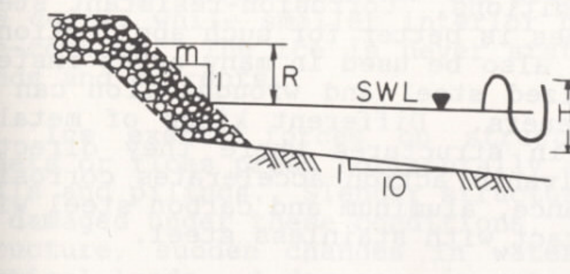
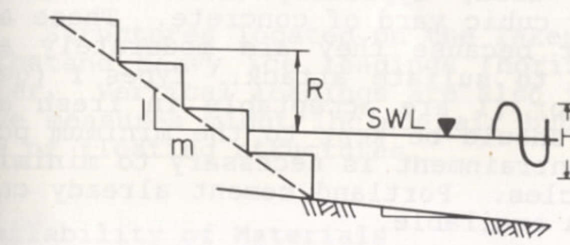
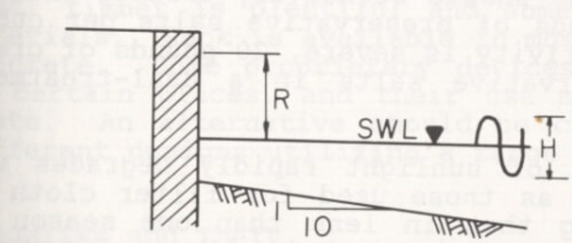
	m	R
 SMOOTH FACE	1.5 2.5 4.0	2.25H 1.75H 1.50H
 ROUGH FACE	1.5 2.5 4.0	1.25H 1.00H 0.75H
 STEPPED FACE	1.5	2.00H
 VERTICAL FACE	—	2.00H

Table 4 Wave Runup Heights

Environmental Factors

Many different materials can be used for shore protection structures, including rock, concrete, timber, metal, and plastics. The choice often depends on the relative permanence of the desired protection. Durable materials usually cost considerably more than shorter-lived materials used for temporary protection. Materials are important because the coastal environment is a harsh testing ground for all man-made structures. Aside from wave forces, which themselves are formidable, a host of chemical, biological, and other natural factors can degrade structural materials.

Corrosion is a primary problem with metals and concrete in brackish (saline) water. Plain carbon steel used for sheet piling in bulkheads or as bolts for fasteners has a life of probably less than five years under some conditions. Corrosion-resistant steel marketed under various trade names is better for such applications, while aluminum sheet piling can also be used in many areas instead of steel.

Stainless or galvanized steel and wrought iron can be used for bolts and other fasteners. Different kinds of metals, however, should not be mixed in structures -where they directly contact each other, because galvanic action accelerates corrosion of one of the metals. For instance, aluminum and carbon steel will quickly deteriorate when in contact with stainless steel.

Concrete can also be degraded by chemical reaction with salt water. Concrete used in structures should be high quality, and aggregates should be durable and not reactive with cement. Dense (cement rich) mixes should be used, typically about 7 bags of type II or V portland cement per cubic yard of concrete. These are suitable for use in salt water because they are moderately and highly resistant, respectively, to sulfate attack. Types I (general purpose portland cement) or II are acceptable in fresh and brackish water. Water content should be kept to the minimum possible for workability and air entrainment is necessary to minimize damage from freeze and thaw cycles. Portland cement already containing air-entraining agents is available.

Timber structures submerged in brackish and salt water are subject to damage from marine borers. Timber used for bulkhead or other construction in such areas should be heavily treated with 20 pounds of creosote or 2.5 pounds of preservative salts per cubic foot of timber. Where borer activity is severe, 20 pounds of creosote and 1.5 pounds of preservative salts in a dual-treatment process is recommended.

The ultraviolet component of sunlight rapidly degrades untreated synthetic fibers, such as those used for filter cloth or sandbags, totally deteriorating them in less than one season if heavily exposed. Therefore, any fabric used for shore protection devices should be stabilized against ultraviolet light. The addition of, for instance, carbon black to the synthetic compound gives it a black or dark color in contrast to the white or light gray color of unstabilized cloth. Even filter cloth covered by a structure should be stabilized since small cracks or openings in the structure could admit enough light to destroy the fabric.

Abrasion damage occurs in all structures where waves move coarse sediments such as sand and gravel back and forth across their faces. Coarse gravels and cobbles can also cause impact damages when hurled by large waves. In either case, little can be done to prevent damages beyond the use of durable rock and concrete as armoring in such critical areas as along the bottom of structures like sheet pile groins. It is along the sand line that such structures typically experience the greatest abrasion.

Cold region waterbodies develop ice covers whose extent depends on the size, geographic location, and exposure of the waterbody. Large bodies such as the Great Lakes usually develop partial ice covers while smaller interior bays and lakes become completely ice-covered. The ice is never stationary but moves in response to winds and currents.

Ice exerts forces on structures in several ways. Moving sheets or floes press horizontally against vertical structures like walls and pilings. Slender structures such as piling can be heavily damaged under these conditions. If the ice sheets adhere to the structure, sudden changes in water level can cause considerable vertical loads. A decrease in water level can force pilings deeper into' the bottom, while a rise will tend to jack the piles upward while soil collapses beneath the tip and prevents the pile from returning to its original position.

Structures located on the lakes and some bays, therefore, must withstand heavy ice loadings (horizontal) if they extend into the water. Vertical loadings are also important on the lakes. Protective measures might include air bubbler systems, pile sleeves, and use of floating structures.

Availability of Materials

Structures should be designed and built with locally available materials when possible. In some areas, such as the Pacific Northwest, timber is plentiful and somewhat less expensive than other materials. Rock is available in most areas, as are scrap tires and concrete. Some proprietary devices, however, are fabricated only in certain places, and their use may require high transportation costs. An alternative should be chosen only after comparison of different designs utilizing a range of available materials.

Vandalism and Theft

A final factor is the susceptibility of the structure to vandalism. If this is a problem, materials should be selected which cannot easily be cut, carried away, dismantled, or otherwise damaged. For instance, sand-filled fabric bags are easily slashed by knives, small concrete blocks can be stolen, and wire mesh baskets can be opened with wire cutters and the contents scattered.

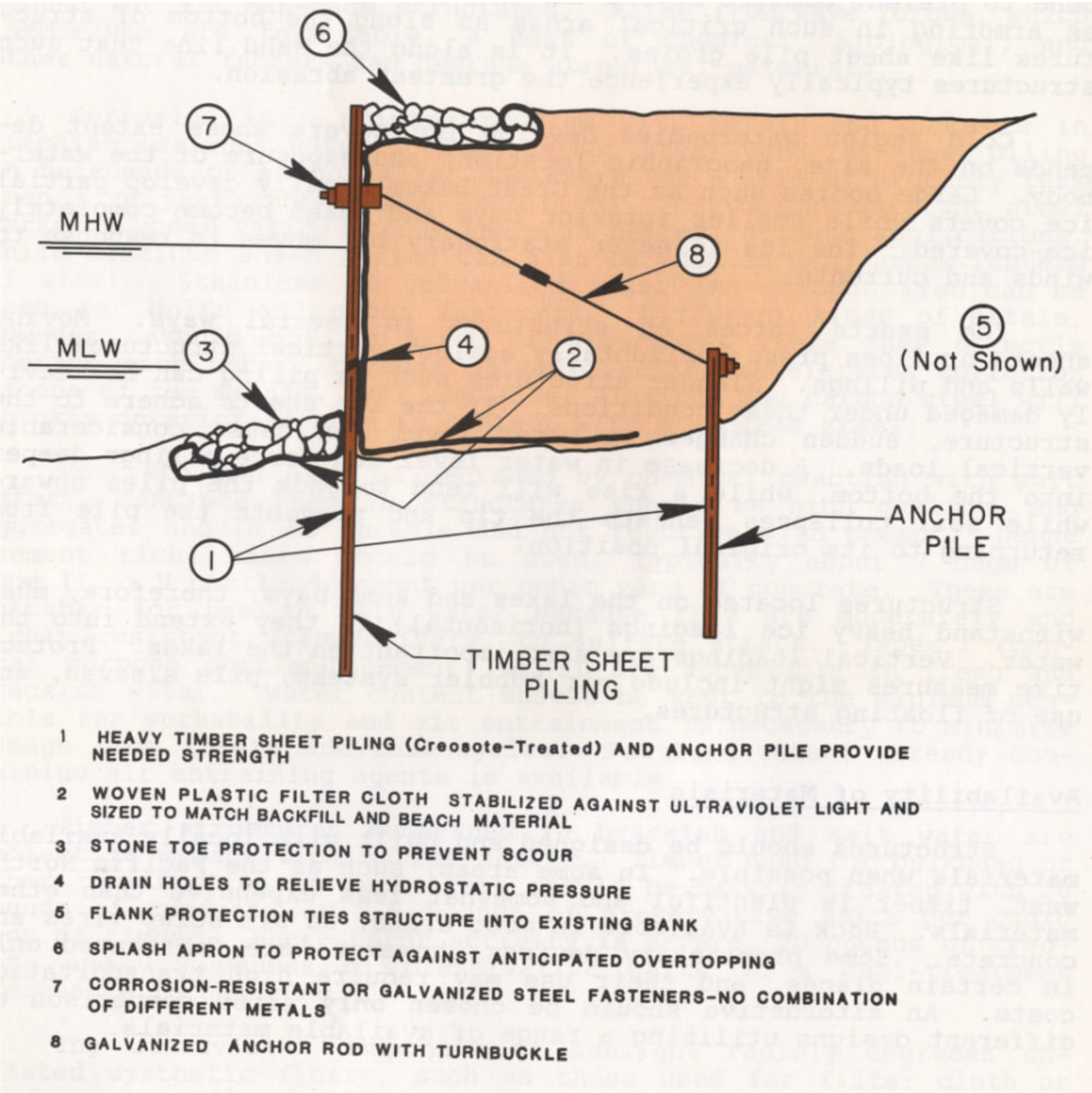


Figure 23 Illustration of Structural Design Considerations

THE CONSTRUCTION STAGE

Even with a correct design, the success or failure of a shore protection device often depends on how well the ideas set forth in the design are finally implemented at the site. Several items are important to minimizing problems during construction.

Permits

Federal, state, and possibly local permits are required for construction in, across, under, or on the banks of navigable waters of the United States. Federal permits affecting homeowners are issued primarily as a result of two laws, Section 10 of the Rivers and Harbors Act of 1899 and Section 404 of the Clean Water Act of 1977, as amended. Section 10 of the 1899 Act requires permits for structures and dredging in navigable waters of the United States, which are those coastal waters subject to tidal action and inland waters used for interstate or foreign commerce. In tidal areas, this includes all land below the mean high water line.

On the Great Lakes, permits are required under this section for construction lakeward of the highwater mark, the definition of which varies from state to state and often with the federal definition. Where doubt exists, an appropriate local state agency or Corps district office can provide assistance.

Section 404 of the Clean Water Act mandates a Corps permit for Placement of fill or dredged material in waters of the United States, which extend inland to the headwaters of rivers at a point where the average flow is 5 cubic feet per second.

The permit application process would be involved if a homeowner wishes to construct, for example, a bulkhead and beach fill adjacent to navigable waters. The permit for the bulkhead comes under Section 10. The beach fill requires a Section 404 permit and may, in some locations, also require a Section 10 permit. Upon receipt of the application, including a location map and drawing, a public notice describing the proposed work and inviting comments is normally issued. The comment period is usually 30 days but may be shortened for emergency construction. Permit applications are generally coordinated with appropriate federal, state, and local agencies, as well as adjacent property owners. This sometimes leads to comments, which then require modification of the original proposal. Beyond these possible modifications, if the comments received and the study conducted by the Corps reveal no overriding public interest or environmental problems, the application is then approved and a permit issued. Although variations exist, the process normally takes between 75 and 90 days for routine applications. Controversial applications can take considerably longer.

The Corps has adopted a number of conditional general permits on a regional and nationwide basis to reduce red tape and paperwork. No separate application is required for activities where general permits have been issued. Applicants should check with the local District Engineer to determine if the proposed work is covered by a general permit and what conditions may apply.

Additional information pertinent to your local area is available at Corps of Engineers' district offices or state coastal zone management offices and local agencies. *The landowner is strongly advised to contact them early in his planning so that later delays can be avoided.*

<u>Site Accessibility</u>

Proper planning also involves determining if the project can be built using only hand tools and portable power equipment, or if heavy equipment is also necessary. If equipment, such as pile drivers or front-end loaders, is required, you must determine if access to the site is available. Although this usually should not be a problem, it may be difficult to get equipment and materials to the water's edge in some areas, such as along high bluff shorelines. In such cases, it may be possible to reach the shoreline on a neighbor's property and drive along the shore to the job site, all of which requires special permission and possible extra expense for property damage.

<u>Hiring a Contractor</u>

If seeking to employ a contractor, identify a reputable firm in your area and ask for a list of his recent similar projects. Contact the owners to arrange for personal inspection of the work, and ask questions to help you assess if the contractor's past performance equals his claims. After selecting a contractor, plans and specifications should be prepared before work begins. You can provide them to the contractor or have the contractor prepare and submit them to you for approval. In either case, these documents should contain some or all of the following items [U.S. Army Corps of Engineers (1979)].

1. The location of the work site should be clearly identified in relation to identifiable references, such as the highway right-of-way, the shore, and your house. The limits of work should also be clearly delineated.

2. A survey showing property lines and the elevations of devices and fill according to a standard datum, such as MLW, MLLW, LWD, or IGLD.

3. A typical cross section(s) including all dimensions, slopes, connections, and other necessary design details.

4. A materials list showing estimated quantities required for the entire job.

5. The limits of excavation and backfill as they affect measurement and payment.

6. Other construction details, such as weep holes, construction joints, flank protection, anchorage, splicing and bracing, filters, and arrangement of cables and fasteners.

7. Pile construction details, such as number of piles, their length, driving requirements, cutoff elevations, and framing details.

Sample specifications describing requirements of the work are shown in Figure 24.

The sample specifications given below are typical of those needed for a contractor to build several shore protection structures. They are supplied only for illustrative purposes and are not intended to be exhaustive lists of particulars (guide specifications) from which specifications for any particular job could be developed. Additional information given in the text or the suggested reading list could also be used to supplement the specifications given below. Specifications for other materials not mentioned could be developed from information given in the text or provided by manufacturers and suppliers, or from federal, state and local government agencies.

SITE PREPARATION

The required work consists of furnishing and placing a stone revetment, a timber bulkhead, and a steel sheet pile bulkhead as indicated on the drawings and herein. All work shall be conducted so as to prevent damage to structures which are to remain and to maintain or improve the aesthetics and ecology of the site.

QUARRYSTONE

Areas where quarrystone is to be placed shall be trimmed and dressed as needed to provide stable bedding and placement within allowable tolerances. Where armor stone areas are below the required depth, they shall be brought to grade by filling with a stone underlayer. To the extent practicable, the larger sizes of stone in the underlayer shall be placed on the upper surface of the underlayer. Armor and toe stone shall be in pieces generally compact in shape and as nearly cubical as possible, with the least dimension of any stone being not less than one-third its greatest dimension.

All required stone shall be produced from quarries approved by the Owner.

It shall consist of a well-graded mixture of sizes that will form a compact mass in place. The armor and underlayer stone shall conform to maximum and minimum size limits as specified on the drawings. Where space does not permit the inclusion of the larger sizes of stone, these shall be omitted from the mixture.

Stones shall be placed by equipment suitable for handling material of the sizes required. The armor stone shall be placed a minimum of two layers thick. Suitable equipment shall be used to carefully place the stone. End dumping will not be permitted, nor shall stones be dropped from a height greater than three feet. Stones shall not be dropped onto exposed filter fabric.

Armor and toe stones shall be placed to the grades sown up the drawings, within a tolerance of 0.5 foot above grade or 0.5 foot below grade, measured perpendicular to the grade lines. The intention is for the stone protection to be built to at least the grade lines, with the outer surfaces reasonably even and uniform in appearance, and with no extreme ranges in tolerance between adjacent stones.

FILTER FABRIC

The armor and toe stone shall be underlain with a plastic filter cloth, the openings of which are appropriate for the soil conditions at the site. The cloth shall contain stabilizers or inhibitors to prevent deterioration of the fabric due to ultraviolet light or heat exposure. The fabric should be manufactured so that the yarns maintain their relative positions and spacings. In addition, the edges of the fabric shall be finished to prevent ravelling or pulling away from the main body of the cloth.
All seams in the fabric shall be sewn with thread that matches the chemical and strength requirements described above, or they shall be bonded by cementing or by heat.

No fabric shall be used if it has defects, rips, flaws, holes or otherwise shows signs of deterioration or damage during manufacture, transportation or storage. The fabric shall be placed with the long dimension perpendicular to shore and shall be free of tension, stress, folds, wrinkles or creases.

Overlap between adjacent sheets shall be a minimum of 15 inches. Securing pins shall penetrate both layers of overlapped fabric at 3-foot intervals. These pins shall be 3/16-inch in diameter, at least 18inches long, and with heads capable of retaining 1.5-inch washers.

SHOP DRAWINGS

Shop drawings shall be submitted to the Owner for his approval. The Contractor shall furnish, at the Owner's request, a certified copy of all mill reports covering the chemical and physical properties of the steel used in the work.

SHEET PILING.'STEEL AND TIMBER

Steel sheet piling, including special fabricated sections, shall be of the types indicated on the drawings and when in place, must be continuously interlocked throughout their entire length. The interlock feature must permit free and easy threading. All piles shall be provided with standard handling holes located approximately four inches below their tops. Each steel pile shall be free from kinks and shall not possess camber, twist, or warp which would prevent easy and ready driving of the pile.

Wood piles shall be treated in accordance with recognized standards such as the American Wood Preserves'-Association, Standard C18-77. The wood piles shall be pressure-treated with a minimum of one pound of preservative salts per cubic foot followed by an addition treatment of no less than 20 pounds per cubic foot of creosote. Structural lumber shall be dual treated with 1.5 pounds per cubic foot of preservative salts followed with a minimum of 20 pounds per cubic foot of creosote. The Contractor shall make provisions for field treating all cuts, holes and abrasions in the piles and lumber. Such areas shall be repaired using two brush coats of creosote followed by a heavy coat of tar paint. The lengths of piles shall be as specified on the drawings.

Equipment shall be properly sized to permit driving to required penetrations without serious damage to the piling. A protective pile cap shall be used during driving to prevent damage to the tops of the piles. Spliced piles shall not be used.

QUALITY CONTROL

The Contractor shall establish and maintain a quality control system for all operations performed under this contract to assure compliance with requirements. The Contractor shall also maintain records of his quality control for all operations performed.

Figure 24. Sample Specifications
[Adapted From U. S. Army Corps of Engineers (1978c)]

A final precaution is to begin work at the appropriate season and allow sufficient time for completion before the end of the construction season. Require firm commencement and completion dates from the contractor and hold him to schedule as long as weather permits.

Safety

While safety considerations are generally matters of common sense, the chances for serious injury and even death are increased when they are overlooked. Typical safety rules include:

1. Safe access and working conditions must always be maintained

2. A first aid kit should be available, and only those physically able to undertake the work should participate. Children and other non-workers should be excluded from the site.

3. Protective equipment, such as safety shoes, gloves, goggles, and hard hats, should be used when appropriate.

4 . Construction materials should be stored in a neat, -orderly manner, and waste materials and refuse should regularly be removed.

<u>Inspecting the Work</u>

Close inspection of the work is required, particularly if the work is performed by a contractor. You should keep a photographic record beginning with existing conditions and proceeding through completion of construction. Lines, grades, slopes, and elevations of structures should be measured to assure compliance with plans, while materials should be examined for adequate conformity with specifications. After construction, maintain a photographic record throughout the life of the structure, particularly after storms.

CONCLUSIONS

EXAMPLE DESIGN PROBLEM

A low bluff shoreline will be examined (Figure 25). The nine-foot bluff face is steep and there is no fronting beach except at low tide when gravel-covered shoreline is exposed. At high tide, the water is just above the toe of the bluff. The bluff soils are sandy-silt and the offshore slope is mild. The shoreline has steadily receded for years as is evident by the fallen trees along the shore.

Figure 25 Example Design Problem Site

The owner purchased the land to construct a retirement home (no structures have yet been built). He intends to extend a dock out to deeper water but he has no other plans for the shoreline. After examining the site, he determines that no slope stability or groundwater seepage problems exist and erosion is being caused by wave action undercutting the bluff toe (Figure 26).

Figure 26 Eroded Bluff

Design Parameters

Figure 27 is a profile of the site. As shown on the figure, the water depth was measured, the depths at spring tide and the design Stillwater level were calculated (using the Tide Tables) and the design wave height was determined following procedures described earlier in the text. The bluff toe is susceptible to erosion during the design storm when it is submerged under approximately 3.0 feet of water. A protective device must be installed to prevent further erosion.

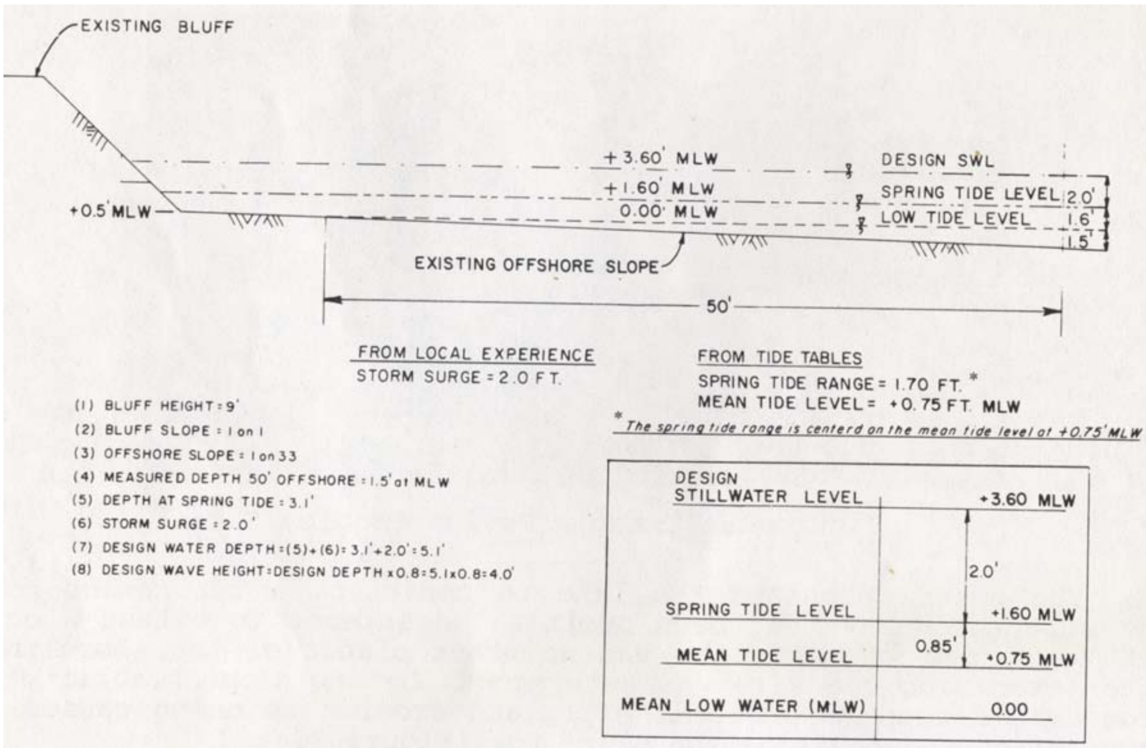


Figure 27 Profile and Physical Conditions at the Site

Device Selection

Bulkheads are applicable to low bluffs if frequent access to the shore is not required. At this site, a bulkhead would not interfere with the planned use of the property and once backfilled to the height of the existing bluff, the amount of useable land would be increased. Any of the sheet pile bulkheads would easily meet the design wave and other criteria. It is likely, however, that their material and installation costs at this site would be significantly greater than other devices that would also meet the design criteria. The post supported bulkhead using treated timber sheeting is well suited and will be illustrated in this design example. The Longard tube was not selected for aesthetic reasons and its short life expectancy when exposed to water-borne debris. The stacked used tire and used concrete pipe bulkheads were rejected because they did not meet the design wave criteria.

Regrading is acceptable, as the land is undeveloped, so revetments are a possibility. Little useable land would be lost in this case because of the low bluff height. A rubble revetment is a likely alternative because stone is available in the area at a reasonable price. A typical design will be shown. Concrete blocks would also be applicable. The steps involved in designing concrete block and stone revetments are similar and therefore will not be repeated, but in a real design, the comparative costs of stone and concrete block revetments should be developed. Stacked bags and mats were eliminated for aesthetic reasons and because of short life expectancy when exposed to water-borne debris and bombardment by stones and cobbles. Gabions were also judged to be too short-lived in this situation. Materials for fuel barrel and concrete slab revetments were unavailable.

A breakwater does not provide positive protection to the bluff toe. To avoid downdrift erosion problems, sand would have to be imported from a borrow area nearby. This would require additional expense and would still not provide positive toe protection. Therefore, all breakwaters were eliminated. Groins were also rejected for the same reasons.

A beach fill and a perched beach were considered as possibilities because the offshore slope is mild. However, they do not positively protect the bluff toe and enhanced recreational use of shoreline was not a high priority of the owner. Because neither would provide the needed protection, they were not selected as possible alternatives. Slope flattening or infiltration and drainage controls were inappropriate. Slope flattening, however, would be a part of the revetment design and proper groundwater drainage would be included in all designs.

Vegetation, if used alone, would be ineffective. Completion of the Vegetation Stabilization Site Evaluation Form (Figure 28) yields a score of 32, which places the site just beyond the acceptable range.

One possible combination approach will be developed that employs devices that were rejected when considered alone: a gabion revetment, a perched beach retained by a sand bag sill, and vegetation. The vegetation will provide a buffer zone to inhibit wave action against the bluff toe. The existing gravel beach will not support plantings so the perched sand beach and sill are provided to encourage plant growth while also protecting the new plantings against wave action. A recomputation of the Evaluation Form (Figure 28), with a perched beach of medium sand, yields a score of 28, which is in the acceptable range.

1. SHORE VARIABLES	2. DESCRIPTIVE CATEGORIES (SCORE AS INDICATED)						3. SCORE	
a. FETCH - AVERAGE AVERAGE DISTANCE IN KILOMETERS (MILES) OF OPEN WATER MEASURED PERPENDICULAR TO THE SHORE AND 45° EITHER SIDE OF PERPENDICULAR	Score : 0 LESS THAN 3.0 (1.8)	Score : 2 3.1 (1.9) to 6.0 (3.7)	Score : 4 6.1 (3.8) to 9.0 (5.6)	Score : 6 9.1 (5.7) to 12.0 (7.5)	Score : 8 12.1 (7.6) to 15.0 (9.4)	Score : 10 GREATER THAN 15.0 (9.4)	0	Average Fetch = 0.9 mi.
b. FETCH - LONGEST LONGEST DISTANCE IN KILOMETERS (MILES) OF OPEN WATER MEASURED PERPENDICULAR TO THE SHORE OR 45° EITHER SIDE OF PERPENDICULAR	Score : 0 LESS THAN 4.0 (2.5)	Score : 2 4.1 (2.6) to 8.0 (5.0)	Score : 4 8.1 (5.1) to 12.0 (7.5)	Score : 6 12.1 (7.6) to 16.0 (10.0)	Score : 8 16.1 (10.1) to 20.0 (12.6)	Score : 10 GREATER THAN 20.0 (12.6)	0	Longest Fetch = 1.3 mi
c. SHORELINE GEOMETRY GENERAL SHAPE OF THE SHORELINE AT THE POINT OF INTEREST PLUS 200 METERS (660 FT) ON EITHER SIDE	Score : 0 COVE (SHORE SITE)	Score : 2 IRREGULAR SHORELINE (SHORE SITE)	Score : 4 HEADLAND OR STRAIGHT SHORELINE (SHORE SITE)				0	Cove
d. SHORE SLOPE SLOPE OF THE PLANTING AREA (VERTICAL TO HORIZONTAL)	Score : 0 GRADUAL 1 to 15 OR LESS	Score : 4 STEEP MORE THAN 1 to 15					0	1 on 33
e. SEDIMENT GRAIN SIZE OF SEDIMENTS	Score : 0 SILT & CLAY	Score : 2 FINE SAND	Score : 4 MEDIUM SAND	Score : 6 COARSE SAND	Score : 8 GRAVEL		8	Coarse Gravel
f. BOAT TRAFFIC PROXIMITY OF SITE TO NAVIGATION CHANNELS FOR LARGE VESSELS OR SMALL RECREATIONAL CRAFT	Score : 0 NO NAVIGATION CHANNEL WITHIN 1 KILOMETER (0.6 MILES)	Score : 8 NAVIGATION CHANNEL WITHIN 1 KILOMETER (0.6 MILES)	Score : 16 NAVIGATION CHANNEL WITHIN 100 METERS (330 FT)				16	<100m
g. WIND THE ORIENTATION OF THE SITE IN RELATION TO LOCAL WINDS	Score : 0 SHELTERED FROM WIND	Score : 4 DOES NOT FACE IN THE DIRECTION OF PREVAILING WINDS OR FREQUENT STORM WINDS	Score : 8 FACES IN THE DIRECTION OF PREVAILING WINDS OR FREQUENT STORM WINDS				8	Exposed
4. CUMULATIVE WAVE CLIMATE SCORE							32	

SCORE = 1 TO 10:	USE SPRIGS AT 3-FOOT SPACINGS IN 10-FOOT (MINIMUM) ZONES.
= 11 TO 20:	USE SPRIGS OR 15-WEEK SEEDLINGS AT 1½-FOOT SPACINGS IN 10-FOOT (MINIMUM) ZONES.
= 21 TO 30:	USE 5-7 MONTH SEEDLINGS OR PLUGS AT 1½-FOOT SPACINGS IN 20-FOOT (MINIMUM) ZONES.
= ABOVE 30:	DO NOT PLANT

Figure 28 Site Evaluation Form for Marsh Plants [U.S. Army Corps of Engineers (1980)]

<u>Design Example No. 1 - Treated Timber Bulkhead</u>

Runup Calculation. From Table 4. with the design wave height,
H = 4.0 feet for a vertical face

$$R = 2.0\ H = 2.0 \times 4.0 = 8.0 \text{ feet}$$

The design top of structure is at the crest of the bluff, or +9 feet MLW. The runup above the design Stillwater level would be to +11.6 feet MLW (8.01 + 3.61). The structure, therefore, will be overtopped during design conditions, and a splash apron must be provided at the crest.

Backfill. Only granular backfill material should be used. The fall must be placed and compacted around the deadmen before any is placed behind the wall. Otherwise, load would be applied to the wall without support of the anchoring system and failure could result.

Filter Cloth. A continuous filter cloth is provided behind the planks and under the overtopping apron. It is needed to prevent the backfill and natural bluff material from being washed out. Additional holes in the wall were not included in the design because the small spacing between the planks will provide sufficient drainage.

Toe Protection. Toe protection is provided to insure stability against scour. A filter cloth is used to prevent settlement of the rock. Given a unit weight of stone, w = 165 lbs/ft and a design wave height, H = 4.0 feet; from Tables B-1, B-2 and B-3 *(APPENDIX B)*, find the required stone weight, W.

From Table B-1, with H = 4.0 feet, W = 390 pounds.

The toe protection is placed on an essentially flat surface so enter Table B-2 with the flattest slope shown (1:6) to correct W.

From Table B-2, for a 1 on 6 slope (1:6), the correction factor, K_1= 0.3. Therefore,

$$W = 390 \times 0.3 = 120 \text{ pounds}$$

The range of allowable stone weights is 0.75W to 1.25W with 75% greater than W, therefore,

$$w_{min} = 0.75 \times 120 = 90 \text{ pounds}$$
$$w_{max} = 1.25 \times 120 = 150 \text{ pounds}$$

Seventy-five percent should exceed 120 pounds and no stone should be accepted if the longest dimension is more than three times the shortest.

Flanking. The bulkhead will be tied into the existing bluff.

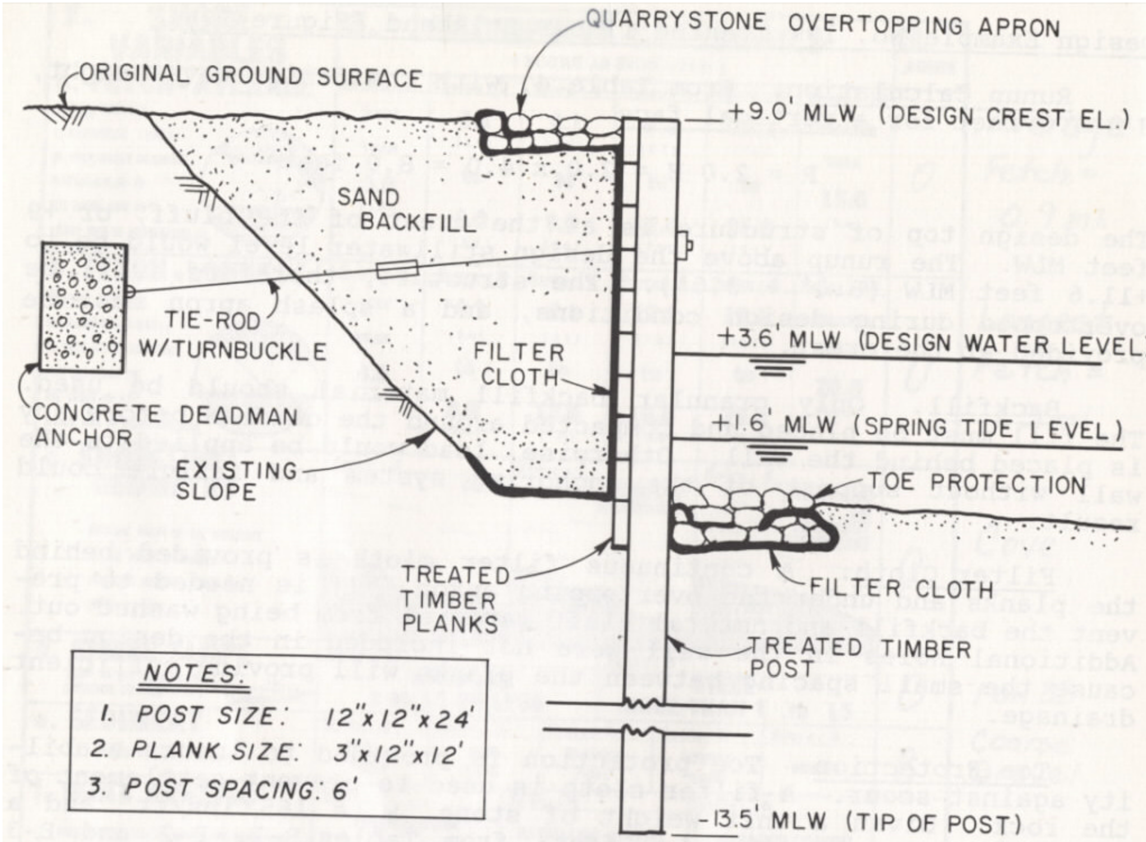


Figure 29 Treated Timber Bulkhead

Design Example No. 2 - Quarrystone Revetment (Figure 30)

Required Slope. The selected slope angle depends on the amount of available land at the top of the bluff, the amount of runup expected and the cost of materials. A milder angle results in less runup, smaller stone sizes, greater slope length, and more loss of land. A 1 on 2.5 slope was selected.

Runup Calculation. From Table 4, for a rough face structure with a 1 on 2.5 slope, the runup, R = 1.0 H or 4.0 feet. The revetment must extend vertically 4.0 feet above the design stillwater level. There is enough height available (5.4 feet) and no splash apron is required.

Weight of Armor and Underlayer Stone. Use Tables B-1 and B-

Armor Stone. Given: H = 4.0 feet

W = 390 pounds (Table B-1)
K_1 = 0.8 (Table B-2) for a 1 on
2.5 slope

Therefore: Use W = 390 x 0.8 = 310 pounds.

Underlayer Stone. Use W/10 = 30 pounds.

Range of Allowable Stone Weights. The range for both the armor and underlayer is 0.75W to 1.25W with 75% of the stones weighing more than W. All stones should be sized so that no side is greater than 3 times its least dimension.

Armor Layer. W_{min} = 0.75 x 310 = 235 pounds.
W_{max} 1.25 x 310 = 390 pounds.

75% must exceed 310 pounds.

Underlayer. W_{min} = 0.75 x 30 = 20 pounds.
W_{max} = 1.25 x 30 = 40 pounds.

75% must exceed 30 pounds.

Filter Cloth. A properly sized filter cloth will allow water to pass while retaining the bluf f soil. When laying the filter cloth, insure continuous coverage by overlapping the cloth edges at least 18 inches.

Toe Protection. Bury the toe (extend the slope down into shore) at least one design wave height below the existing bottom. Add an additional layer of armor stone to thicken the toe section.

Flank Protection. The revetment will be tied into the existing bank.

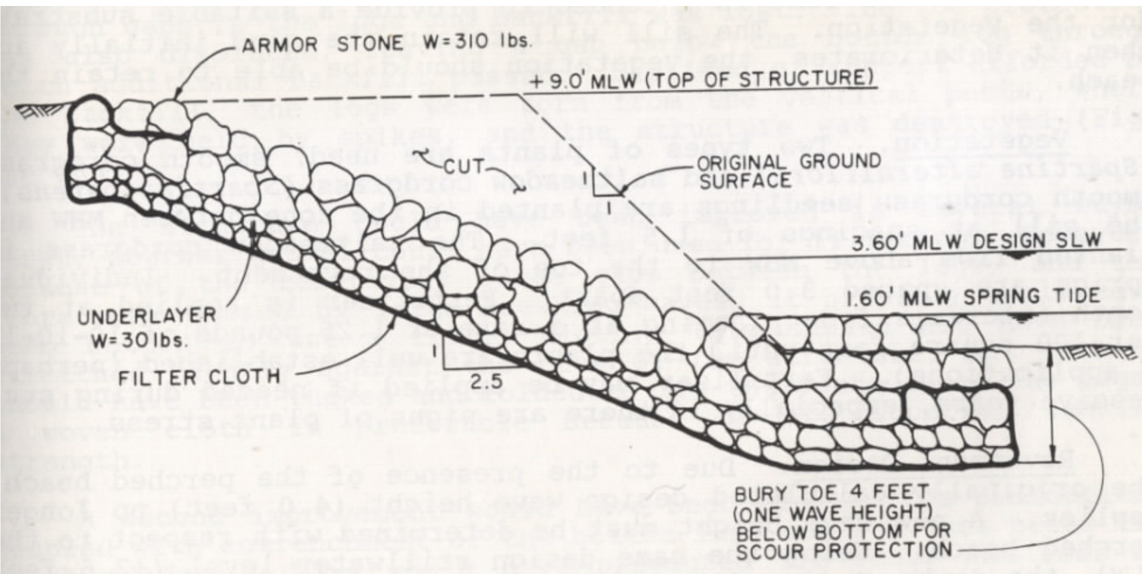


Figure 30 Quarrystone Revetment

Select Sill Material. Sand filled bags were chosen because the sill is only needed temporarily while the vegetation becomes established. The bag material and seams should be ultraviolet resistant. To insure better bag-to-bag contact, they should be filled to about 75 percent capacity and stacked. Settlement should not be a problem because the bags are underlain with a suitable filter cloth that provides a foundation. The splash apron is provided to prevent sand fill from being eroded when a wave breaks over the sill. Toe protection for the sill is provided by a row of sandbags on the edge of the filter cloth.

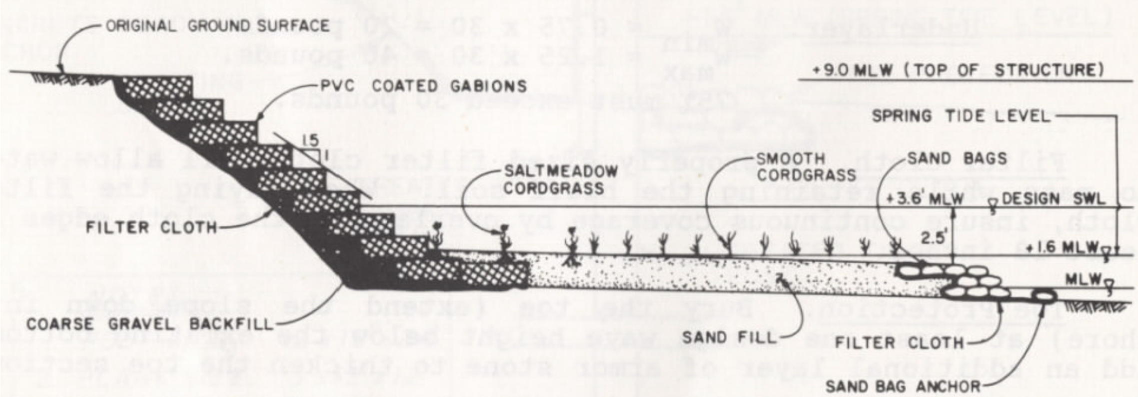


Figure 31 Perched Beach With Vegetation and Revetment

Sand Fill. Medium sand is imported from a nearby site for the beach fill. The sand is intended to provide a suitable substrate for the vegetation. The sill will retain the sand initially and when it deteriorates, the vegetation should be able to retain the beach.

Veqetation. Two types of plants are used, smooth cordgrass *(Spatina alterniflora)* and saltmeadow cordgrass *(Spartina patens)*. Smooth cordgrass seedlings are planted in the zone between MHW and the sill at spacings of 1. 5 feet. The saltmeadow cordgrass is planted from above MHW to the toe of the revetment. Individual sprigs are spaced 3.0 feet apart. Fertilizer is applied at two month intervals from planting at a rate of 1.25 pounds of 10-10-10 per 100 square feet until the plants are well established (perhaps 4 applications). Fertilizer may be applied if needed during successive years, especially if there are signs of plant stress.

Revetment Design. Due to the presence of the perched beach, the originally calculated design wave height (4.0 feet) no longer applies. A new wave height must be determined with respect to the perched beach. Using the same design Stillwater level (+3.6 feet MLW), the depth at the sill should be about 2.5 feet, assuming that the sill is roughly 1.5 feet high. The design wave height (H) is, therefore, 0.8 x 2.5 = 2.0 feet. Gabions are used to form a stepped face revetment. Using Table 4, for a 1 on 1. 5 slope, the expected runup, R = 2. 0 H or 2. 0 x 2. 0 = 4. 0 feet. The proposed design provides more than enough height (5.4 feet) above the design Stillwater level to accommodate the runup. To construct the revetment, the existing bluff does not have to be graded to a milder slope; however, some excavation is needed for the top tier of baskets. The baskets should be PVC-coated and packed tightly with stones at least four inches in diameter.

Filter Cloth. Two filter cloths are used in the design. The cloth for he sill should be sized to match the sand fill and insitu bottom material. The filter cloth for the revetment should be sized to retain the bluff material. To insure continuity, the cloth should have an 18-inch overlap at the seams.

SELECTED CASE HISTORIES

Untreated Log Bulkhead

Figure 32 is a photograph taken in November 1978 showing a bulkhead constructed in mid-1978 with untreated logs and designed to protect the toe of a high bluff. The logs are substantial and do not appear susceptible to damage by even severe wave action. In addition, stone toe protection was provided to prevent problems due to scour. Gravel was placed behind the logs as a filter. On February14, 1979, a severe storm struck the site with wave heights of perhaps four to five feet (these were greater than the design conditions). As a result, the gravel filter material was washed through gaps in the logs and backfill was lost. The toe protection was also displaced, leaving a gap below the bottom log through which additional backfill passed. Deprived of support afforded by the backfill, the logs were torn from the vertical posts, where they were held by spikes, and the structure was destroyed (Figure 33).

The structure could have been improved in several ways. First, coarser gravel could have been used for filtering. However, because of the relatively large gaps between the logs, and the vibrations caused by large breaking waves, it probably would have been better to use a filter cloth-. This should not have been stretched tightly against the back of the structure, but rather, should have been tucked and folded to fit the contours of the logs. A woven cloth is preferable because of its superior tensile strength. A second improvement would have been heavier toe protection, coupled with entrenchment of the bottom logs several feet below the beach surf ace. This would have prevented toe scour and loss of backfill material through the bottom.

Figure 32 Untreated Log Bulkhead (November 1978)

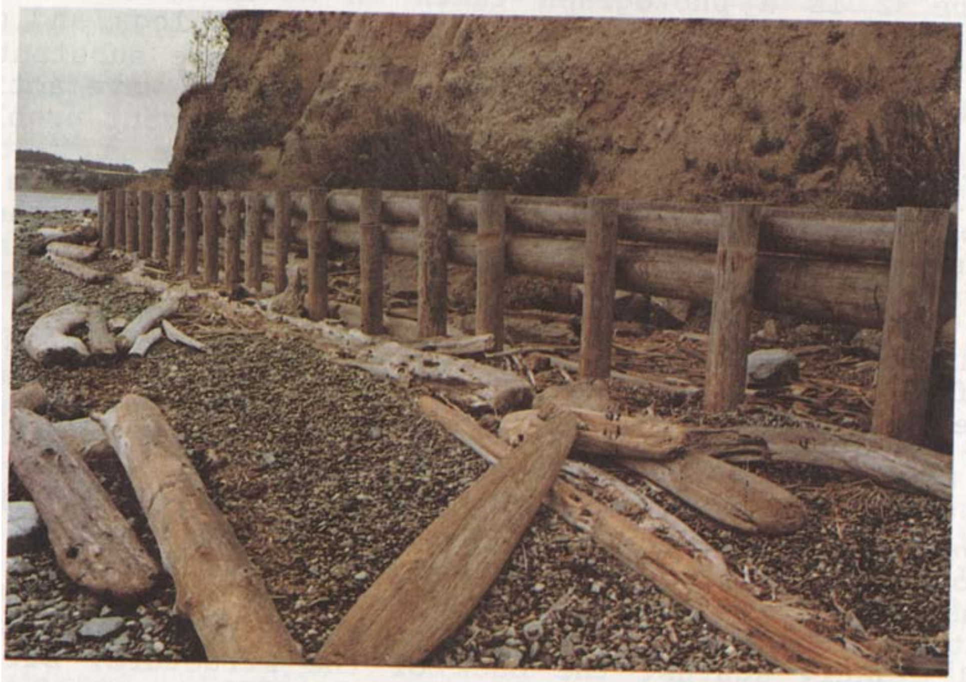


Figure 33 Untreated Log Bulkhead (February 1979)

<u>Monoslab Revetment BEGIN FULL REVISONS HERE</u>

Figure 34 shows a Monoslab (Turfblock) revetment constructed 1978. The structure was battered by a large storm after completion. Waves during the storm were estimated at more than six feet high (these were greater than the design wave height). The most likely cause of failure was the uncompacted fill material containing large rocks. As this material consolidated after placement, the Monoslabs were subjected to differing amounts of settlement. Blocks left resting on rocks in the fill became tilted and vulnerable to overturning by the passing wave uprush. Failure probably began with a few isolated blocks and quickly spread through most of the revetment. The blocks seem to have had sufficient weight because they were not displaced very far.

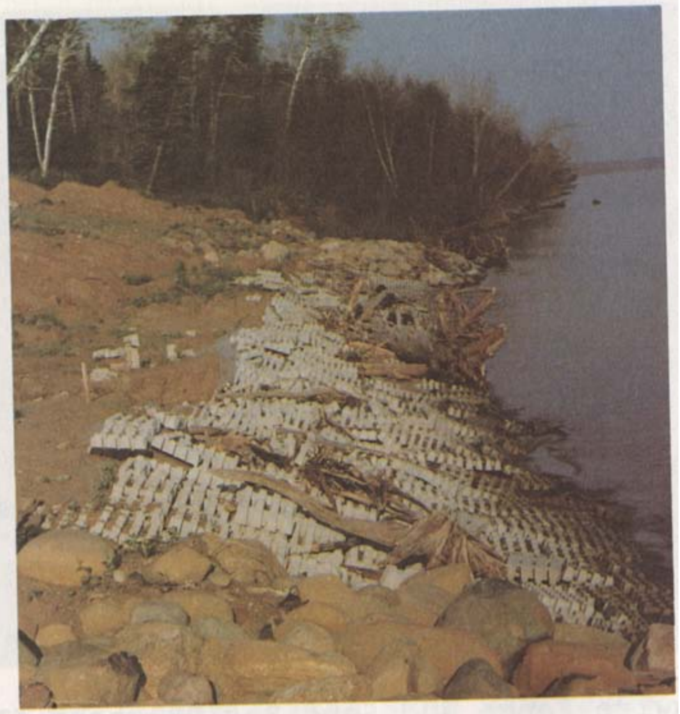


Figure 34 Monoslab Revetment

The lesson here is the necessity of a firm foundation. Any fill material should be adequately compacted prior to revetment construction, and no large rocks or foreign bodies should be in the fill. The structure also illustrates how suddenly the design conditions, or greater, can occur, and how quickly and completely an investment in shore protection can be lost.

Hogwire Fence - Sand Bag Bulkhead

Figure 35 shows the structure, which was intended to protect the low bluff from wave erosion, immediately after its construction in December 1978. Scour was anticipated during design but as it actually occurred, the bags slid down the inside of the hogwire fence, some being torn by the wire and spilling their contents (Figure 36). At the other end of the bulkhead, a different kind of bag, not resistant to ultraviolet light, was used. The bottom photograph, Figure 37, illustrates the dramatic deterioration that occurred in only six months.

Figure 35 Hogwire Fence and Sand Bag Bulkhead (December 1978)

Figure 36 Hogwire Fence and Sand Bag Bulkhead (June 1979)

Improvements to the structure would include the following. First, the bags and fence should have been founded in a trench excavated several feet below the existing beach level to eliminate movement against all but severe toe scour. Second, the outside course of bags should have been filled with grout, which would eliminate dependence on the bag fabric. Third, PVC-coated wire fencing should have been used since it would have had less tendency to tear the bags, and the wire itself would be free of corrosion. Finally, since sand filling was used, only bags with ultraviolet resistant fabric and seams should have been placed.

Figure 37 Deteriorated Sand Bag (June 1979)

OTHER HELP

Corps of Engineers Offices

It is imperative to contact the Corps early in your planning to preclude any unnecessary delays later in the permit process. Corps offices are also possible sources of information on water levels, wave action, and other physical conditions at the site. Mail addresses, office locations, and phone numbers for Corps personnel familiar with coastal processes are in Table 5.

Table 5

CORPS OF ENGINEERS OFFICES

Address	Phone	Jurisdiction
U. S. Army Engineering Division, New England 424 Trapelo Road Waltham, Massachusetts 02154	617/894-2400 X-554	Atlantic coast from Maine to the Connectic New York Line
U. S. Army Engineering District, New York 26 Federal Plaza New York, New York 10007	212/264-5174	Atlantic coast of New York and the New Jersey coast north of Manasquan Inlet

U. S. Army Engineering District, Philadelphia U. S. Custon House 2nd and Chestnut Street Philadelphia, Pennsylvania 19106	215/597-4714	Atlantic coast of New Jersey and Delaware from Manasquan Inlet, south to the Delawa Maryland Line, including Delaware Bay ar the C&D Canal
U. S. Army Engineering District, Baltimore P. 0. Box 1715 Baltimore, Maryland 21203 Office Location: 31 Hopkins Plaza Baltimore, Maryland 21201	301/962-2545	Atlantic and Chesapeake Bay shorelines of Maryland
U. S. Army Engineering District, Norfolk 803 Front Street Norfolk, Virginia 23510	804/441-3764	Atlantic and Chesapeake Bay shorelines of Virginia
U. S. Army Engineering District, Wilmington P. 0. Box 1980 Wilmington, North Carolina 28402 Office Location: 308 Federal Building Wilmington, North Carolina	919/343-4778	Atlantic coast and interior bays and sounds of North Carolina
U. S. Army Engineering District, Charleston P. 0. Box 919 Charleston, South Carolina 29402 Office Location: Federal Building 334 Meeting Street Charleston, South Carolina 29402	803/724-4248	Atlantic Coast of South Carolina
U. S Army Engineering District, Savannah P. 0. Box 889 Savannah, Georgia 31402 Office Location: 200 E Saint Julian Street Savannah, Georgia 31402	912/944-5502	Atlantic coast of Georgia
U. S. Army Engineer District, Jacksonville P. 0. Box 4970 Jacksonville, Florida 32201 Office Location: 400 West Bay Street Jacksonville, Florida 32202	904/791-2204	Atlantic coast of Florida and Gulf coast of Florida to the St. Marks River
U. S. Army Engineering District, Mobile P. 0. Box 2288 Mobile, Alabama 36628 Office Location: 109 St. Joseph Street Mobile, Alabama 36602	205/690-3482	Gulf Coast of Florida from the St. Marks River west Louisiana-Mississippi line

U. S. Army Engineering District, New Orleans P. 0. Box 60267 New Orleans, Louisiana 70160 Office Location: Foot of Prytania Street New Orleans, Louisiana 70160	504/838-2480	Gulf coast of Louisiana
U.S. Army Engineering District, Galveston P.0. Box 1229 Galveston, Texas 77553 Office Location: 110 Essayons Boulevard 400 Barracuda Avenue Galveston, Texas 77550	713/764-1211 X -314	Gulf coast of Texas
U.S. Army Engineering District, Los Angeles P.0. Box 2711 Los Angeles, California 90053 Office Location: 300 North Los Angeles Street Los Angeles, California 90012	213/688-6400	Pacific coast of CA from the Mexican border North to Cape San Martin
U. S. Army Engineering District, San Francisco 211 Main Street San Francisco, California 94105	415/556-5370	Pacific coast of CA from Cape San Martin north to the CA-OR line including San Francisco Bay
U.S. Army Engineering District, Portland P.0. Box 2946 Portland, Oregon 97208 Office Location: Mulnomah Building 319 S.W. Pine Portland, Oregon 97204	503/221-6477	Pacific coast of Oregon
U.S. Army Engineering District, Seattle P.0. Box C-3755 Seattle, Washington 98124 Office Location: 4735 East Marginal Way South Seattle, Washington	206/764-3555	Pacific coast of Washington and Puget Sound
U.S. Army Engineering District, Alaska P.0. Box 7002 Anchorage, Alaska 99510 Office Location: Building 21-700 Elmendorf Air Force Base, Alaska	907/752-3925	Coast of Alaska
U. S. Army Engineering Division, Pacific Ocean Building 230 Ft. Shafter, Hawaii 96858	808/438-2837	Hawaii and the Pacific Trust Territories

Address	Phone	Jurisdiction
U.S. Army Engineering District, Detroit P.0. Box 1027 Detroit, Michigan 48231 Office Location: Patrick V. McNamara Building R 477 Michigan Avenue Detroit, Michigan 48226	313/226-6791	U.S. shorelines of Lakes Superior, Huron and St. Clair; the Lake Michigan Shoreline except in IL and IN, Lake Erie shoreline of MI
U. S. Army Engineering District, Chicago 219 S. Dearborn Street Chicago, Illinois 60604	312/353-0789	Lake Michigan shoreline of IL and IN
U. S. Army Engineering District, Buffalo 1776 Niagara Street Buffalo, New York 14207	716/876-5454 x-2230	U.S. shorelines of Lake Ontario and Erie except in Michigan

Table 6

State	Office Address and Phone Number

State	Office Address and Phone Number

State	Office Address and Phone Number
Virginia	Council on the Environment Ninth Floor, Ninth Street Office Building Richmond, Virginia 23219 804/786-4500
Washington	Department of Ecology PV-11 State of Washington Olympia, Washington 98504 206/753-4348

State	Office Address and Phone Number
Wisconsin	Office of Coastal Management Department of Administration General Executive Facility 2 101 South Webster Street Madison, Wisconsin 53702 608/266-3687

Proprietary Devices and Specialty Materials

The devices and many materials in this report are not generally available or familiar to local suppliers. Table 7 covers principal manufacturers that are active nationwide. Inclusion of manufacturers in this directory does not necessarily represent endorsement or recommendation by the government. In fact, some items listed herein were not recommended for specific applications in this report.

(WARNING! The accuracy of the following information has not been verified since the original publication of this document.)

Table 7

Device or Material	Manufacturer

Device or Material	Manufacturer
	DuPont Company Room 38095 Wilmington, Delaware 19898
	(Nonwoven) Menardi-Southern Division of United States Filter Soil and Erosion Control Department Headquarters 3908 Colgate Houston, Texas 77017 713/643-6513
	(Woven and Nonwoven) Nicolon Corporation Erosion Control Products Suite 1990 Peachtree Corners Plaza Norcross (Atlanta), Georgia 30071 404/447-6272 800/241-9691
	(Woven) Erosion Control Products, Inc. Route 5 Box 406 Daphne, Alabama 36526 205/626-3510

Device or Material	Manufacturer
Gabions	Terra Aqua Corporation Division of Bekaert Steel Wire Corporation P. 0. Box 7546 Reno, Nevada 89510 702/329-6262
	Maccaferri Gabions, Inc. P.O. Box 43A Williamsport, MD 21795 301/223-8700
Gobi Blocks Gobimat	Nicolon Corporation Erosion Control Products Suite 1990 Peachtree Corners Plaza Norcross (Atlanta), Georgia 30071 404/447-6272 800/241-9691
Jumbo Blocks Jumbo Ercomats	Erosion Control Systems, Inc. 3349 Ridgelake Drive Suite 101-B Metairie, Louisiana 70002 504/834-5650
Lok-Gard Blocks	Coastal Research Corporation 1100 Crain Highway, S.W. Glen Burnie, Maryland 21061 301/761-0584
Longard Tube	Edward E. Gillen Company 218 West Becher Street Milwaukee, Wisconsin 53207 414/744-9824
Nami Ring	Robert Q. Palmer 5027 Justin Drive, N.W. Alburquerque, New Mexico 87114
Sandgrabber	Sandgrabber, Inc. 3105 Old Kawkawlin Road Bay City, Michigan 48706 517/686-6601
Surgebreaker	Great Lakes Environmental Marine, Ltd. 39 South LaSalle Street Chicago, Illinois 60603 312/332-3377

Device or Material	Manufacturer
Terrafix Blocks	Erosion Control Products, Inc. 9151 Fairgrounds Road West Palm Beach, Florida 33411 305/793-5650
Turfblock (Monoslab)	Anchor Block Company P. 0. Box 3360 St. Paul, Minnesota 55165 612/777-8321
Wave-Maze	Robert L. Stitt 10732 E. Freer Street Temple City, California
Z-Wall	The Fanwall Corporation 670 Old Connecticut Road Farmingham, Massachusetts 01701 617/879-3350

Other Sources of Information

Hydrographic Charts. Hydrographic charts are available for a small fee for all U. S. coastal waters and provide information on water depths and fetch lengths to determine exposure of a site to wave action. Identification of the specific chart for your area and important information about the available chart series are in the Nautical Catalogs below. **(WARNING! The accuracy of the following information has not been verified since the original publication of this document.)**

Catalog No. 1 - Atlantic and Gulf Coasts
Catalog No. 2 - Pacific Coast and Hawaii
Catalog No. 3 - Alaska
Catalog No. 4 - Great Lakes.

For information or mail orders write to:
Distribution Division, C44
National Ocean Survey
Riverdale, Maryland 20840
301/436-6990

Counter sales are also available at that location as well as regional offices of the National Ocean Survey at:

439 West York Street
Norfolk, Virginia 23510

and

1801 Fairview Avenue East
Seattle, Washington 90102

Charts can also be obtained from the U. S. Coast Guard at the locations below.

3rd District
Governors Island
New York, New York 10004

9th District
1240 East 9th Street
Cleveland, Ohio 44199

Water Levels. Tide Tables are available for all coastal areas of the United States. These contain predictions of high and low tide elevations and their time of occurrence for one calendar year t primary tide stations. Values of time and elevation differences from the primary station are also given for numerous secondary stations, as are normal and spring tide ranges for all stations. Tide Tables are available from the Distribution Division, National Ocean Survey, at the address above.

Lake levels are also available in summary form through the Monthly Bulletin of Lake Levels for the Great Lakes. This contains the current level for each lake, a six-month projection of future lake levels, and historic high and low lake levels. The Monthly Bulletin is available, free, from the:

Department of the Army
Detroit District, Corps of Engineers
P. 0. Box 1027
Detroit, Michigan 48231

GLOSSARY

Accretion - Accumulation of sand or other beach material at a point due to natural action of waves, currents and wind. A build-up of the beach.

Alongshore - Parallel to and near the shoreline; same as LONGSHORE.

Backhoe - Excavator similar to a power shovel except that the bucket faces the operator and is pulled toward him.

Bar - Fully or partly submerged mound of sand, gravel, or other unconsolidated material built on the bottom in shallow water by waves and currents.

Beach - Zone of sand or gravel extending from the low water line to a point landward where either the topography abruptly changes or permanent vegetation first appears.

Beach Fill - Sand or gravel placed on a beach by mechanical methods.

Beach, Perched - See PERCHED BEACH.

Bluff - High, steep bank at the water's edge. In common usage, a bank composed primarily of soil. See CLIFF.

Boulders - Large stones with diameters over 10 inches. Larger than COBBLES.

Breaker - A wave as it spills, plunges or collapses on a shore, natural obstruction, or man-made structure.

Breaker Zone - Area offshore where waves break.

Breaking Depth - Stillwater depth where waves break.

Breakwater - Structure aligned parallel to shore, sometimes shore connected, that provides protection from waves.

Bulkhead - A structure that retains or prevents sliding of land or protects the land from wave damage.

Clay - Extremely fine-grained soil with individual particles less than 0.00015 inches in diameter.

Cliff - High steep bank at the water's edge. In common usage, a bank composed primarily of rock. See BLUFF.

Cobbles - Rounded stones with diameters ranging from 3 to 10 inches. Cobbles are intermediate between GRAVEL and BOULDERS.

Crest - Upper edge or limit of a shore protection structure.

Cross Section - View of a structure or beach as if it were sliced by a vertical plane. The cross section should display structure, ground surface, and underlying material.

Culm - Single stem of grass.

Current - Flow of water in a given direction.

Current, Longshore - Current in the breaker zone moving essentially parallel to shore and usually caused by waves breaking at an angle to shore. Also called alongshore current.

Deep Water - Area where surf ace waves are not influenced by the bottom. Generally, a point where the depth is greater than one-half the surface wavelength.

Diffraction- Progressive reduction in wave height when a wave spreads into the shadow zone behind a barrier after the wave has passed its end.

Diurnal - Period or cycle lasting approximately one day. A diurnal tide has one high and one low in each cycle.

Downdrift - Direction of alongshore movement of littoral materials.

Dune - Hill, bank, bluff, ridge, or mound of loose, wind-blown material, usually sand.

Duration - Length of time the wind blows in nearly the same direction across a FETCH (generating area).

Ebb Tide - Part of the tidal cycle between high water and the next low. The falling tide.

Equilibrium - State of balance or equality of opposing forces.

Erosion - Wearing away of land by action of natural forces.

Fetch - Area where waves are generated by wind, which has steady direction and speed. Sometimes called FETCH LENGTH.

Fetch Length - Horizontal direction (in the wind direction) over which a wind generates waves. In sheltered waters, often the maximum distance that wind can blow across water.

Filter Cloth - Synthetic textile with openings for water to escape,
but which prevents passage of soil particles.

Flood Tide - Part of the tidal cycle between low water and the next high. The rising tide.

Glacial Till - Unstratified glacial drift consisting of unsorted clay, sand, gravel, and boulders, intermingled.

Longshore - Parallel to and near the shoreline: same as ALONGSHORE.

Longshore Transport Rate - Rate of transport of littoral material parallel to shore. Usually expressed in cubic yards per year.

Low Tide - Minimum elevation reached by each falling tide.

Low Water Datum (LWD) - The elevation of each of the Great Lakes to which are referenced the depths shown on navigation charts and the authorized depths of navigation projects.
Marsh - Area of soft, wet, or periodically inundated land, generally treeless, and usually characterized by grasses and other low growth.

Mean Higher High Water (MHHW) - Average height of the daily higher high waters over a 19-year period. Only the higher high water of each pair of high waters of a tidal day is included in the mean.

Mean High Water (MHW) - Average height of the daily high waters over a 19-year period. For semidiurnal or mixed tides, the two high waters of each tidal day are included in the mean. For diurnal tides, the single daily high water is used to compute the mean.

Mean Lower Low Water (MLLW) - Average height of the daily lower-low waters of a 19-year period. Only the lower low water of each pair of low waters of a tidal day is included in the mean. Long used as the datum for Pacific coast navigation charts, it is now gradually being adopted for use across the United States.

Mean Low Water (MLW) - Average height of the low waters over a 19-year period. For semidiurnal and mixed tides, the two low waters of each tidal day are included in the mean. For a diurnal tide, the one low water of each tidal day is used in the mean. Mean Low Water has been used as datum for many navigation charts published by the National Ocean Survey, but it is being phased out in favor of Mean Lower Low Water for all areas of the United States.

Mean Sea Level - Average height of the sea surface over a 19-year period. Not necessarily equal to MEAN TIDE LEVEL.

Mean Tide Level - Plane midway between MEAN HIGH WATER and MEAN LOW WATER. Not necessarily equal to MEAN SEA LEVEL. Also called half-tide level.

Mixed Tide - A tide in which there is a distinct difference in height between successive high and successive low waters. For mixed tides there are generally two high and two low waters each tidal day. Mixed tides may be described as intermediate between semidiurnal and diurnal tides.

Module - A structural component, a number of which are joined to make a whole.

Neap Tides - Tides with decreased ranges that occur when the moon is at first or last-quarter- ;4nl in opposition to each other. The neap range is smaller than the mean range for semidiurnal and mixed tides.

Nearshore - In beach terminology, an indefinite zone extending seaward from the shoreline well beyond the breaker zone

Nourishment - Process of replenishing a beach either naturally by longshore transport or artificially by delivery of materials dredged or excavated elsewhere.

Offshore - (1) (Noun) In beach terminology, comparatively flat zone of variable width extending from the breaker zone to the seaward edge of the Continental Shelf. (2) (Adjective) Direction seaward from the shore.

Overtopping - Passing of water over a structure from wave runup or surge action.

Peat - Residual product produced by partial decomposition of organic matter in marshes and bogs.
Peat Pot (vegetation) - Pot formed from compressed peat and filled either with soil or peat moss in which a plant or plants, grown from seed, are transplanted without being removed from the pot.

Perched Beach - Beach or fillet of sand retained above the otherwise normal profile level by a submerged dike or sill.

Permeable - Having openings large enough to permit free passage of appreciable quantities of (1) sand or (2) water.

Pile - Long, heavy section of timber, concrete or metal driven or jetted into the earth or seabed as support or protection.

Pile, Sheet - Pile with a generally slender, flat cross section driven into the ground or seabed and meshed or interlocked with like members to form a diaphragm, wall, or bulkhead.

Piling - Group of piles.

Plug - Core containing both plants and underlying soil, usually cut with a cylindrical coring device and transplanted to a hole cut by the same device.

Polyvinyl Chloride (PVC) - Plastic material (usually black) that forms a resilient coating suitable for protecting metal from corrosion.

Profile, Beach - Intersection of the ground surface with a vertical plane that may extend from the top of the dune line to the seaward limit of sand movement.

PVC - See POLYVINYL CHLORIDE.

Ravelling - Progressive deterioration of a revetment under wave action.

Refraction (of water waves) - (1) Process by which direction of a wave moving in shallow water at an angle to the contours is changed. Part of the wave advancing in shallower water moves more slowly than the part still advancing in deeper water, causing the wave crest to bend toward alignment with the underwater contours. (2) Bending of wave crests by currents.

Revetment - Facing of stone, concrete, etc., built to protect a scarp, embankment, or shore structure against erosion by waves or currents.

Rhizome - Underground stem or root stock. New shoots are usually produced from the tip of the rhizome.

Riprap - Layer, facing, or protective mound of stones randomly placed to prevent erosion, scour, or sloughing of a structure or embankment; also, the stone so used.

Rubble - (1) Loose, angular, waterworn stones along a beach. (2) Rough, irregular fragments of broken rock or concrete.

Runup - The rush of water up a structure or beach on breaking of a wave. Amount of runup is the vertical height above stillwater level that the rush of water reaches.

Sand - Generally, coarse-grained soils having particle diameters between 0.18 and approximately 0.003 inches. Sands are intermediate between SILT and GRAVEL.

Sandbag - Cloth bag filled with sand or grout and used as a module in a shore protection device.

Sand Fillet- Accretion trapped by a groin or other protrusion in the littoral zone.

Scour - Removal of underwater material by waves or currents, especially at the base or toe of a shore structure.

Screw Anchor - Type of metal anchor screwed into the bottom for holding power.

Seawall - Structure separating land and water areas primarily to prevent erosion and other damage by wave action. See also BULKHEAD.

Semidiurnal Tide - Tide with two high and two low waters in a tidal day, each high and each low approximately equal in stage.

Setup, Wind - Vertical rise in the Stillwater level on a body of water caused by piling up of water on the shore due to wind action. Synonymous with wind tide and STORM SURGE. STORM SURGE usually pertains to the ocean and large bodies of water. Wind setup usually pertains to reservoirs and smaller bodies of water.

Shallow Water - Commonly, water of such a depth that surface waves are noticeably affected by bottom topography. It is customary to consider water of depths less than one-twentieth the surface wavelength as shallow water.

Sheet Pile - see PILE, SHEET.

Shoot - Collective term applied to the STEM and leaves, or any growing branch or twig.

Shore - Narrow strip of land in immediate contact with the sea, inc uding the zone between high and low water lines. A shore of unconsolidated material is usually called a beach.

Shoreline - intersection of a specified plane of water with the shore or beach (e.g., the high water shoreline would be the intersection of the plane of mean high water with the shore or beach). Line delineating the shoreline on National Ocean Survey nautical charts and surveys approximates the mean high water line.

Sill - Low offshore barrier structure whose crest is usually submerged, designed to retain sand on its landward side.

Silt - Generally refers to fine-grained soils having particle diameters between 0.003 and 0.00015 inches. Intermediate between CLAY and SAND.

Slope - Degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating 1-unit vertical rise in 25 units of horizontal distance; or in degrees from horizontal.

Specifications - Detailed description of particulars, such as size of stone , quality of materials, contractor performance, terms, and quality control.

Sprig - Single plant with its roots relatively bare, as pulled apart from a clump and used for transplanting.

Stem - Main axis of a plant, leaf-bearing and flower-bearing, as distinguished from the root-bearing axis.

Stillwater Level - Elevation that the surface of the water would assume if all wave action were absent.

Storm Surge - Rise above normal water level on the open coast due to action of wind on the water surface. Storm surge resulting from a hurricane also includes the rise in level due to atmospheric pressure reduction as well as that due to wind stress. See SETUP, WIND.

Swell - Wind-generated waves traveling out of their generating area. Swell characteristically exhibits a more regular and longer period, and has flatter crests than waves within their fetch.

Tidal Range - Difference in height between consecutive high and low or higher high and lower low) waters. The mean range is the difference in height between mean high water and mean low water. The diurnal range is the difference in height between mean higher high water and mean lower low water. For diurnal tides, the mean and diurnal range are identical. For semidiurnal and mixed tides, the spring range is the difference in height between the high and low waters during the time of spring tides.

Tide - Periodic rising and falling of water resulting from gravitational attraction of the moon, sun and other astronomical bodies acting upon the rotating earth. Although the accompanying horizontal movement of the water resulting from the same cause is also sometimes called tide, it is preferable to designate the latter as tidal current, reserving the name TIDE for vertical movement.

Tide Station - Place at which tide observations are being taken. A primary tide station is a location where continuous observations are taken over a number of years to obtain basic tidal data for the locality. A secondary tide station is operated over a short period of time to obtain data for a specific purpose.

Tie Rod - Steel rod used to tie back the top of a bulkhead or seawall. Also, a U-shaped rod used to tie Sandgrabber blocks together, or a straight rod used to tie Nami Rings together.

Tiller - A plant SHOOT which springs from the root or bottom of the original plant stalk.

Topography - Configuration of a surface, including relief, position of streams, roads, buildings, etc.

Transplant - SHOOT or CULM removed from one location and replanted in another.

Trough of Wave - Lowest part of a waveform between successive crests. Also, that part of a wave below stillwater level.

Updrift - Direction opposite the predominant movement of littoral materials in longshore transport.

Wake (boat) - Waves generated by the motion of a vessel through water.

Wale - Horizontal beam on a bulkhead used to laterally transfer loads against the structure and hold it in a straight alignment.

Waterline - Juncture of land and sea. This line migrates, changing with the tide or other fluctuation in water level. Where waves are present on the beach, this line is also known as the limit of backrush. (Approximately, the intersection of land with Stillwater level.)
Wave - Ridge, deformation, or undulation of the surface of a liquid.

Wave Climate - Normal seasonal wave regimen along a shoreline.

Wave Crest - Highest part of a wave or that part above stillwater level.

Wave Diffraction - See DIFFRACTION.

Wave Direction - Direction from which a wave approaches.

Wave Height - Vertical distance between a crest and the preceding trough.

Wavelength - Horizontal distance between similar points on two successive waves measured perpendicular to the crest.

Wave Period - Time in which a wave crest traverses a distance equal to one wavelength. Time for two successive wave crests to pass a fixed point.

Wave Refraction - See REFRACTION (of water waves).

Wave Steepness - Ratio of wave height to wavelength.

Wave Trough - Lowest part of a wave form between successive crests. Also, that part of a wave below that part of a wave below Stillwater level.

Weep Hole - Hole through a solid revetment, bulkhead, or seawall for relieving pore pressure.

Wind Setup - See SETUP, WIND.

Windward - Direction from which wind is blowing.

Wind Waves - (1) Waves being formed and built up by wind. (2) Loosely, any waves generated by wind.

Wave Direction - Direction from which a wave approaches.

Wave Height - Vertical distance between a crest and the preceding trough.

Wavelenth - Horizontal distance between similar points on two successive waves measured perpendicular to the crest.

Wave Period - Time in which a wave crest traverses a distance equal to one wavelength. Time for two successive wave crests to pass a fixed point.

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Wind Setup - See SETUP, WIND.

Windward - Direction from which wind is blowing.

Wind Waves - (1) Waves being formed and built up by wind. (2) Loosely, any waves generated by wind.

APPENDIX A - BULKHEADS AND SEAWALLS

SHEET PILE BULKHEADS

Wave Height Range: Above five feet.

Runup Characteristic: Vertical (all materials).

Sheet pile bulkheads consist of interconnecting or very tightly spaced sheets of material driven vertically into the ground with special pile-driving equipment. The sheeting can be made of steel, aluminum, or timber (Figures A-1, A-2, and A-3). Sheet pile structures are either cantilevers or anchored (braced).

A cantilever bulkhead is a sheet pile wall supported solely by ground penetration, making it susceptible to failure from toe scour. The sheet piling must be driven deep enough to resist overturning, which usually requires penetration to a depth two to three times the free standing height, including the anticipated scour depth (usually about one wave height below the existing bottom).

Figure A-1 Steel Sheet Pile Bulkhead

An anchored or braced bulkhead is similar to a cantilever structure, but gains additional support against seaward deflection from embedded anchors or tilted structural bracing on the seaward side. For this structure, sheet piling generally only need be embedded to a depth one and one-half to two times the height of the wall above the anticipated scour depth. Anchors are usually a row of piles or line of heavy objects with a large surface area (deadmen) driven or buried a distance behind the bulkhead. Connections between pile anchors or deadmen and the wall should be wrought iron, galvanized, or other suitably corrosion protected steel. Plain carbon steel should not be used for long term protection. Horizontal wales at or near the top of the wall facilitate construction and distribute the anchor loads laterally along the wall. Anchor systems are not well suited to sites with buildings close to the shoreline because of the distance needed between the bulkhead and anchors. In that case, brace piles may be used in place of anchoring. Figure A-4 contains cross sections of a cantilever and an anchored sheet pile bulkhead.

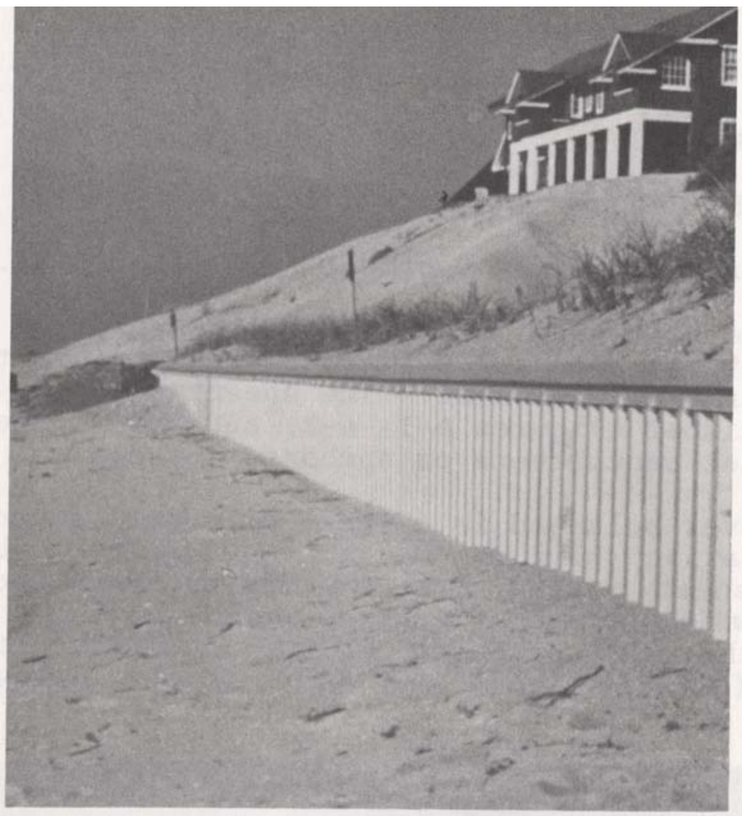


Figure A-2 Aluminum Sheet Pile Bulkhead
(Photo Courtesy of Koppers Company, Inc.)

Figure A-3 Timber Sheet Pile Bulkhead
(Photo Courtesy of Koppers Company, Inc.)

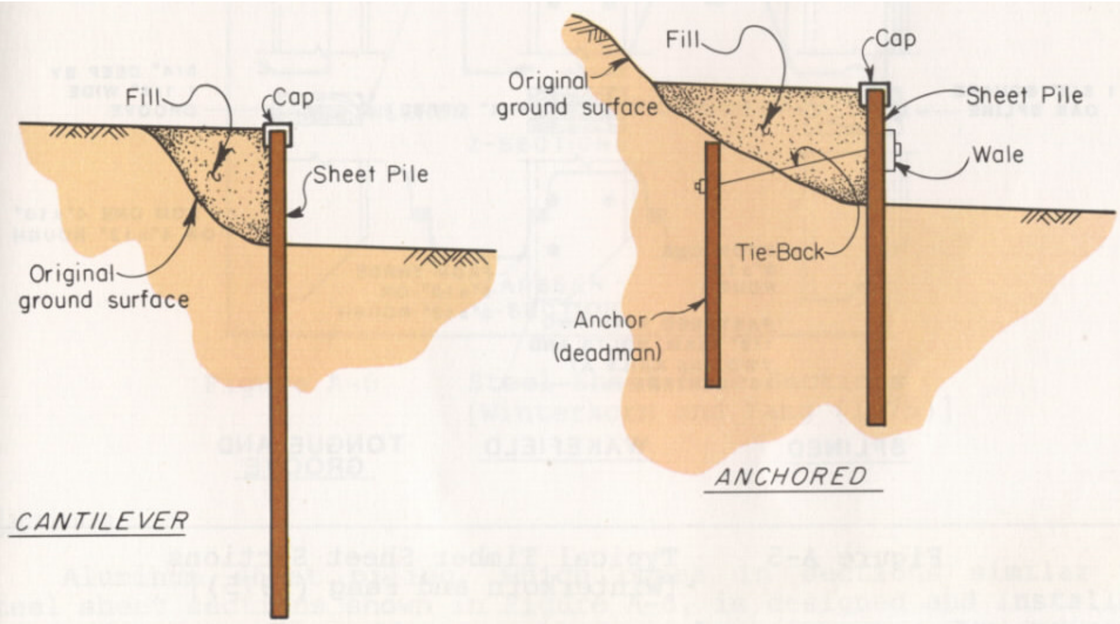


Figure A-4 Cantilever and Anchored Sheet Pile Bulkheads

The type of soil at a site determines the type of sheet piling that can be used. Steel sheet piles can be driven into hard soil and some soft rock. Aluminum and timber sheet piles can be driven into softer soil. An investigation is required to determine the subsurface conditions at a site and it should be performed prior to selection of materials.

The advantages of sheet pile bulkheads are their long and relatively maintenance-free life and their uniform appearance. Their disadvantages include the special pile-driving equipment and trained operators required to install them. The equipment requires a fairly wide access route and ample maneuvering room at the site, and it is noisy.

The different materials available for sheet pile bulkheads are discussed below.

Treated Timber

Well-designed and built timber structures have long been recognized as viable and economical for bulkhead construction. Figure A-5 illustrates the common types of timber sheeting used.

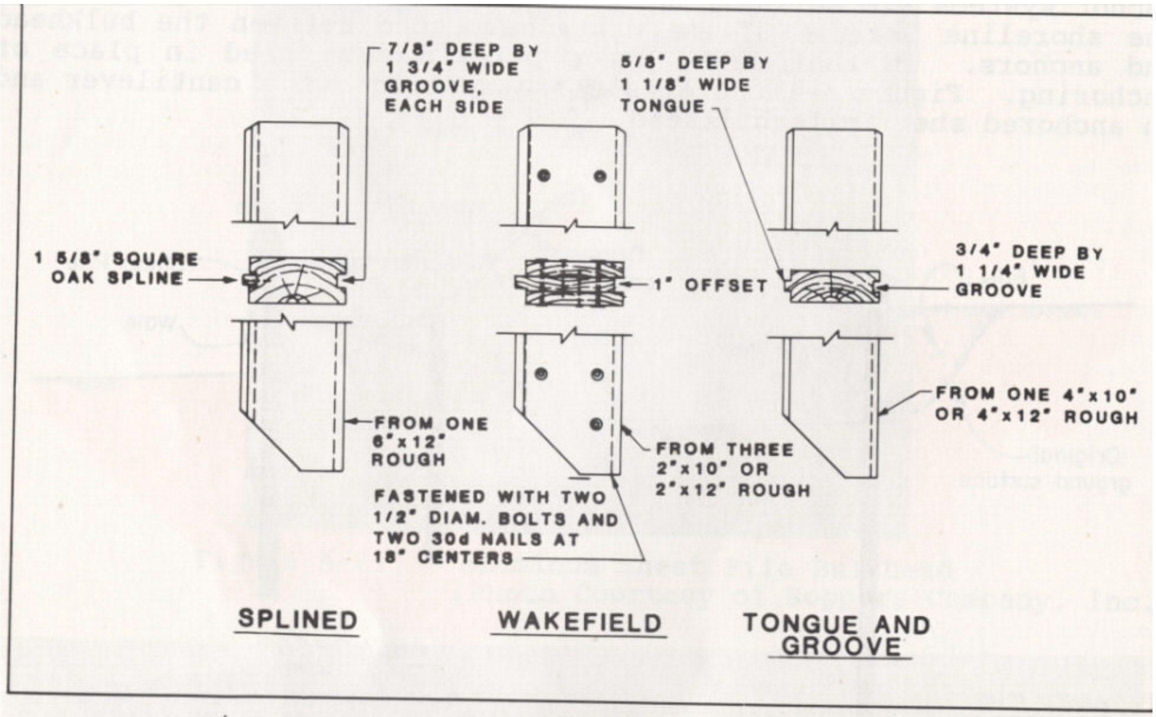


Figure A-5 Typical Timber Sheet Sections [Winterkorn and Fang (1975)]

Only specially treated timber should be used for marine construction. Only granular material should be used for backfill. If anchor piles are used, the backfill should be mounded over them before filling commences against the bulkhead. Joints between sheets should be kept as tight as possible. The use of a filter fabric is advisable as an added precaution against loss of backfill through cracks. Supplemental drain holes should be placed at regular intervals to further facilitate movement of water from behind the structure and must <u>always</u> be backed with filter cloth or crushed stone filters. only corrosion-resistant steels should be used for all hardware and fasteners. Wrought iron anchor rods with turnbuckles and bolts have proven to be durable. Galvanized fasteners are also recommended. Carbon steel should not be used unless protected with special coatings, such as coal-tar epoxy or other bituminous materials.

Minimize the number of washers under bolt heads and nuts to reduce the length of exposed bolt shanks and provide a tight fit between bolted timbers so that bolt shanks are not exposed in the gaps. Bolt holes should be no more than 1/16 of an inch larger than the bolt shank to insure a tight fit.

Steel

Steel sheet piling, probably the most widely used bulkhead material, can be driven into hard, dense soils and soft rock (Figure A-6). The interlocking feature of sheet pile sections provides a relatively sand-tight fit, generally precluding the need for filters. The close fit may also be essentially water-tight, so regularly spaced weep holes are recommended. These and lifting holes in the piling should be backed with properly graded stone filters or filter fabric to prevent loss of backfill.

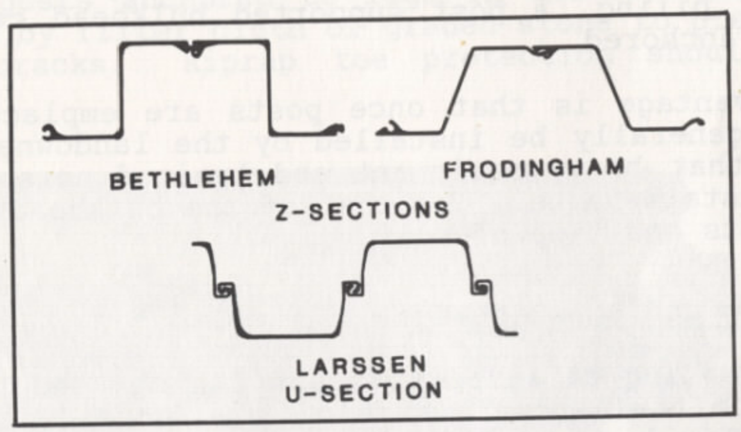


Figure A-6 Steel Sheet Pile Sections [Winterkorn and Fang (1975)]

Aluminum

Aluminum sheet piling, which comes in sections similar to steel sheet sections shown in Figure A-6, is designed and installed using the same conventional methods and equipment. Its primary advantages over steel are lighter weight and superior corrosion resistance. Individual sheets can be carried and maneuvered by one man, and most drilling and cutting can be performed with simple hand tools. Its main disadvantage, compared to steel, is that it is less rugged when driven and cannot penetrate logs, rock, or other hard obstructions.

Asbestos-Cement

This material seems to suffer significant and rapid deterioration in a marine environment and should not be used when long service is desired.

POST SUPPORTED BULKHEADS

Wave Height Range: Below five feet.

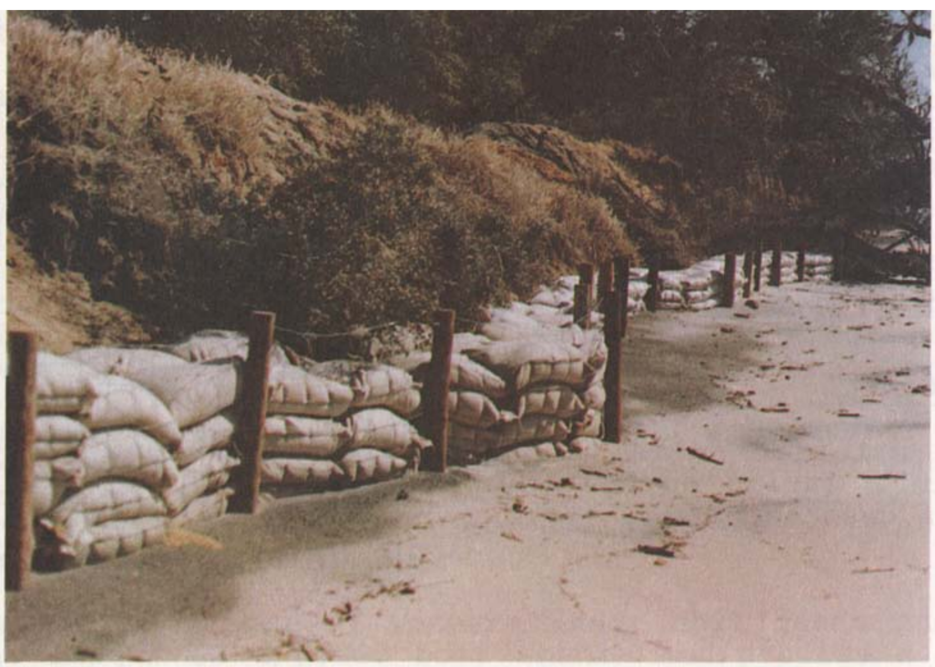
Runup Characteristic: Vertical.

A post supported bulkhead consists of regularly spaced posts, usually timber, driven into the ground with an attached facing material that forms a retaining wall. The posts support the bulkhead and resist the earth pressures exerted against the structure. As with sheet piling, a post supported bulkhead can be either a cantilever or anchored.

Their advantage is that once posts are emplaced, the facing material can generally be installed by the landowner. Their disadvantage is that heavy equipment and trained personnel are often required to install posts. The cost of the bulkhead depends on the spacing of posts and type of soil.

Hogwire Fencing and Stacked Bags

Hogwire fencing attached to posts can be used to support sand bags stacked on the landward side of the fence (Figure A-7). The structure can fail for a combination of reasons, primarily the vulnerability of the sand bags to tearing, which occurs when toe scour undercuts the structure and the bags slide against the hogwire fence. However, the structure is relatively inexpensive. For best performance, use a small mesh wire with PVC coating for longer life and protection of the bags. Provide toe protection or place the bottom bags and fencing in a trench excavated to at least the depth of anticipated toe scour and use only bags that are resistant to ultraviolet light. Tearing of the front row of bags can be prevented by filling them with a sand-cement mixture. Burlap bags can be substituted for the more expensive bags when a sand-cement mixture is used.



igure A-7 Hogwire Fence and Stacked Bag Bulkhead

Treated Timber

Horizontal, creosote-treated planks can be spiked to the landward side of posts anchored to logs in the backfill. The planks must be backed by filter cloth or graded stone to prevent soil loss through the cracks. Riprap toe protection should be provided (Figure A-8).

Figure A-8 Treated Timber Bulkhead

Untreated Logs

Horizontal untreated logs can also be attached to the landward side of posts and can be used in areas such as the Pacific Northwest, where there is an abundance of logs. The same precautions about adequate toe protection and filtering also apply, since large gaps between logs make adequate filter design more difficult. If a cloth is used, it should follow the log contours so that it is not excessively stressed by bridging the large gaps. In any case it is vulnerable to damage or vandalism, which would jeopardize the entire structure with the resulting loss of fill. The use of logs is definitely more risky than the use of uniform, treated-timber planking.

Used Rubber Tires

Used tires can be strung over two rows of treated posts set in a staggered pattern, with the tires abutting each other and filled with gravel. The posts are tied back to logs buried in the backfill, with filter cloth placed behind the tires before backfilling. Under wave action, the gravel tends to wash out of the tires, and backfill can then escape. Although used tires can generally be obtained free, the cost of the structure is probably comparable to other post bulkheads because of the required close spacing of post holes. *This kind of structure is not recommended.*

Steel H-Piles and Railroad Ties

Steel H-piles can be used as posts with railroad ties placed between their flanges (Figure A-9). The toe should be protected by armor stone and proper filtering and granular fill are needed behind the structure. A 12-inch steel channel is welded to the top of the H-piles as a cap to align the H-piles and protect the timber ties. While the structure has performed well and would be useful where bedrock prevents driving sheet piling, its cost is higher than other potentially effective devices.

Figure A-9 Steel H-Pile and Railroad Tie Bulkhead

MISCELLANEOUS BULKHEADS

Longard Tubes

Wave Height Range: Below five feet.

Runup Characteristic: Vertical.

A Longard tube is a patented woven polyethylene fabric tube filled with sand at installation and available in two diameters (40 and 69 inches) and in lengths up to 328 feet (Figure A-10). Adequate performance depends on the device remaining intact and completely filled. When filled, the tube is very heavy, yet flexible enough to settle *if depressions occur*. *A properly* installed Longard tube bulkhead is placed on a woven filter cloth extending 10 feet seaward of the tube. A small (10-inch) tube, factory stitched to the seaward edge of the filter cloth, settles into a scour trench under wave action to provide toe protection.

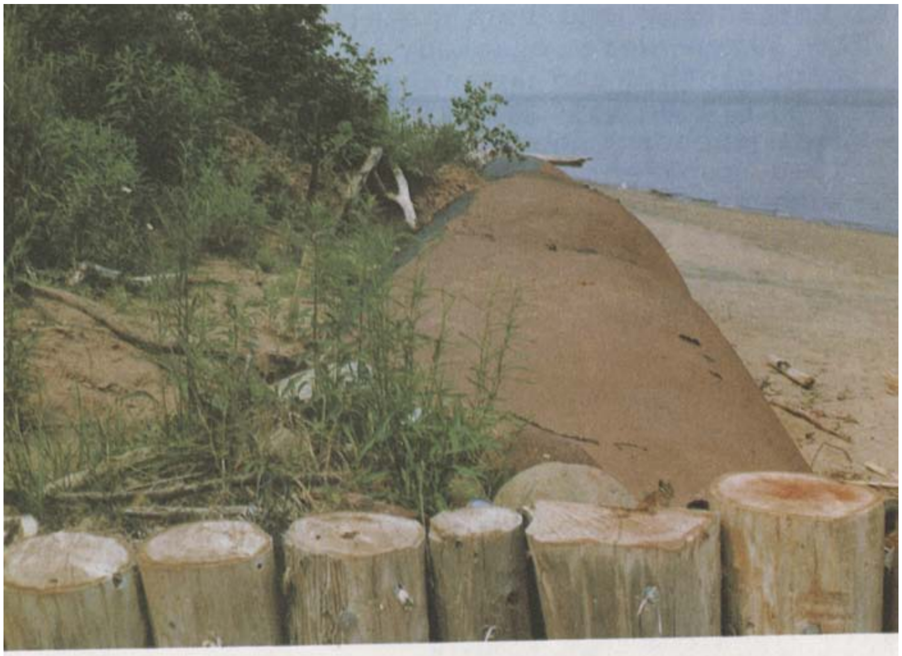


Figure A-10 Longard Tube Bulkhead

The, primary advantage of a Longard tube is the ease and speed with which it is filled once equipment and materials are in place. Repairs can be made by sewing on patches. The major disadvantage is its vulnerability to vandalism and damage by water-borne debris. A sand-epoxy coating can be applied to dry tubes after filling to provide significantly greater protection against puncturing. Unfortunately, the coating cannot be applied to a wet tube. Another disadvantage is that a large supply of good quality sand is required to fill the tube. Patented filling equipment must be mobilized at the site before filling can begin, and only qualified personnel can perform the filling.

The Longard tube depends on its weight to resist overturning and on friction to maintain its position. It is not designed to resist earth pressures, but to protect the toe of a bank from wave action. For best performance, the tube should not be placed against a bluff or overtopping waves will continue to cause erosion. The tube should be placed far enough out from the toe so that a sand berm will form between the tube and bluff. Wave energy is then absorbed by this berm, and further bank erosion is prevented. If the height of the structure is insufficient, do not place another Longard tube atop the first one; use another device.

Stacked Used Tires

Wave Height Range: Below two feet.

Runup Characteristic: Stepped.

Because used tires are readily available at most sites at no cost, many have tried to use them for shore protection devices. The bulkhead on Figure A-11 was made with scrap tires interconnected (both vertically and horizontally) by galvanized spikes and pushnuts. The tires were stacked in a staggered pattern over a nonwoven filter cloth, and granular material was used both as backfill in low areas and as fill in the tires. Three rows of galvanized steel anchors secured the structure to the beach. The structure failed apparently because the interconnection between tires was inadequate to hold the structure together. The gravel washed out of the tires, causing them to lose weight until they were lifted by waves. This system is not recommended in view of better, less costly alternatives.

Figure A-11 Stacked Used Tire Bulkhead

This structure illustrates a common deficiency in using scrap tires. while their availability is a strong temptation to use them in shore protection devices, tires are extremely rugged and cannot be fastened together securely except by considerable labor and expense. In almost all cases, failure results when interconnections do not perform as expected.

Used Concrete Pipes

Wave Height Range: Below two feet.

Runup Characteristic: Vertical.

This bulkhead is made by standing used concrete pipes on end, placing them side-by-side and then filling with granular soil (Figure A- 12). It is economical only when there is an available supply of used concrete pipe and where a low structure is adequate. Long life should not be expected because of potential deterioration of the concrete pipe. For best performance, a filter system should be provided behind the structure to relieve hydrostatic pressures. If a filter cloth is used, it should be forced deeply into the grooves between pipes to avoid ballooning the cloth to bursting. The wall should not be more than two pipe diameters high without an anchoring system, and the pipes should be entrenched to provide stability and some toe protection. A continuous concrete cap (not pictured) could also be cast across the top to insure performance as a unit.

Figure A-12   Used Concrete Pipe Bulkhead

APPENDIX B – REVETMENTS

RUBBLE REVETMENTS

Rubble revetments are constructed of one or more layers of stone or concrete pieces derived from demolition of sidewalks, streets, and buildings (Figures B-1 and B-2). Stone revetments are constructed of either two layers of uniform-sized pieces (quarrystone) or a gradation of sizes between upper or lower limits (riprap). Riprap revetments are not recommended for property owners, however, as they are somewhat more difficult to design and inspect because of the required close control of allowable gradations and their tendency to be less stable under large waves. Quarrystone structures are recommended because they are more easily designed and inspected. In either case, stone revetments are time-tested, highly durable, and often the most economical where stone is locally available.

Figure B-1 Stone Revetment

The primary advantage of a rubble revetment is its flexibility, which allows it to settle into underlying soil or experience minor damage and still continue to function. Because of its rough surface, a rubble revetment experiences less wave runup and overtopping than a smooth-faced structure. The primary disadvantage is that placement of the stone or concrete armor material generally requires heavy equipment.

Figure B-2 Concrete Rubble Revetment

Prior to revetment construction, the existing ground should be graded to an appropriate slope, preferably no steeper than 1 vertical on 2 horizontal (1:2). Fill material should be added as needed to achieve a uniform grade. The fill should be free of large stones and firmly compacted before revetment construction proceeds.

Filter layers or cloth should be provided to prevent loss of slope material through voids in the armor. Even when using filter cloth, an intermediate layer of smaller stone below the armor layer helps to distribute the load and prevent rupture of the filter cloth.

No individual armor unit should be longer than three times its minimum dimension. In other words, avoid using plate- or cylinder-shaped pieces. Stones should be block-shaped and not rounded. The toe of the revetment should be located one design wave height (but at least three feet) below the existing grade line to prevent undercutting, In lieu of deep burial, a substantial sacrificial berm of additional rubble (with filtering) should be provided.

Quarrystone

Wave Height Range: Above five feet.

Runup Characteristic: Rough slope.

Stone revetments, a proven method of shoreline protection, are durable and can be relatively inexpensive with a local source of suitable armor stone. Such stone should be clean, hard, dense, durable, and free of cracks and cleavages. Figure B-3 shows a typical cross section of a stone rubble revetment. Table B-1, which gives the required weight of armor units for a given design wave height, was developed for a 1:2 bank slope and a stone unit weight of 165 lbs/ft3. If your bank slope is something other than 1:2, find the value on Table B-2 and multiply the stone weight from Table B-1 by this factor. Flatter slopes require smaller rock sizes. Table B-3 contains a second correction factor to be applied when the unit weight (density) of the rock varies from 165 lbs/ft The tables contain an illustrative example of their use.

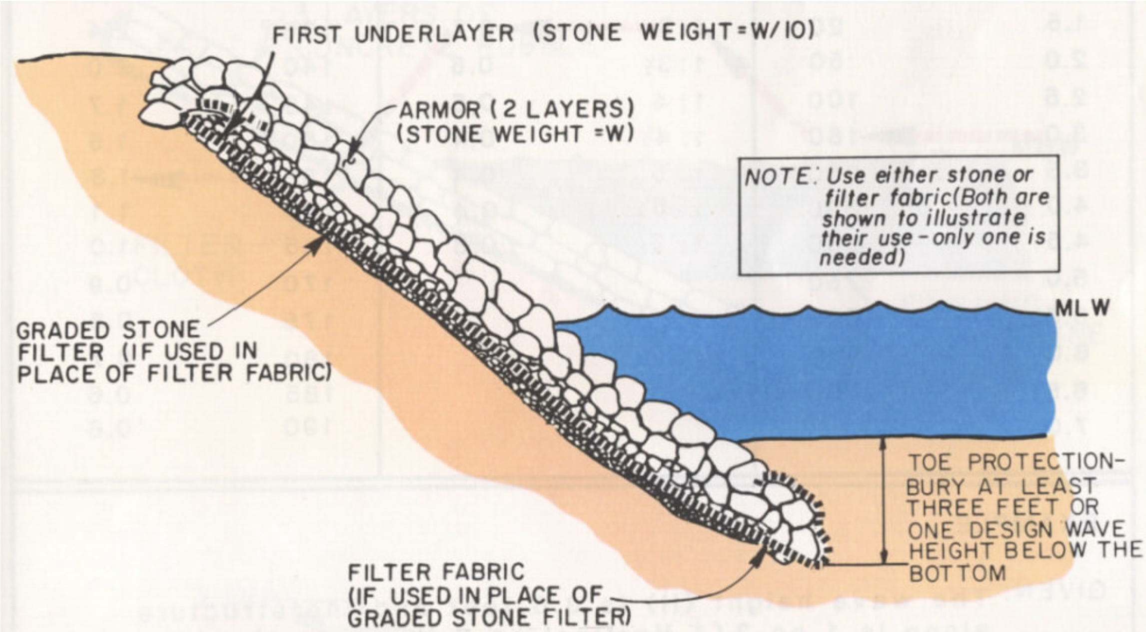


Figure B-3 Typical Quarrystone Revetment

Since it is not possible to obtain quarrystones of exactly the same weight, one must specify a range of permissible sizes. For any given required weight, W, stones ranging from 0.75W to 1.25W can be used, but at least 75% should weigh W or more. For example, if 100-pound stones are required, the armor stones may range from 75 to 125 pounds, as long as 75% weigh at least 100 pounds. If graded stone filter material is used, it generally will be much finer than the armor stone. An intermediate layer of stone, between the armor and filter, one-tenth as heavy as the armor units (100/10 = 10 pounds in the example), should provide the necessary transition to the filter material.

TABLE B-1 ESTIMATED WEIGHT OF ARMOR STONE

WAVE HEIGHT H (ft)	ESTIMATED WEIGHT W (lb)
0.5	1
1.0	10
1.5	20
2.0	50
2.5	100
3.0	160
3.5	260
4.0	390
4.5	550
5.0	750
5.5	1000
6.0	1300
6.5	1650
7.0	2100

TABLE B-2 CORRECTION FOR SLOPE

SLOPE (ft/ft)	CORRECTION FACTOR K_1
1:2	1.0
1:2½	0.8
1:3	0.7
1:3½	0.6
1:4	0.5
1:4½	0.4
1:5	0.4
1:5½	0.4
1:6	0.3

TABLE B-3 CORRECTION FOR UNIT WEIGHT

UNIT WEIGHT w_r (lb/ft^3)	CORRECTION FACTOR K_2
120	4.3
130	2.8
135	2.4
140	2.0
145	1.7
150	1.5
155	1.3
160	1.1
165	1.0
170	0.9
175	0.8
180	0.7
185	0.6
190	0.6

EXAMPLE

GIVEN: The wave height (H) is 3.0 feet and the structure slope is 1 on 3 (1 Vertical on 3 Horizontal) and one cubic foot of rock weighs 155 lbs (w_r)

FIND: The required weight of armor stone (W) from the tables (Dashed Line)

W = 160 lbs x 0.7 x 1.3 = 145 lbs

Concrete

Wave Height Range: Below five feet.

Runup Characteristic: Rough or stepped.

A concrete rubble revetment utilizes a waste product otherwise difficult to dispose of in an environmentally acceptable manner. The concrete should have the strength to resist abrasion by waterborne debris and ice pressure. In addition, all protruding reinforcing bars should be burned off prior to placement. Numerous concrete rubble revetments have failed in the past, usually because of neglect of filter requirements. Figure B-4 shows two cross sections that would probably be more successful than random dumping on a slope. The upper section uses up to three layers of concrete rubble shaped so that the longest dimension is no greater than three times the shortest. This increases stability by minimizing uplift on the slabs from wave forces. The revetment shown in Figure B-2 was similar, except that only one layer of rubble was used. This revetment subsequently suffered damages, but more than one layer might have improved its performance. The lower section in Figure B-4 utilizes shaped rubble, stacked on the slope to create a stepped face.

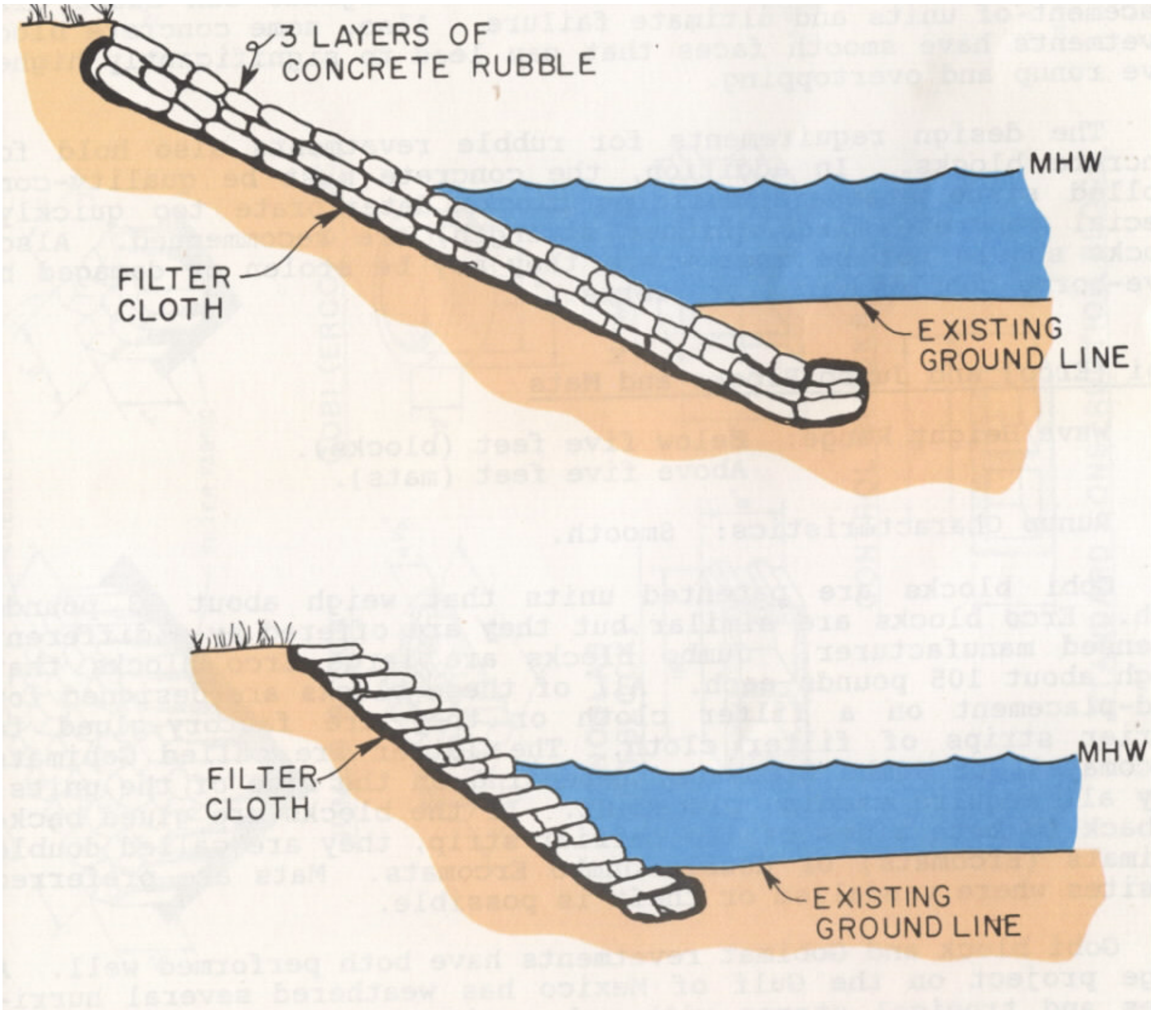


Figure B-4 Possible Concrete Rubble Revetment Sections

CONCRETE BLOCK REVETMENTS

Concrete blocks, many of them patented, have various intermeshing or interlocking features (Figure B-5). Concrete blocks have the advantage of a neat, uniform appearance. Many units are light enough to be installed by a landowner once the slope has been prepared. The disadvantage is that interlocking between units must be maintained. Once one block is lost, other units soon dislodge, and complete failure usually results. A good, stable foundation is required since settlement of the toe or subgrade can cause displacement of units and ultimate failure. Also, some concrete block revetments have smooth faces that can lead to significantly higher wave runup and overtopping.

The design requirements for rubble revetments also hold for concrete blocks. In addition, the concrete must be quality-controlled since standard building blocks deteriorate too quickly. Special concrete mixes (higher strength) are recommended. Also, blocks should not be used where they may be stolen or damaged by wave-borne cobbles, ice, or debris.

Gobi (Erco) and Jumbo Blocks and Mats

Wave Height Ranqe: Below five feet (blocks).

Above five feet (mats).

Runup Characteristics: Smooth.

Gobi blocks are patented units that weigh about 13 pounds each. Erco blocks are similar but they are offered by a different licensed manufacturer. Jumbo blocks are large Erco blocks that weigh about 105 pounds each. All of these blocks are designed for hand-placement on a filter cloth or they are factory-glued to carrier strips of filter cloth. The latter are called Gobimats (Ercomats), or Jumbo Ercomats, depending on the size of the units. They all require machine placement. If the blocks are glued back to-back to both sides of the carrier strip, they are called double Gobimats (Ercomats) or double Jumbo Ercomats. Mats are preferred at sites where vandalism or theft is possible.

Gobi block and Gobimat revetments have both performed well. A large project on the Gulf of Mexico has weathered several hurricanes and tropical storms with only moderate damage to the block sections and little or no damage to the mat portions.

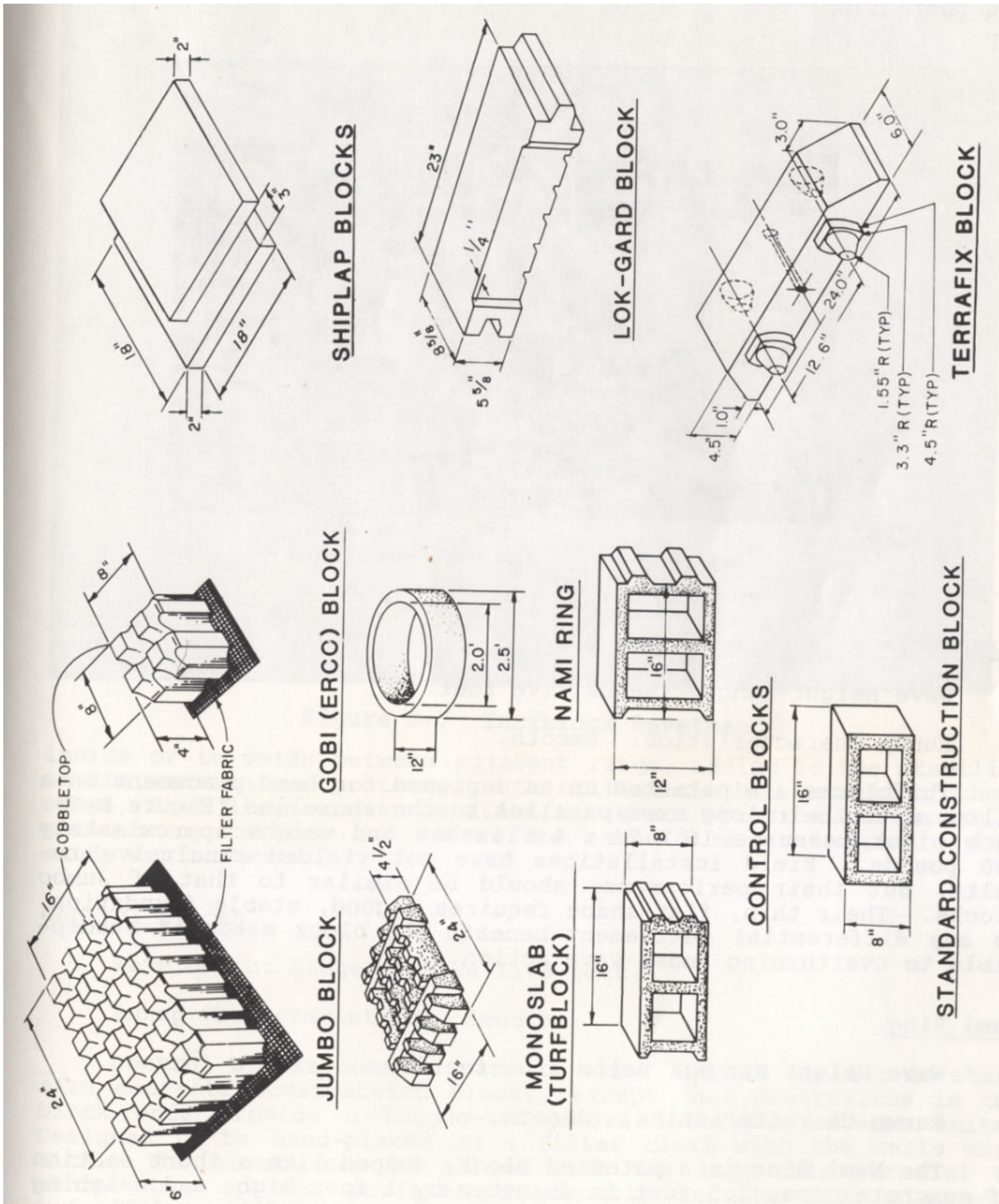


Figure B-5 Revetment Blocks
[After U.S. Army Corps of Engineers (1981b)]

Turfblocks are patented units designed for hand placement on filter with their long axes parallel to the shoreline (Figure B-7) Each block measures 16 x 24 x 4.5 inches and weighs approximately 100 pounds. Field installations have not yielded conclusive re suits, but their performance should be similar to that of Jumbo blocks. Their thin, flat shape requires a good, stable foundation as any differential settlement beneath the block makes it susceptible to overturning under wave action.

Figure B-6 Ercomat Revetment

Nami Ring

Wave Height Range: Below five feet.

Runup Characteristics: Smooth.

The Nami Ring is a patented block, shaped like a short section of concrete pipe, 2.5 feet in diameter by 1 foot high, and weighing 240 pounds. The rings are placed on a slope over filter cloth, but better performance occurs when they are joined with tie rods. Sand or gravel caught in the wave turbulence tends to be deposited inside or in voids between adjacent rings, adding to the stability of the section and protecting the filter cloth. Because of their shape, Nami Rings are susceptible to severe abrasion and damage by water-borne cobbles and, therefore, should be used primarily in sandy environments.

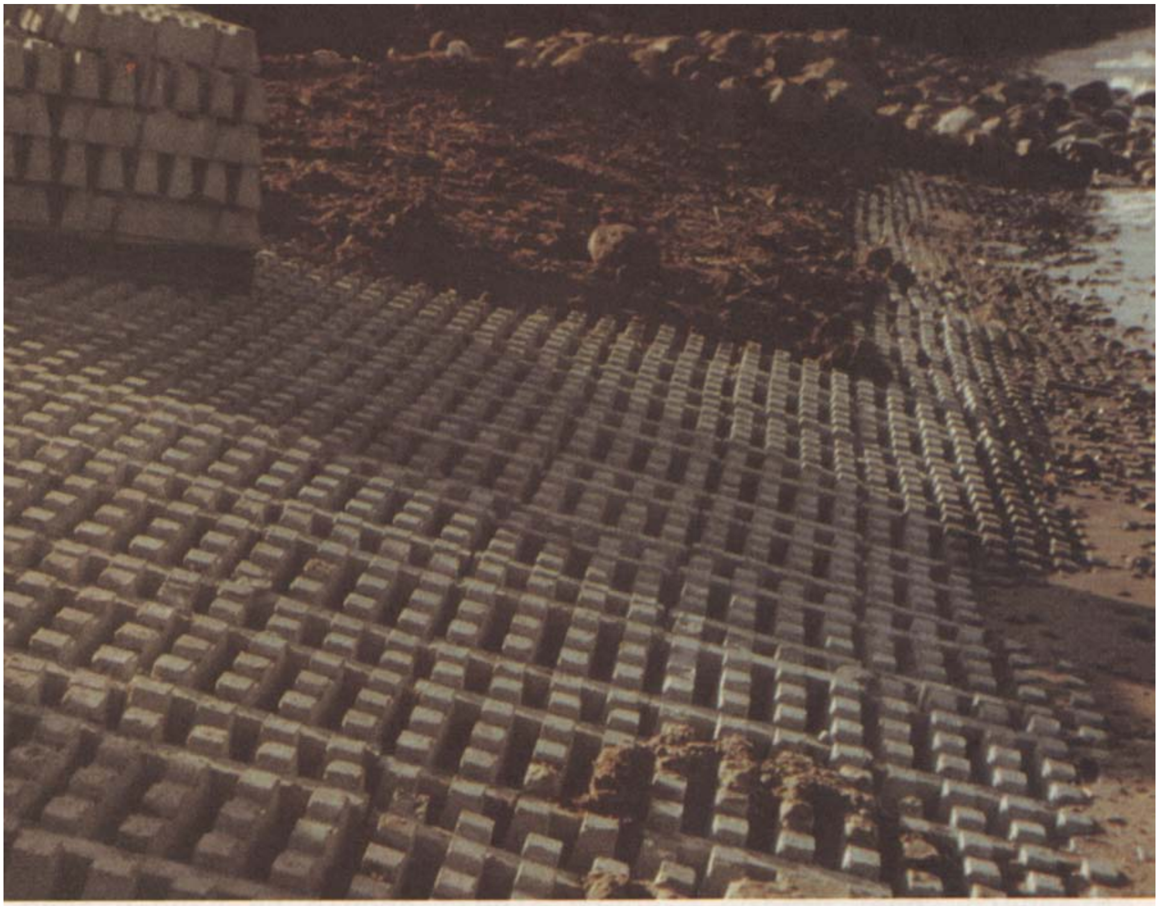


Figure B-7 Turfblock Revetment

Control Blocks

Wave Height Range: Above five feet.

Runup Characteristics: Smooth.

Control blocks come in various sizes and are similar to standard concrete construction blocks, except that protrusions in the block ends provide a tongue-and-groove interlock between units. Designed to be hand-placed on a filter cloth with the cells vertical, the blocks can be aligned with the long axis parallel to shore, but optimum performance probably results from placement perpendicular to the water's edge (Figure B-8).

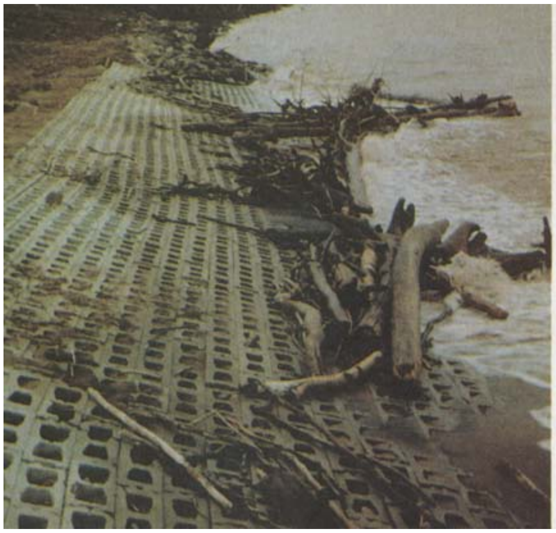


Figure B-8
Control Block Revetment

(Note: Perpendicular orientation of blocks is preferred over the parallel orientation shown in the photograph.)

<u>Concrete Masonry Blocks</u>

Wave Height Range: Above five feet.

Runup Characteristics: Smooth.

Standard construction masonry blocks should be hand-placed on a filter cloth with their long axes perpendicular to the shoreline and the hollows vertical. Their general availability is a primary advantage, but they are also susceptible to theft and deterioration of the concrete. They form a deep, tightly fitting section which is stable provided the toe and flanks are adequately protected. Their primary disadvantage is that standard concrete for building construction is not sufficiently durable to provide more than a few years service in a marine environment.

<u>Shiplap Blocks</u>

Wave Height Range: Below five feet.

Runup Characteristics: Smooth.

Shiplap blocks are formed by joining standard concrete patio blocks with an epoxy adhesive. At 100 pounds or more per unit, hey are designed to be hand-placed on a filter (Figure B-9). The precautions about concrete deterioration apply here as well.

Figure B-9 Shiplap Block Revetment

Lok-Gard Blocks

Wave Height Range: Below five feet

Runup Characteristics: Smooth.

Lok-gard blocks join together with a tongue-and-groove system. The 80-pound, patented units are designed to b hand-placed on a filter with their long axes perpendicular to the shoreline.

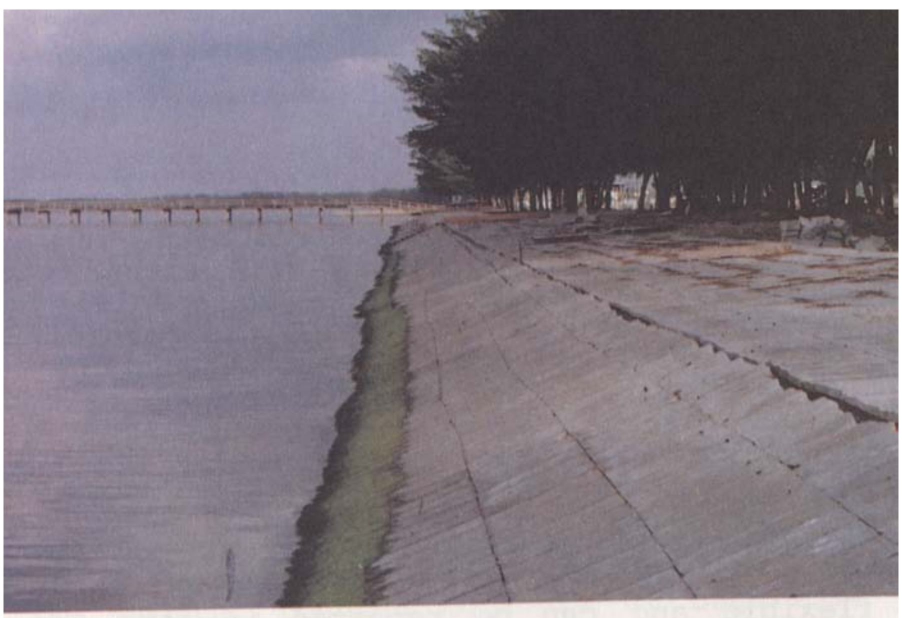


Figure B-10 Lok-Gard Block Revetment

Terrafix Blocks

Wave Height Range: About five feet

Runup Characteristics: Smooth.

Terrafix blocks are patented units, joined together mortise and tenon system, that have two cone-shaped project which fit holes in the bottom of adjacent blocks (Figure B-5). In addition, holes through the center of each block allow for less steel wire connection of many individual blocks. The interlocking of the 50-pound units creates a neat, clean app (Figure B-11).

Figure B-11 Terrafix Block Revetment
(Photo Courtesy of Erosion Control Products, Inc.)

STACKED BAGS OR MATS

Wave Height Range: Below five feet.

Runup Characteristics: Smooth or steeped.

Several manufacturers produce bags and mats, in various size and fabrics that are commonly filled with either sand or lean concrete for use in revetments. While no special equipment is required to fill bags with sand, a mixer and possibly a pump are needed for concrete-filled units. Bags should be filled an stacked against a prepared slope with their long axis parallel t the shoreline and joints offset as in brick work (Figure B-12) Grout-filled bags can be further stabilized by steel rods drive through the bags.

The advantage of a bag revetment is that it can usually be constructed by a landowner at moderate cost. Sand-filled bags are relatively flexible and can be repaired if some are dislodged.

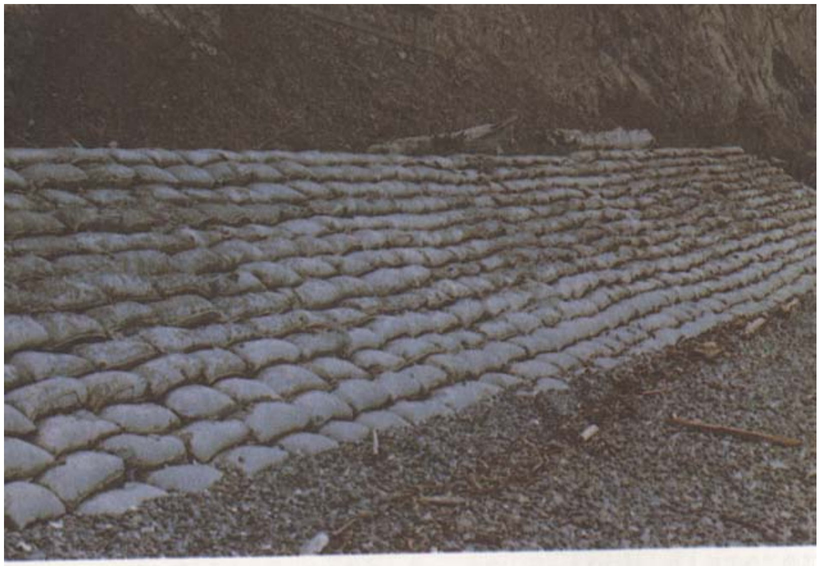


Figure B-12 Stacked Bag Revetment

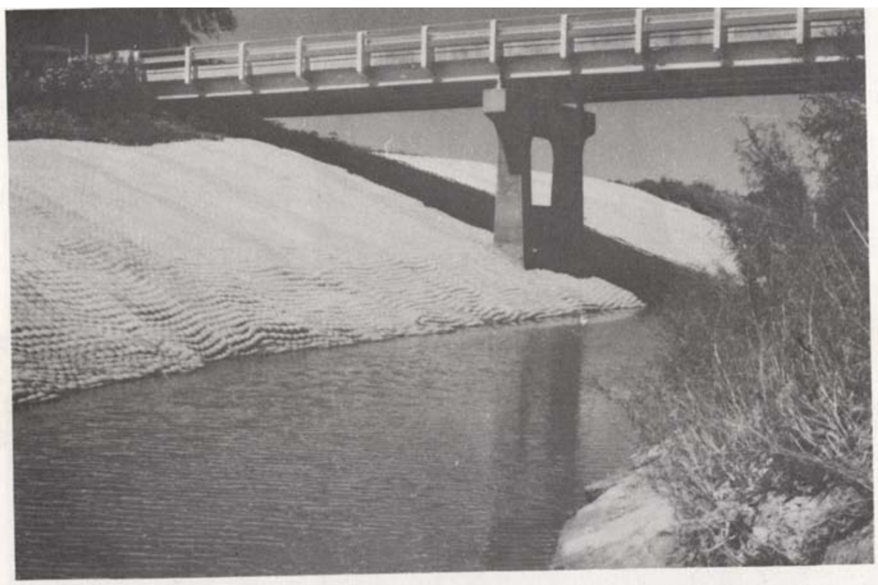


Figure B-13 Concrete-Filled Mattress
(Photo Courtesy of Construction Techniques, Inc.)

They are particularly suited to temporary emergency protection measures. Among their disadvantages are limitation to low energy areas, a relatively short service life compared to other revetments, and their generally unattractive appearance. Since concrete-filled structures are rigid, any movement or distortion from differential settlement of the subgrade can cause a major failure that would be hard to repair. Sand-filled bags are highly susceptible to damage and possible failure from vandalism, impact by water-borne debris, and deterioration of material and seams by sunlight. The smooth, rounded contours of bags also present an interlocking problem and they should be kept f latter and un filled for stability.

Mattresses are designed to be laid flat on a prepared slope, joined together, and then filled with concrete (Figure B-13). From a large mass of pillow-like concrete sections with regularly spaced filter meshes for the passage of water.

Bags and mats should be placed only on a stable slope. When a stacked bag revetment can be placed at a steeper slope that mattress, it should not exceed 1 vertical on 1.5 horizontal. stacked bag revetment should be at least two bags thick. For permanence, the outside layer should be concrete-filled but the layer may be sand-filled.

Bags that have been used include:

<u>Burlap Bags</u>

These are recommended only when filled with concrete because of their rapid deterioration and the ease with which they can torn.

<u>Sand Pillows</u>

Sand Pillows are ultraviolet-resistant bags made from woven acrylic fabric. They weigh approximately 100 pounds when filled.

<u>Dura Bags</u>

Dura Bags are large (4 x 12 x 1.7 feet) and must be filled i place with a pumped sand slurry or concrete. Their large size makes them more resistant to movement under wave attack. Fabricated of ultraviolet-resistant material, they can be used in e posed installations.

<u>Fabriform Nylon Mat</u>

The mat is designed to be filled with a highly fluid grout mixture. The exterior cloth envelope serves primarily as a for until the grout hardens. Fabriform comes in several fabric styles. Including some with filter points (weep holes) for slope drainage Fabriform mats are patented and should be installed according the manufacturer's instructions.

MISCELLANEOUS REVETMENTS

<u>Gabions</u>

Wave Height Range: Above five feet.

Runup Characteristics: Rough.

Gabions are rectangular baskets or mattresses made of galvanized, and sometimes PVC-coated, steel wire in a hexagonal mesh (Figure B-14). Subdivided into cells of approximately equal size, standard gabion baskets are 3 feet wide and are available in lengths of 6, 9, and 12 feet and heights (thicknesses) of 1, 1.5, and 3 feet. Mattresses are either 9 or 12 inches thick. At the job site, the baskets are unfolded and assembled by lacing the edges together with steel wire. The individual baskets are then wired together and filled with 4- to 8-inch diameter stones. The use of interior liners or sandbags for small size material is not recommended. The lids are finally closed and laced to the baskets, forming a large, heavy mass (Figure B-15).

Figure B-14 Unfilled Gabions

The chief advantage of a gabion structure is that construction may be accomplished without heavy equipment. The structure is flexible and maintains functional integrity even if the foundation settles. Gabions can be repaired by opening, refilling the baskets, and then wiring them shut again. Depending on the supply of stone, a gabion revetment can be a low cost option.

Figure B-15 Gabion Revetment

The disadvantage of a gabion structure is that the baskets may open under heavy wave action. Also, since structural integrity depends on the wire mesh, abrasion and damage to the PVC coating can lead to rapid corrosion of the wire and failure of the basket. Therefore, they should not be used where water-borne debris or cobbles can cause damages. The baskets should be tightly packed to minimize movement of the stone and subsequent damage to the wire. Periodic refilling may be necessary to maintain this packing. Rusted and broken wire baskets also pose a safety hazard to foot traffic. Periodic inspections are required so that repairs are made before serious damage occurs.

Steel Fuel Barrels

Wave Height Range: Below five feet.

Runup Characteristics: Rough.

This type of revetment is limited to areas such as remote arctic regions, with an abundance of used fuel barrels of little salvageable value (Figure B-16). Due to rapid corrosion o f the barrels in temperate climates, the system is only reliable in the f ar north. The barrels should be completely filled with coarse granular material to preclude damage by floe ice and debris and the critical seaward barrels should be capped with concrete. The barrels should also be partially buried to increase stability.

Figure B-16 Steel Fuel Barrel Revetment

Concrete Slabs

Steel Fuel Barrel Revetment

Wave Height Range: Below five feet.

Runup Characteristics: Smooth.

Photographs of one structure were shown in Figure 17. The structure failed due to improper filtering, inadequate toe protection, and lack of flank protection. Placed on a flatter slope and with due regard for proper design considerations, this type of structure could provide low cost protection when large slabs are available.

Fabric and Ballast

Revetments using a fabric filter cloth as the slope's armor layer an(! held in place by some form of ballast have not been successful and are not recommended.

APPENDIX C - BREAKWATERS

FLOATING BREAKWATERS

Floating breakwaters can be constructed of virtually any buoyant material, such as rubber tires, logs, timbers, and hollow concrete modules. Floating breakwaters are particularly advantageous where offshore slopes are steep and fixed breakwaters would be too expensive because of water depths, where the tide range is large and fixed breakwaters would be subject to widely varying degrees of submergence, and where temporary protection of vegetation is required.

One disadvantage of floating breakwaters is that they are effective only against small, short-period waves (less than five seconds). Fortunately, these are all that strike the great majority of sheltered shorelines. They also may be regarded as eyesores in some areas and they tend to collect floating debris and require more maintenance than fixed breakwaters.

Rubber Tires

Two possible arrangements are shown in Figure C-1. The upper configuration, known as a wave-Maze, is patented and cannot be used unless royalties are paid to the patent holder (see *OTHER HELP* Section). The bottom configuration was developed by the Goodyear Tire and Rubber Company for promotional purposes and may be used without royalties. The use of other configurations is limited only by the imagination of the designer.

The length parallel to shore should be sufficient to provide protection according to the structure's distance from shore. The width will depend on the wavelength at the site. To determine this, time 11 successive wave crests as they pass a stationary point. Divide this time by 10 to obtain the wave period, T. The breakwater width should be 2.5 x T^2 (e.g., if the wave period is 5 seconds, the width should be 2.5 x 5 x 5 = 62.5 feet).

The depth of penetration in the water (draft) will determine the structure's effectiveness. A breakwater riding only on the surface does little to break up waves. The draft should be greater than one-half the wave height. Two-layer structures or the use of truck or tractor tires help to achieve greater draft.

The air trapped within the top of vertical tires provides sufficient flotation in most cases. In still water, the air is eventually dissolved by the surrounding water, but wave action replenishes the air supply. Of course, care must be taken not to use tires with puncture holes. More permanent flotation is possible with Styrofoam blocks or foam injected into the crowns of the tires. In salt water, marine growth will eventually sink the structure unless it is periodically scraped off. Sand can also collect in the tires and sink them, but this can be prevented by drilling holes in the bottoms of the tires. In that case, flotation aids, such as styrofoam blocks, should be used.

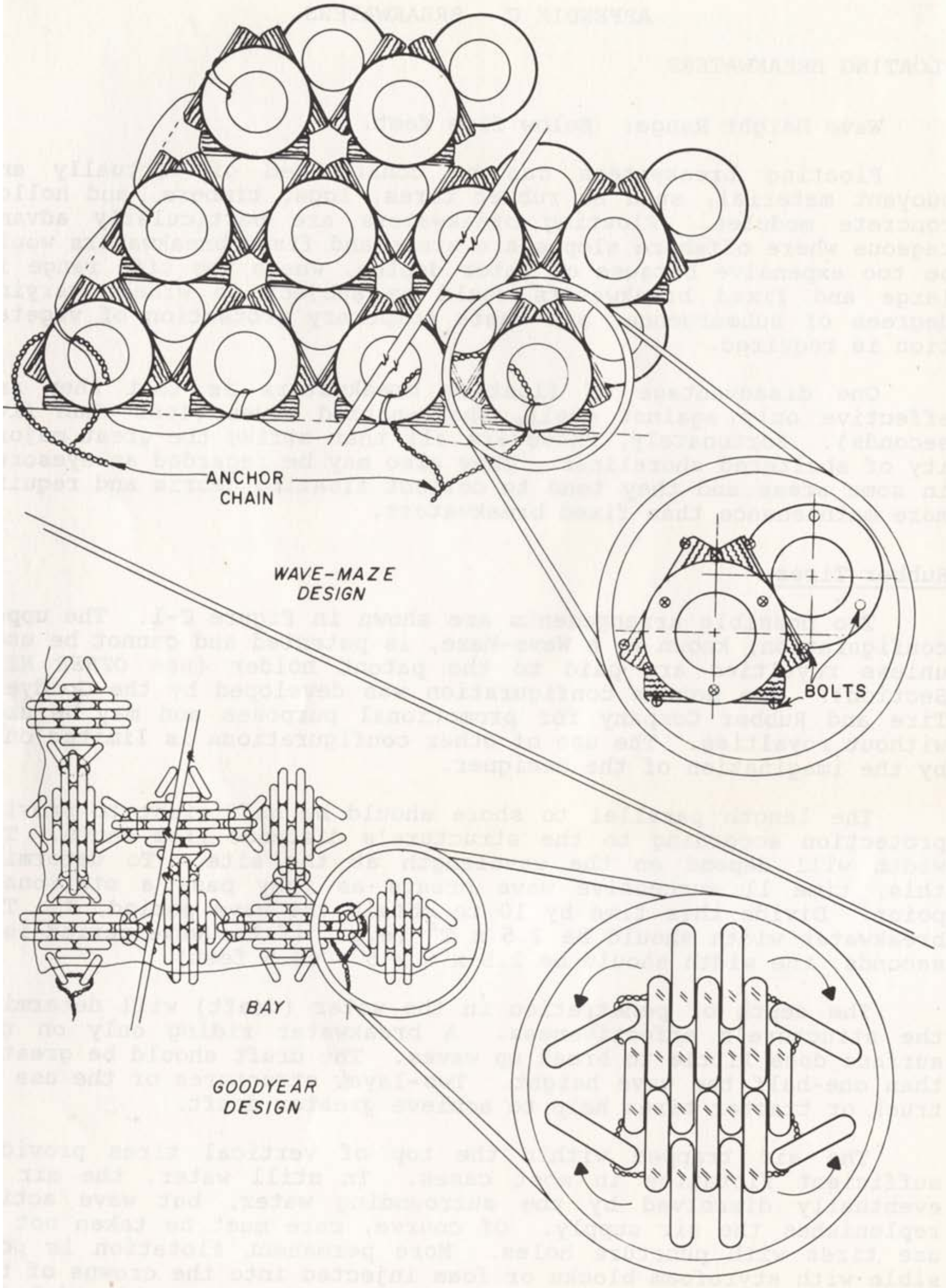


Figure C-1 Floating Breakwater Modules
[After U.S. Army Corps of Engineers (1978a)]

Stainless and galvanized steel cable, polypropylene, nylon, Poly-D, and Kevlar rope, galvanized and raw steel chain, and rubber conveyor belt edging have been used as fastening materials. Of these, the conveyor belt edging has proven most satisfactory. The others failed because of corrosion in seawater, abrasion by the tires, fatigue, or deterioration from other factors. Steel cables sawing through the tires have caused some devices to fail. Rubber belt edging, a scrap material derived from manufacture of conveyor belts, is available from several rubber companies in a wide range of widths and thicknesses. For tire breakwater construction, the belting should be at least 2 inches wide and 0.375 inches thick.

Secure anchorage is necessary to prevent displacement. Danforth, screw anchors and large concrete blocks have been used with mixed results. They are satisfactory for seasonal use in mild waves, but they tend to creep over long periods in soft bottoms and are not always desirable for permanent installations. In these cases, driven piling is the best means of stable anchorage over long periods. Pile driving, of course, adds considerably to total installation costs.

Other Materials

Bundles of logs can be chained together or other barriers can be fabricated from treated timber. Modules of lightweight concrete filled with flotation foam have also been successful. The proportioning and design factors presented for rubber tire breakwaters also apply to these.

FIXED BREAKWATERS

The most important feature of a fixed breakwater is its height, which determines how much wave energy is dissipated. In building a fixed breakwater or sill, some settlement should be anticipated in the structure's design height. The amount depends on the type of soil, the structure's weight, and type of foundation. Uniform settlement does not necessarily adversely affect performance, but if one portion of breakwater sinks significantly below the others, there will be increased wave transmission over the low section.

Longard Tubes

Wave Height Range: Below five feet.

The same advantages and disadvantages mentioned for Longard tube bulkheads *(APPENDIX* A) apply when they are used as breakwaters. An added disadvantage is that the protective epoxy coating cannot be applied to wet tubes so that damages are more like Therefore, they should not be used at locations where the tube exposed to vandalism or water-borne debris. Figure C- 2 shows before and after views of a Longard tube slashed by vandals. Damage eventually caused the entire tube to deflate. Where 69-inch tube cannot provide sufficient height; an alternate breakwater system should be used.

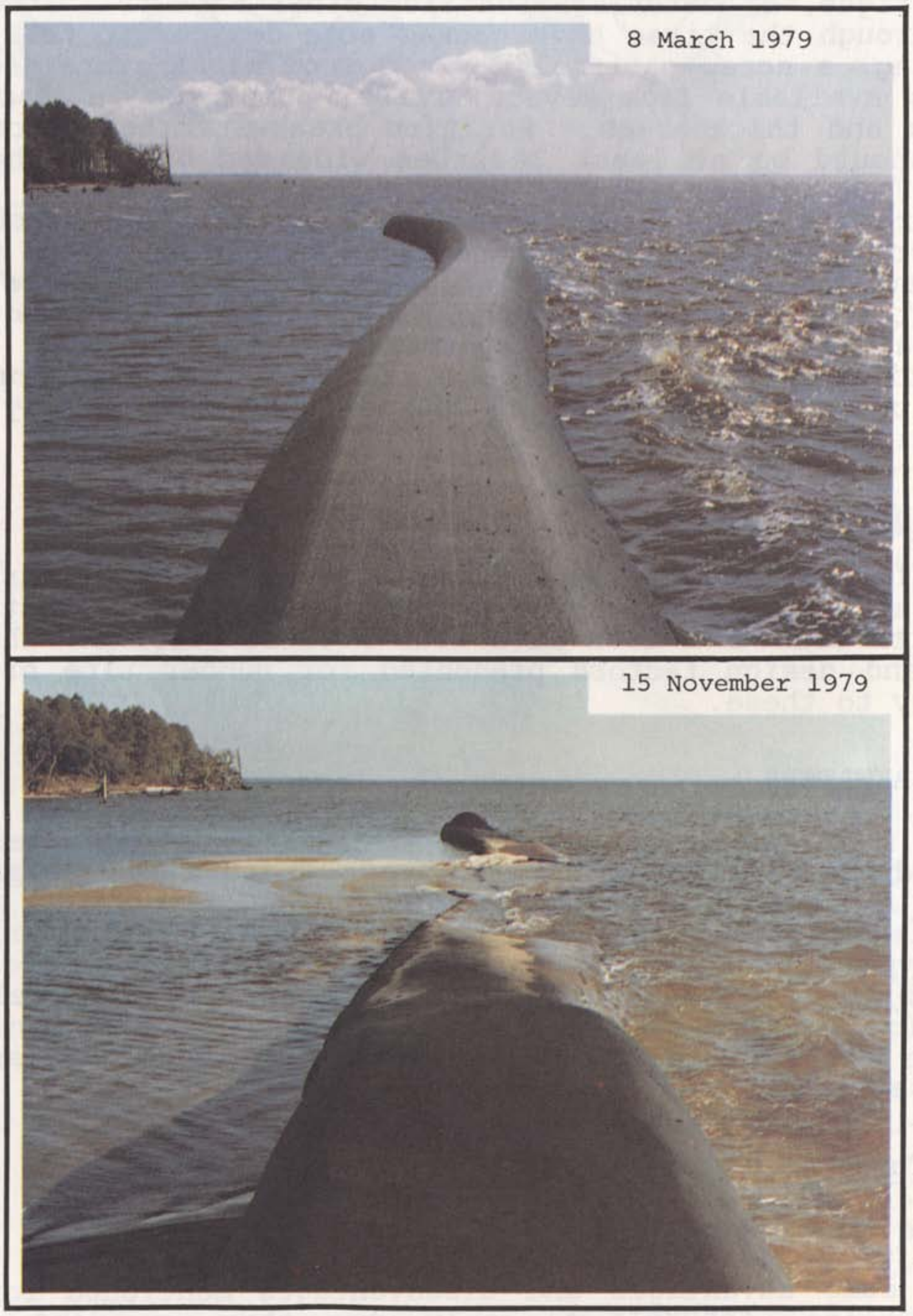


Figure C-2 Longard Tube Breakwater

Sand-Filled Bags

Wave Height Range: Below five feet.

Sand-filled bag breakwaters use stacked bags in a staggered pattern (Figure C-3). The structure's integrity depends on the individual bags remaining in place and intact. The bags and seams must be resistant to ultraviolet light to preclude deterioration from prolonged sunlight exposure. Lighter bags (100-pound range), such as those used for revetments, are displaced when exposed to even moderate waves. Larger units such as Dura Bags are recommended even though they are more difficult to handle, and must be filled in place.

Figure C-3 Sand-Filled Bag Breakwater

A filter cloth should be placed under the bags to reduce settlement in soft bottoms (Figure C-4). During construction, bag-to-bag abutment should be insured to preclude wave transmission through gaps between bags. Unlike a sand-filled bag revetment, a sand-filled bag breakwater cannot be built easily by a landowner. Special pumps are needed to fill the larger bags offshore, and alignment is more critical.

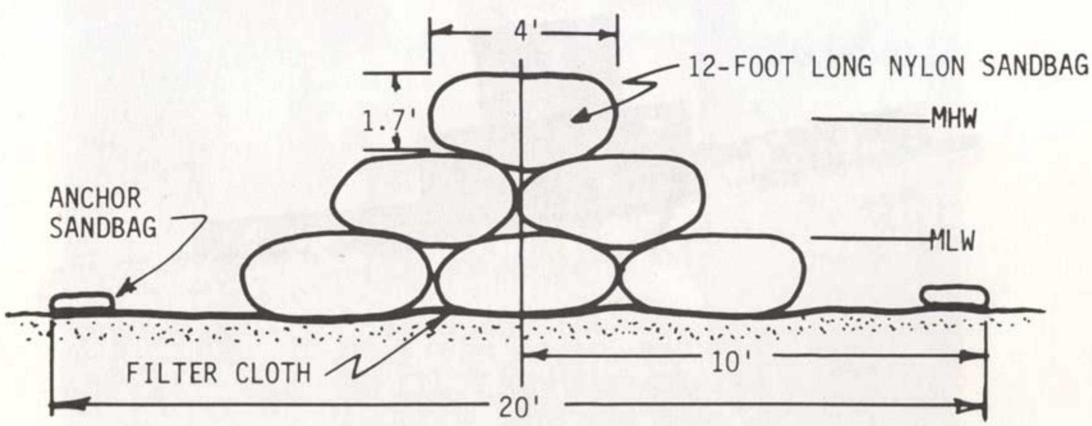


Figure C-4 Sand-Filled Bag Breakwater Section
[After U.S. Army Corps of Engineers (1978b)

Grout-Filled Bags

Wave Height Range: Below five feet.

The major advantage of grout-filled bags is that the units hold their shape after the fabric deteriorates or is torn. Again, it is recommended that larger bags be used for breakwater construction because the smaller ones are susceptible to displacement. In addition, larger bags reduce the number of bag contact points where openings may develop.

Recommendations made for sand-filled bags also apply to groutfilled bags, except that vandalism is not a major concern.

<u>Gabions</u>

Wave Height Range: Below five feet.

The same basic design considerations given for gabion revetments *(APPENDIX B)* apply here. The wire mesh should be PVC-coated, the baskets should be tightly packed, and a filter cloth should be used beneath the structure to help control settlement. A gabion mat should be provided around the structure to protect against scour. Tight packing of the stone is particularly important to avoid large distortion of the baskets under wave action. A cross section and photograph of a gabion breakwater are shown in Figures C-5 and C-6.

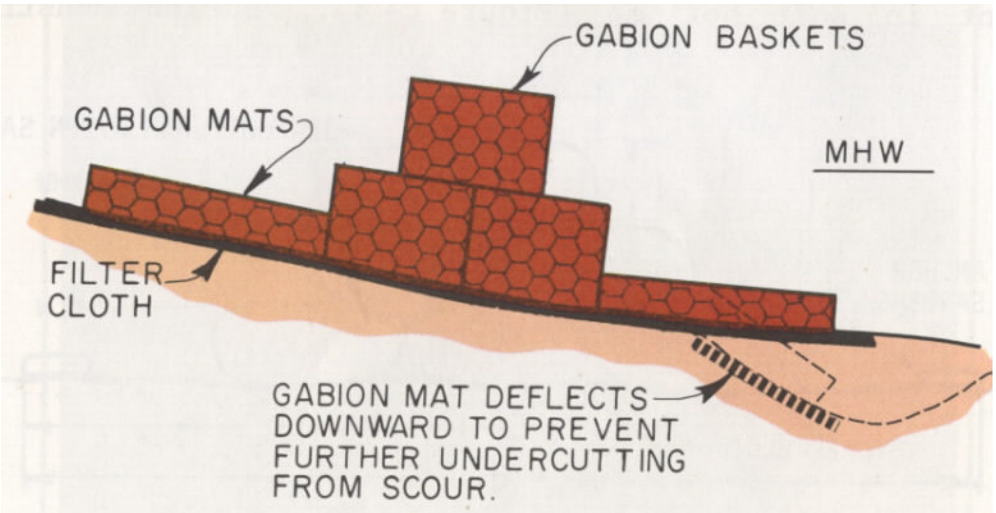


Figure C-5 Gabion Breakwater Section

Figure C-6 Gabion Breakwater

Z-Wall

Wave Height Range: Above five feet.

A Z-Wall is a patented device, forced concrete panels set on edge. The structure is designed constructed with steel-reinforced concrete panels set on edge in a zigzag fashion. For placement close to shore on the existing bottom without use of a filter material. Heavy construction equipment and trained personnel are required for installation. A single bolt acts as a hinge that interconnects adjacent panels and allows them to settle nonuniformly, but with limited tolerance, so that Z-Walls are sensitive to bottom conditions. If the tolerable differential settlement is exceeded, the panels lean against or pull apart from each other, causing the concrete to spall in stressed areas. The nuts on the connecting bolts tend to loosen and unwind under wave agitation. Eventually, the end units may fall away if the nuts unwind completely.

Figure C-7 Z-Wall

The structure performs best at a site with a firm bottom and generally not only protects the shoreline from high wave action, but builds up the beach. of course, potential downdrift damages should be carefully considered. Also, the six-foot height of the panels limits them to relatively shallow water.

<u>Surgebreaker</u>

Wave Height Range: Above five feet.

A Surgebreaker is a modular device constructed with 3,700pound, precast, reinforced concrete modules with vent holes to release wave pressure buildup. The patented triangular modules are 4 feet high by 7 _ feet wide (Figure C-8). They are designed to be placed side-by-side on the existing bottom with the flatter sloped face of the device toward the waves (Figure C-9). Installation must be performed by a franchised contractor.

Figure C-8 Surgebreaker Modules

Figure C-9 Surgebreaker

Sandgrabber

Wave Height Range: Below five feet.

A patented configuration of interconnected concrete construction blocks, a Sandgrabber is a device that allows for some differential settlement of the blocks by using U-shaped, galvanized-steel connecting rods (Figure C-10). The hollow blocks allow waves to wash sand through, trapping the coarser, water-borne particles behind the structure. The Sandgrabber must be installed by a licensed-franchised contractor.

Figure C-10 Sandgrabber

The current design does not use any form of toe protection, nor is the structure placed on a filter. As a result, the structure normally settles unevenly and rotates seaward into a scour trench. Because of these movements, the allowable amount of differential settlement is sometimes exceeded, and the resulting stress of the U-ties against the concrete blocks may crack or break them. Weak concrete hastens the process so compressive strength tests should be performed on each batch of blocks before construction to insure that standards are met. Block breakage can eventually lead to complete structural failure.

<u>Quarrystone</u>

Wave Height Range: Above five feet.

A quarrystone breakwater (Figure C-11) and revetment are structurally similar and stone sizes should be selected in the same *way (APPENDIX B).* One major advantage is that the structure does not fail when differential settlement occurs. Time-tested and quite economical if suitable rock is available locally, stone has been used for breakwater construction more than any other material. Of course, rock construction also requires heavy equipment, which, depending on local conditions, may have to be barge-mounted, resulting in higher costs.

Figure C-11 Quarrystone Breakwater

Timber Piles and Brush

Wave Height Range: Below two feet.

A brush breakwater is constructed of two parallel rows of posts driven into the offshore bottom, connected across the top with timber crossties, and filled with brush. Brush should be cut longer than the space between the posts and placed parallel to the structure alignments. Not suitable for permanent protection, it can be used as an energy absorber for temporary sheltering of new vegetation.

Used Tires and Timber Piles

Wave Height Range: Below two feet.

Timber piles are driven into the bottom so that every three piles form a triangular pattern, and used automobile tires are then stacked on the piles. Just above the top tires, the triangularly grouped piles are interconnected with 2 x 6-inch planks bolted to the piles (Figure C-12). The structure, whose stability depends on the depth of pile penetration, has proven effective against mild wave action.

Figure C-12 Used Tire and Timber Pile Breakwater

APPENDIX D - GROINS

Stacked Bags

Wave Height Range: Below five feet.

A stacked bag groin is similar to a stacked bag breakwater (Figure D-1). The bags can either be sand or grout-filled. A with breakwaters *(APPENDIX C)*, larger bags are recommended because lighter, smaller bags are too susceptible to displacement by waves. The suggested recommendations for bag breakwaters apply to groins. The bags in the photo were filled between wooden forms to achieve their block shape, but this was unnecessary. When installed properly, stacked bag groins have performed well. They should only b considered a short-term solution however when filled with sand.

Figure D-1 Stacked Bag Groin

Gabions

Wave Height Range: Above five feet.

The recommendations for gabions given in the revetments section *(APPENDIX B)* also apply to groins. The groin should be und lain with filter cloth to inhibit settlement and all baskets should be made from PVC-coated wire mesh. Tiers of baskets should be tied together with appropriately sized wire to prevent shifting of up tiers over lower tiers, and tight packing is needed to minimal distortion. Adequate toe protection is required to prevent settlement and basket distortion. Thin gabion mattresses are ideal

Figure D-2 Gabion Groin

Steel Fuel Barrels

Wave Height Range: Below five feet.

The use of steel fuel barrels for construction is economical only in remote arctic areas where used barrels are readily available and have no other salvage value. Barrel groins have worked well where littoral transport characteristics are suitable for shore stabilization with a low groin. The recommendations given for barrel revetments *(APPENDIX B)* also apply here. It is particularly important to entrench the barrels sufficiently to prevent undermining by scour on the downdrift side.

Quarrystone

Wave Height Range: Above five feet.

Quarrystone, a durable and time-tested material for shore protection, should always be considered where locally available. The structural form of a stone groin is the same as for a stone breakwater *(APPENDIX C).* Sizing is discussed under stone revetments *(APPENDIX B).*

Figure D-3 Quarrystone Groin

Longard Tubes

Wave Height Range. Below five feet.

Longard tubes have performed fairly well as groins when remaining intact (Figure D-4). Failure has usually resulted from Longard Tube Groin holes or tears in the fabric and loss of sand fill. Longard tubes are probably best as a short-term or emergency measure because of their vulnerability to damage. When used as a groin, the Longard tube should be underlain by a filter cloth with 10-inch tubes factory-stitched to each side. The filter cloth helps to prevent settlement, and the 'small tubes hold it in place.

Figure D-4 Longard Tube Groin

Sheet Piling

Wave Height Range: Above five feet.

Sheet pile groins, an old and proven means of shore protection, can employ timber (Figure D-5), steel, or aluminum sheeting. Toe protection or adequate penetration is required to insure the structure's stability. Recommendations for sheet pile bulkheads *(APPENDIX A)* also largely apply to groins.

Figure D-5 Timber Sheet Pile Groin

Timber and Rock

Wave Height Range: Above five feet.

Many structural forms are possible for timber and rock groins. Figure D-6 shows a timber crib structure that retains a stone fill. Care must be taken to insure that the rock is larger than the gaps between the timbers. Rock has escaped from the offshore compartment of the groin in the figure for that reason. Treated timbers should be used and securely fastened together for structural stability, such as with long wrought iron or coated steel rods threaded at the ends to accommodate washers and nuts.

Figure D-6 Timber Crib Groin

APPENDIX E - VEGETATION

Vegetation has been used for stabilizing shorelines either as a substitute for, or supplement to, structures. Vegetation is an inexpensive, and generally easy, approach to providing erosion control. It is not, however, applicable to all situations. It cannot always prevent erosion, nor can it stop the recession of bluffs caused by groundwater seepage. In order to confront these types of problems, the landowner is advised to consider a combination solution such as a structural device and vegetation.

Vegetation uses are limited by site characteristics such as climate, soil properties, wave exposure, and salinity regimes. The following discussion will focus on species which may be used for marsh, beach, dune and slope plantings. For each species, the applicable geographical region and planting specifications will be described. Further information on these and other species not mentioned in this report can be obtained from offices of county soil conservation services, state coastal zone management programs, or Corps of Engineers districts.

MARSH PLANTS

Coastal marshes are those herbaceous plant communities, which are normally inundated or saturated by surface or groundwater. They may be narrow fringes along steep shorelines or they may cover wide areas in shallow, gently sloping shore regions typically found in bays and estuaries (Figure E-1). In saltwater marshes, salinity is generally equal to or slightly less than seawater (35 parts per thousand salt). Freshwater marshes experience water level fluctuations resulting from groundwater table and seasonal climatic changes.

To establish a coastal marsh, the site must be evaluated based on geographic area, tidal elevation and range, salinity, fetch length, and soil properties. The vegetation prevalent in three saltwater marsh regions and the Great Lakes are discussed below. Planting specifications are summarized in Table E-1. The suitability of a site for marsh plantings can be evaluated using Figure E-2.

Atlantic Coast Marshes

Common vegetation found in Atlantic coast marshes is described briefly below.

Smooth Cordgrass *(Spartina alternaflora)*. This is the dominant marsh grass from Newfoundland to about central Florida. It is well adapted to soils not exposed to air that range from coarse sands to silty clays. Three distinct height forms are recognized. The tall form is generally found along tidal creeks and drainage channels, the short form grows on flat or gently sloping areas away from channels, and the medium form, when present, is found in transition areas between stands of the short and tall forms.

Figure E-1 Marsh Vegetation

Smooth cordgrass can be planted with a better chance of success than any other coastal marsh species native to the United States. Its ideal salinity range is 10 to 35 parts per thousand (ppt) . Two to four weeks after planting, 30 to 45 lb/ac of a fertilizer which contains equal parts of available nitrogen and phosphate should be applied.

Saltmeadow Cordgrass *(Spartina patens).* This species is extensive in the irregularly flooded high marsh zone along the Atlantic coast. It is able to withstand extended periods of both flooding and drought, growing in spots where the surface drainage is poor and water ponds during rainy periods. It cannot, however, tolerate the daily flooding of the intertidal zone. Saltmeadow cordgrass is a valuable stabilizer in the zone between smooth cordgrass and the upland grass species.

Two to four weeks after planting, 30 to 45 lb/ac of fertilizer containing equal parts of nitrogen and phosphate should be applied.

Table E-1

PLANTING SPECIFICATIONS FOR MARSH PLANTS

Type	Planting Time	Plant Form Recommended	Spacing	Tidal Range and Plant Location
Atlantic Coast Marshes				
Smooth cordgrass (*Spartina alternaflora*)	March-May	Sprigs 15 week old seedlings 6 month old seedlings or plugs	3' apart 1.5' apart 1.5' apart	< 4.5' range-plant MLW to MHW > 4.5' range-plant MTL to MHW
Saltmeadow cordgrass (*Spartina patens*)	March-May	Sprigs 15 week old seedlings	3' apart	MHW to estimated highest tide
Black needle rush (*Juncus roemerianus*)	Spring	Seedlings	As 1-5 percent of cordgrass plantings	Above MHW
Common reed (*Phragmites communis*)	Spring	Sprigs	1.5'-3.0' apart	Above MHW
Mangroves Black (*Avicennia germinans*) Red (*Rhizophara mangle*) White (*Laguncularia racemosa*)	Late February-March	Seedlings Established plants	1.5' apart 6'-10' apart	Generally MTL and above
Gulf Coast Marshes				
Gulf cordgrass (*Spartina spartinae*)	March-May	Sprigs 15 week old seedlings 6 month old seedlings	1.5'-3.0' apart 1.5' apart 1.5' apart	MHW and above
Saltgrass (*Distichlis spicata*)	Spring	Seedlings	1.5'-3.0' apart	MHW and above
Pacific Coast Marshes				
Pacific cordgrass (*Spartina foliosa*)	April	Sprigs	1.5'-3.0' apart	Below MTL
Pickleweed (*Salicornia spp.*)	Spring	Sprigs Seeds	0.5'-3.0' apart 5-10 seeds/sq ft	MHW to estimated highest tide
Sedge (*Carex lyngbyei*)	April-June	Seedlings	1.4'-3.0' apart	Above MTL
Tufted hair grass (*Deschampsia caespitosa*)	April-May	Seedlings	1.5'-3.0' apart	Above MLHW
Arrowgrass (*Triglochlin maritima*)	April-June	Seedlings	1.5'-3.0' apart	Above MTL

1. SHORE VARIABLES	2. DESCRIPTIVE CATEGORIES (SCORE AS INDICATED)						3. SCORE
a. FETCH - AVERAGE AVERAGE DISTANCE IN KILOMETERS (MILES) OF OPEN WATER MEASURED PERPENDICULAR TO THE SHORE AND 45° EITHER SIDE OF PERPENDICULAR 	Score : 0 LESS THAN 3.0 (1.8)	Score : 2 3.1 (1.9) to 6.0 (3.7)	Score : 4 6.1 (3.8) to 9.0 (5.6)	Score : 6 9.1 (5.7) to 12.0 (7.5)	Score : 8 12.1 (7.6) to 15.0 (9.4)	Score : 10 GREATER THAN 15.0 (9.4)	
b. FETCH - LONGEST LONGEST DISTANCE IN KILOMETERS (MILES) OF OPEN WATER MEASURED PERPENDICULAR TO THE SHORE OR 45° EITHER SIDE OF PERPENDICULAR 	Score : 0 LESS THAN 4.0 (2.5)	Score : 2 4.1 (2.6) to 8.0 (5.0)	Score : 4 8.1 (5.1) to 12.0 (7.5)	Score : 6 12.1 (7.6) to 16.0 (10.0)	Score : 8 16.1 (10.1) to 20.0 (12.6)	Score : 10 GREATER THAN 20.0 (12.6)	
c. SHORELINE GEOMETRY GENERAL SHAPE OF THE SHORELINE AT THE POINT OF INTEREST PLUS 200 METERS (660 FT) ON EITHER SIDE	Score : 0 COVE	Score : 2 IRREGULAR SHORELINE	Score : 4 HEADLAND OR STRAIGHT SHORELINE				
d. SHORE SLOPE SLOPE OF THE PLANTING AREA (VERTICAL TO HORIZONTAL)	Score : 0 GRADUAL 1 to 15 OR LESS	Score : 4 STEEP MORE THAN 1 to 15					
e. SEDIMENT GRAIN SIZE OF SEDIMENTS	Score : 0 SILT & CLAY	Score : 2 FINE SAND	Score : 4 MEDIUM SAND	Score : 6 COARSE SAND	Score : 8 GRAVEL		
f. BOAT TRAFFIC PROXIMITY OF SITE TO NAVIGATION CHANNELS FOR LARGE VESSELS OR SMALL RECREATIONAL CRAFT	Score : 0 NO NAVIGATION CHANNEL WITHIN 1 KILOMETER (0.6 MILES)	Score : 8 NAVIGATION CHANNEL WITHIN 1 KILOMETER (0.6 MILES)	Score : 16 NAVIGATION CHANNEL WITHIN 100 METERS (330 FT)				
g. WIND THE ORIENTATION OF THE SITE IN RELATION TO LOCAL WINDS	Score : 0 SHELTERED FROM WIND	Score : 4 DOES NOT FACE IN THE DIRECTION OF PREVAILING WINDS OR FREQUENT STORM WINDS	Score : 8 FACES IN THE DIRECTION OF PREVAILING WINDS OR FREQUENT STORM WINDS				

4. CUMULATIVE WAVE CLIMATE SCORE ____

SCORE = 1 TO 10: USE SPRIGS AT 3-FOOT SPACINGS IN 10-FOOT (MINIMUM) ZONES.
= 11 TO 20: USE SPRIGS OR 15-WEEK SEEDLINGS AT 1½-FOOT SPACINGS IN 10-FOOT (MINIMUM) ZONES.
= 21 TO 30: USE 5-7 MONTH SEEDLINGS OR PLUGS AT 1½-FOOT SPACINGS IN 20-FOOT (MINIMUM) ZONES.
= ABOVE 30: DO NOT PLANT

Figure E-2 Site Evaluation Form for Marsh Plants [After U.S. Army Corps of Engineers (1980)]

Black Needle Rush *(Juncus roemerianus).* This species is extensive along the Atlantic coast south of New England. It is found in high marshes where it is flooded only by wind-driven tides or in areas near the edge of uplands where freshwater seepage regularly occurs. It is a good stabilizer, although difficult to propagate; yet under favorable conditions it will invade areas already populated by cordgrasses.

Common Reed *(Phragmites communis).* The common reed grows 4.5 to 12 feet tall and is widely distributed in brackish (salinity range 1 to 35 ppt) to freshwater areas above the mean high water level. It is easy to transplant and provides good stability; however, it does tend to compete with other plants and may become a nuisance by crowding out more desirable species.

Mangroves. Three species of mangrove--black *(Avicennia ger-minans), red (Rhizophora mangle),* and white *(Laguncularia race*mosa)--occur along the south Atlantic coast, primarily in Florida. Mangroves are good stabilizers; however, they require considerably more time (2 or 3 years) than grasses to become established. During this time, the plants are susceptible to possible damage from tides, traffic, and browsing animals. Mangrove seeds, seedlings, or plants are best planted in established cordgrass stands, which provide stability until the mangroves are established.

Slow-release (e.g., Osmocote) or a magnesium-ammonium phosphate fertilizer can be placed in the planting hole if needed, especially for the larger transplants. Daily watering may be required if flooding does not occur.

Gulf Coast Marshes

The vegetation found in gulf coast marshes does not substantially -differ from the south Atlantic coast marshes. Grasses, primarily saltgrass and gulf cordgrass, are prevalent, while smooth cordgrass, saltmeadow cordgrass, and black needle rush are also common.

Gulf Cordgrass *(Spartina spartinae).* Gulf cordgrass is found along the gulf coast from southwest Louisiana to Texas. The plant performs well above the mean high water level. It is propagated similarly to saltmeadow cordgrass and the same procedures for planting are used.

Saltgrass *(Distichlis spicata).* Saltgrass is generally limited to the more saline, high marshes along the gulf coast. The plant is usually found in a mixture with saltmeadow cordgrass or black needle rush, and is rarely the dominant species except in poorly drained areas or in narrow bands. Saltgrass is more difficult to establish than the cordgrasses and usually is allowed to volunteer into cordgrass plantings.

Pacific Coast Marshes

Vegetation in marshes along the Pacific coast is more diverse than along the Atlantic coast. Pacific cordgrass is found along the central and southern California coasts. Pickleweed, **sedges,** arrowgrass, and tufted hair grass are common along the northern Pacific coast.

Pacific Cordgrass *(Spartina follosa).* This plant is similar to smooth cordgrass, but it takes longer to establish. It dominates below the mean tide level of intertidal marshes.

Plants and sprigs should be inserted by hand in holes made in soft, fine-textured soils. Fertilizers should contain equal quantities of available nitrogen and phosphate.

Pickleweed *(Salicornia spp.)*. From mean high water to extreme high tide, va-rious species of pickleweed can be used upslope of Pacific cordgrass. Pickleweed will spread both by seeds and vegetatively (by rhizomes and tillers) but because it is shallowrooted, it is probably not as useful for stabilization as Pacific cordgrass. Pickleweed may be easily established by seeding or by transplanted peat-pot seedlings, and in fact, often invades disturbed surfaces during the first growing season.

Sedge *(Carex lvngbgei)*. Sedge marshes are usually found in areas such as river deltas where silty soils exist. They grow above the mean tide level and are not especially salt tolerant. The plant may respond to nitrogen and phosphorous under deficient conditions. It appears to be one of the best marsh plants available in the Pacific Northwest.

Tufted Hair Grass *(Deschampsia caespitosa)*. This plant predominates in high marshes subject to flooding only by higher high tides. It is a good sediment accumulator and stabilizer once established. It is generally easy to transplant and quick to establish. Fertilizers should be applied where nutrient deficiencies are suspected.

Arrowgrass *(Triglochlin maritima)*. This plant will frequently invade and colonize disturbed marshes, trapping sediments and debris and helping to create a substrate for other plants. Planting should follow the method described for sedges.

Great Lakes Marshes

Marshes of the Great Lakes are generally limited in extent, and confined primarily to the protected shores of bays and inlets of Lakes Huron and Michigan. Establishing fresh water marshes may not provide as satisfactory a level of erosion prevention as saltwater marshes. The landowner interested in establishing fresh water marshes should consider the common reed, rushes (Scirpus *spp.*) such as spike rush, bulrush, and great bulrush, and, in some

Planting specifications for several selected species are given in Table E-2.

Table E-2

SELECTED BEACH AND DUNE GRASS PLANTING SPECIFICATIONS

Element	Species (Beach Grass, except Sea Oats) American	Panic	European	Sea Oats
Planting Season				
Late fall to early winter	Yes	Yes	Yes	No
Midwinter	Yes	Optimum	Yes	Optimum
Late winter to early spring	Optimum+	Optimum	Optimum	Yes
Early spring to mid-spring	Yes	Yes	Yes	No
Available Source				
Transplants				
Commercial	Yes	Yes	Yes	Yes
Wild harvest	Yes	Yes	Yes	Yes
Seed				
Commercial	No	No	No	No
Wild harvest	Yes	Yes	Yes	Yes
Planting Density				
Eroding site	18-inch centers	18-inch centers	18-inch centers	18-inch centers
Noneroding site	24-inch centers	24-inch centers	24-inch centers	24-inch centers
Stems per transplant	3	1	3	1
Fertilization, First Growing Season				
Composition NPK#	3-1-0	2-1-1	7-0-0	2-1-1
Rate lbs/acre (annual)	200	24	40	240
Application periods (equal applications in months indicated)	March, May, July, September	April, June, August	April	April, June, August

Illegal to harvest in some states.
+ Season not recommended for Great Lakes.

#NPK--Nitrogen-Phosphorous-Potassium.

3-1-1 in Great Lakes.

[After U. S. Army Corps of Engineers (1977a)].

Figure E-3 Dune and Beach Vegetation

North Atlantic Region

Extending from the Canadian border to the Virginia capes, American beachgrass is the dominant dune stabilizing plant in this region; bitter panicum offers promise as a companion plant.

American Beachgrass *(Ammophila breviligulata).* This species is probably the most widely used for the initial stabilization of blowing sand because it grows rapidly and can effectively trap sand by the middle of the first growing season. once established, it multiplies quickly. It prefers cool weather and plants start growing in early spring and continue through fall under the most favorable conditions - The grass can be transplanted over a long planting season with a good chance of survival. American beachgrass is available commercially or may also be harvested from wild stands. Seedlings are the preferred method of planting. Starting from seed is usually uneconomical because seed supplies are unreliable and weeds are difficult to control.

American beachgrass should be planted 8 to 10 inches deep in loose, dry sand. Shallow planting is the most common cause of failure, therefore it is better to place the plant too deep than too shallow. Transplants may be made from October through May with the optimum period being February through April. The seedlings should be one or more healthy, vigorous stems (culms), with one to three seedlings per hill. First year growth is related to the size of the seedlings (number of stems), planted. Spacing varies with the characteristics of the site, but a strip of beachgrass 24 to 40 feet wide, planted 18 inches apart, will generally be effective by the last half of the first growing season. A more practical (and less expensive) method for planting would be 4 rows at 18-inch spacings at the approximate center of the proposed dune. This plot should be flanked on both sides, by four rows each of plants spaced 24, 36, and 48 inches.

Newly planted stands of American beachgrass will often respond to the application of 90 to 135 pounds of nitrogen and 30 to 45 pounds of phosphorous per acre. These fertilizations should be divided into three applications. The first should be applied as new growth emerges and the subsequent applications should be made at 4- to 6-week intervals.

Bitter Panicum *(Panicum amarum).* This grass is indigenous along the Atlantic coast from Connecticut southward. It is best used as a companion to American beachgrass, especially in those areas where the beachgrass is subject to severe attack by the disease, soft scale.

Bitter panicum should generally be planted at the same time and with the same methods as American beachgrass. Since it prefers warm weather, it may be wise to wait until April to plant. Bitter panicum can be transplanted as mature primary stems or as tillers. Primary stems must be used during late winter and spring until tillers become available. Young tillers, with some roots and rhizomes attached, grow with very little delay and are the preferred method of planting when available. Plants should be placed 8 to 10 inches deep in the soil. Bitter panicum should be planted as a percentage (10-20%) of the total beachgrass planting and in the same pattern. Pure stands of bitter panicum are not usually successful except in very small spots, such as those where beachgrass has bieen reduced by insects or disease. Fertilizer applications are similar to those recommended for beachgrass.

South Atlantic Region

This region extends from the Virginia capes to Key West. Sea oats is the dominant plant; however, both American beachgrass and bitter panicum will successfully establish dunes, when planted in combination with sea oats, especially in the northern part of the region.

Sea Oats *(Uniola paniculata).* More persistent than other stabilizing species, sea oats does not provide much initial protection. It grows slowly, is difficult to propagate, and is not widely available commercially. However, once established, sea oats provide excellent protection. To provide initial protection, sea oats should be planted in mixes with American beachgrass and bitter panicum to the Carolinas and with bitter panicum farther south. As the other grasses thin out, sea oats will spread and dominate the dune.

Planting is similar to both American beachgrass and bitter panicum. Plants should be placed 8 to 10 inches deep, because they are slow starters and the depth is required to prevent dessication and blowouts. Transplanting can be successful at any time given proper moisture conditions and healthy transplants. Optimum planting months are January and February, although in more severe climates, February to April are better. Single stem transplants perform as well as multiple stem plantings under most conditions. Two-year old, nursery-grown plants appear to be the best stock for transplants-

Since sea oats is generally planted as part of a mixture, it is recommended that one or two rows of sea oats (or every 10th to 20th row in extremely large plots) be planted no closer than 24 inches. A moderate application of nitrogen and phosphate similar to that recommended for American beachgrass can be used to speed establishment of new plantings and to maintain growth and vigor in sand-starved areas.

Saltmeadow Cordgrass *(Spartina patens)*. This plant is more commonly used in marsh plantings (see prior discussion), but it will frequently invade a beach area and create small dunes which will support other vegetation. It is particularly well suited for this use on low, moist sites where periodic salt buildup occurs.

Plants should be set 6 to 8 inches deep to stay in the moist zone. For dune stabilizing plantings, the optimum time is late winter and spring; however early summer is adequate for transplanting providing sufficient moisture is available. vigorous, multi-stemmed transplants from uncrowded nursery stands are recommended. With vigorous plants, adequate nutrients, and favorable moisture, saltmeadow cordgrass can be planted 16 to 24 inches apart in a single species planting. The transplants will usually benefit from a total of 90 to 135 pounds of nitrogen per acre applied over two to three applications during the first year. Subsequent fertilization should deliver similar amounts of nitrogen in single applications over the following two or three years.

Bermuda Grass *(Cynodon dactylon)*. Although this is not a prominent dune species, it can be used very effectively in special situations. The coastal hybrid is deep rooting and rapidly establishing and can be used to revegetate areas where American Beachgrass has been killed by insects or disease. Turf hybrids will, when properly managed, perform well on the dune environment where they form a more traffic resistant stand than other types of vegetation.

Sprigs of Bermuda grass, spaced 18 to 24 inches apart, should adequately stabilize the dune once established. For turf development, a spacing of 12 inches should be used. Sprigs may be planted from early spring to the beginning of summer where adequate moisture is available. Sprinkling the sprigs during dry spells will help to assure the survival of the plants. Bermuda grass requires more nutrients than other dune grasses. As soon as new growth begins in the spring, 30 to 45 pounds of nitrogen per acre should be applied every 4 weeks until the end of summer. Traffic resistant turf can be developed by applying 450 to 900 pounds per acre of 10-10-10 formula fertilizer in the early spring and supplementing that with 45 to 70 pounds of nitrogen per acre every four weeks through the summer.

Gulf Region

The region extends from the gulf coast of Florida to the Mexican border. Sea oats and bitter panicum are the dominant dune stabilizing species. other species include railroad vine and saltmeadow cordgrass. Establishment of sea oats, bitter panicum, and saltmeadow cordgrass should follow prior recommendations. Local variations exist, and the landowner should consult local agricultural extension agents and others about differences in technique and management of plantings of these species.

Railroad vine *(Ipomea pes-caprae)*. This plant is one of the more prominent pioneer species in this region. It is not generally planted because it is somewhat less effective in trapping sand than dune grasses. It is, however, capable of rapidly spreading over foredunes, and transplants of the vine may be included as part of a grass establishment planting.

North Pacific Region

This region extends from the Canadian border to Monterey, California. European beachgrass and American dunegrass are the dominant sand stabilizing plants of the region. American beachgrass may also be applicabl6 in the area.

European Beachgrass *(Ammophila arenaria)*. This plant is inexpensive and used widely in this region. Although it effectively traps sand, it forms dense stands with little outward spread, causing the resulting dunes to have steep windward slopes. Another disadvantage is that it will often exclude native species, making it difficult to establish mixed plantings.

Planting should not be done when the temperature exceeds 60' F or is below freezing. Moist sand should be within 3 to 4 inches of the surface and the minimum planting depth should be about 12 inches. The optimum conditions of moisture and temperature for planting usually occur during the late fall, winter, and early spring months in this region. Three to five stems per hill are recommended for transplanting since establishment of dense stands is imperative with the wind conditions of the region. Spacing and planting patterns should be adapted to the site, but generally, an 18- by 18-inch planting with three to five stems per hill is sufficient. A pattern of several rows with plants spaced 12 x 12 inches, bordered by several rows each of plants spaced 18 x 18, 24 x 24, and 36 x 36 inches, will build a stable foredune at less expense than a uniformly spaced planting. When rapid growth begins (early April) 35 to 55 pounds of nitrogen per acre should be applied.

American Dunegrass *(Elymus mollis)*. Although this grass is native t-o the northwest, it is more difficult and expensive to propagate than either European or American beachgrass. The grass tends to produce low, gently sloping dunes, often preferable to those dunes built by European beachgrass.

American dunegrass should be set 12 inches or more deep in moist sand. Satisfactory planting occurs primarily in the months when the grass is dormant, late November through February in the northern portion of the region, and not at all in the southern extent. Planting should be limited to temperatures below 55' F. Planting several stems per hill would be desired; however, due to the expense, a close spacing of 12 inches with one viable stem makes better use of scarce planting stock. An application of 35 pounds of nitrogen per acre from a soluble source is recommended as new growth starts.

South Pacific Region

This region extends from Monterey, California, to the Mexican border. While some of the beach grasses discussed above (e.g., European beachgrass) are applicable in the northern portions of this region, the dominant plants are forbs such as the sea fig.

Sea Fig *(Carpobrotus edulis and C. aequilaterus)*. Sea fig is effective as a sand stabilizer but not good as a dune builder. It is quite easy to establish; cuttings 4 to 6 inches long should be placed about 18 to 24 inches apart in moist sand. An occasional application of nitrogen at a rate of 30 to 35 pounds per acre is recommended to maintain the plants once established.

Great Lakes Region

Dune development is mostly confined to the Michigan and Indiana shores of Lake Michigan; however, the discussion which follows is applicable to all the shores of the Great Lakes. American beachgrass is the dominant species. Native species, especially prairie sandreed, will often invade naturally. Once the dunes have been stabilized, volunteer or planted species of upland vegetation can be established. species of grasses suggested would include reed canarygrass, big bluestem, little bluestem, and switchgrass, all native to the area. These grasses may be planted from early May to the middle of June at a rate of about 0.5 pounds of seed per 1,000 square feet. All require full sun and may be mowed occasionally. Reed canarygrass is especially useful in wet spots.

Various ground covers may also be planted. The species which may be utilized are best suggested by local agricultural experts. The same holds true for shrubs and trees. When planting grasses and ground covers, application of 12 pounds of 12-18-12 fertilizer per 1,000 square feet is recommended.

An additional problem which landowners in the Great Lakes region have is the stabilization of bluffs. Often, structural corrections are required in concert with vegetation. Once the structural stabilization is accomplished, vegetative cover will aid in preventing erosion, reducing seepage, and slowing runoff.

The type of vegetation which can be established on bluff slopes is dependent upon the slope angle. Slopes steeper than 1 on 1 generally preclude successful vegetation; slopes flatter than 1 on 3 can be planted as a lawn and maintained in the usual manner. Slopes between 1 on 3 and 1 on 1 can be planted with grasses which will not be mowed, ground covers, trees and shrubs, or combinations of these three. As mentioned before, local expertise (e.g., agricultural extension agents) can aid the landowner in selecting suitable species, and in describing the most practical methods of establishment and maintenance.

APPENDIX F - PERCHED BEACHES

Perched beach sills can be built using most of the materials described for fixed breakwaters *(APPENDIX* C). They must be made sand-tight to retain fill. Fill material should be chosen in accordance with guidelines previously given for beach fills. Proper filtering should be provided beneath and behind the sill to prevent settlement and loss of retained fill. In some cases, navigation markers may be required.

Materials not included in *APPENDIX C* are discussed below.

<u>Sheet Piling</u>

Sheet pile sills are similar to bulkheads *(APPENDIX A).* Timber sheet piling will generally require filter cloth backing on the shoreward face to prevent loss of the retained sand backfill through joints in the structure. This is not generally a problem with steel or aluminum sheet piling. Sheet pile sills also form an abrupt step to deeper water which would definitely be hazardous to bathers, particularly children.

The same precautions regarding adequate ground penetration and toe protection for a bulkhead also apply to a sheet pile sill. Figure F-1 shows a timber sheet pile sill under construction.

Figure F-1 Timber Sheet Pile Sill Under Construction

Concrete Boxes

Precast, open concrete boxes (for use in drainage structures) can be placed side by side and filled with sand to form a sill (Figure F-2). During placement, the gaps between adjacent boxes must be minimized to prevent excessive wave transmission through the structure and to help retain the perched beach. Filter cloth backing is required and toe protection should be provided on the offshore side.

Figure F-2 Concrete Box Sill

RECOMMENDED READING

Numerous booklets, brochures and reports, many of them free, are available for further study of selected topics and subjects presented in this report. Most government reports include their NTIS or GPO accession numbers. Use the NTIS number to order documents from:

National Technical Information Service (NTIS)
Attention: Operations Division
5285 Port Royal Road
Springfield, Virginia 22161
703/605-6000
http://www.ntis.gov/

Use the GPO number to order documents from:

Superintendent of Documents
U.S. Government Printing Office (GPO)
PO Box 371954
Pittsburg, PA 15250-7954
(866) 512-1800 (toll free)
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S5 Bulkheads: Hardware and Fasteners
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