LOW COST SHORE PROTECTION

…a Guide for Local Government Officials

The U. S. Army Corps of Engineers presents this information as a public service. Inclusion of any shore protection device or method does not necessarily constitute a government recommendation or endorsement, nor is it guaranteed that any particular method will be successful for a specific application.

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INTRODUCTION

OBJECTIVES

This report is intended for planning, regulatory, and other local government officials whose duties include some involvement i shoreline erosion prevention measures. The discussion is limit to the shorelines of sheltered waters that are not subject to t direct action of undiminished oceanic waves. These would include: bays, sounds, tidal rivers, and the Great Lakes.

The erosion problems that are experienced today are oft caused by failure to recognize that shorelines have always be areas of continuous and sometimes dramatic change. This lack understanding of shoreline processes has been catastrophic for ma property owners, both private and public. An objective of the report is to show that the situation is not without remedies and large variety of reasonably low cost alternatives are available However, it must be cautioned, that while appearing deceptive simple, most of them require careful judgment and design, and c entail considerable investment to correctly implement. Therefore before any action is taken, it is important to recognize and understand the natural forces at work in the general area of a propos project. By considering the overall view rather than condition just at the site, a broader perspective of the problem and possible solutions is developed, and a more informed decision can be mad

The solutions presented herein are referred to as "low cost." That does not necessarily mean they are "cheap". In fact, practically any properly implemented shore protection method is expensive. The term "low cost" simply means that the various measure are commensurate with the value of property being protected as they are among the lower priced options available. Whether solution is considered a low cost alternative or not, however, up to the individual or community installing it. The cost of t project must be weighed against both the objective and subjective value of what is being lost to erosion.

This report has five sections. The first provides a b understanding of shoreline processes and the causes of erosion. The second describes a variety of devices as possible solutions. The third provides guidance for selection among the protection alternatives. The fourth outlines permit requirements. And as this report serves only as an introduction, the fifth provides a directory of other sources of help.

The United States Army Corps of Engineers has produced this report as a public service. Unless otherwise noted, the devices described herein have been utilized at sites throughout the United States to slow or arrest erosion problems. However, successful use of the material presented depends on numerous factors that are peculiar to individual situations. Therefore, the government cannot guarantee that any of the described methods will be successful for any specific application, nor does the government necessarily endorse any of the devices presented.

SHORELINE PROCESSES

The first requirement in solving an erosion problem or reviewing a proposed solution is to understand the processes and forces at work. Without such basic knowledge, any solutions are likely to be misguided and inappropriate. The following presents basic information about shoreline processes as a foundation for the subsequent discussion.

Wave Action

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

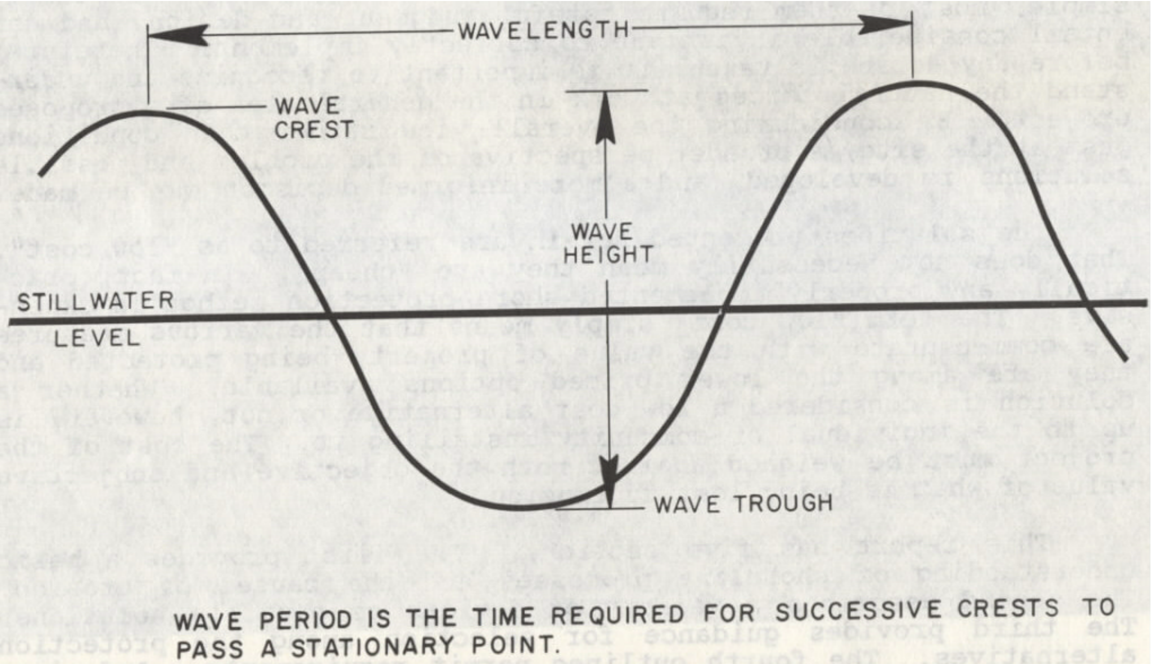


Figure 1 Characteristics of Waves

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 11 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 breaks. For example, a 5-foot wave breaks in a water depth of about 6.5 feet.

Important wave properties are demonstrated when a series of regular waves meet a solid barrier, such as a breakwater (Figure 2). Wave diffraction occurs when the waves pass the barrier, and part of their 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.

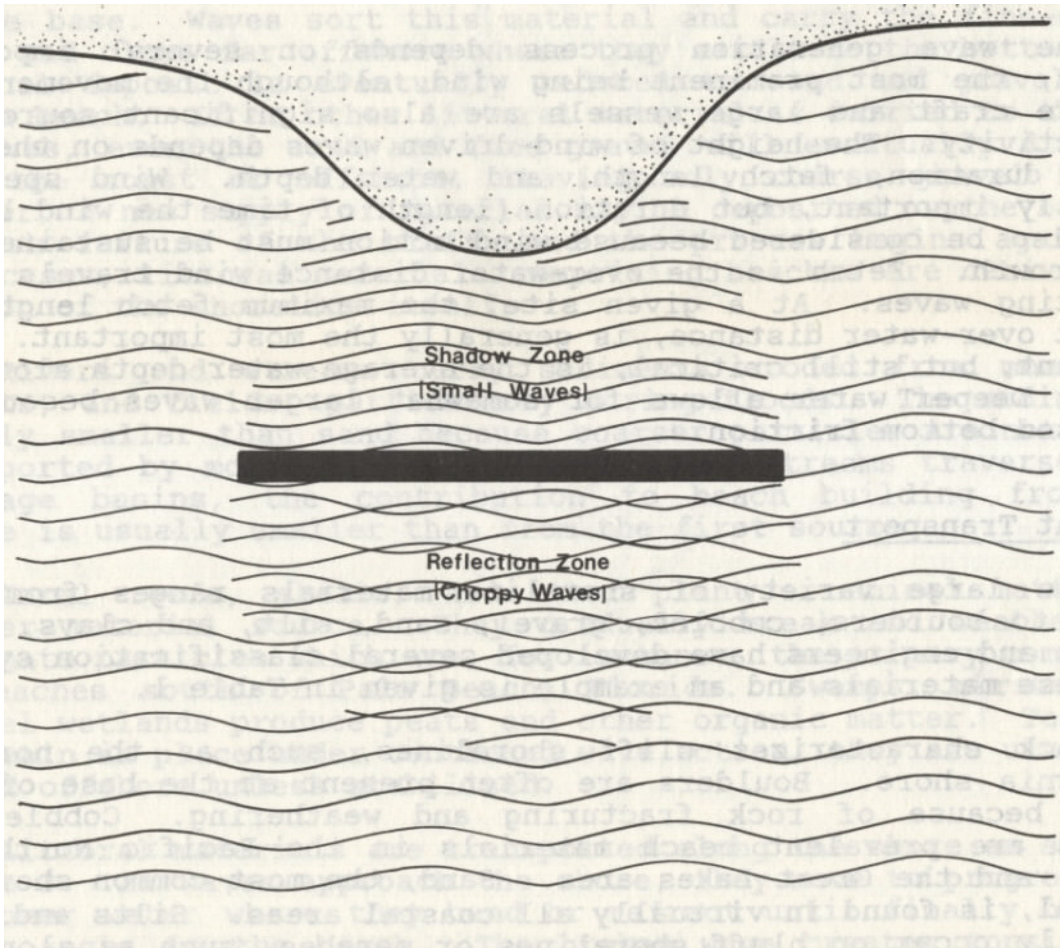


Figure 2 Wave Diffraction and Reflection

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 th6 breakwater, the reflected and incoming waves will reinforce each other to form standing waves, which are twice as high as the incoming waves. These can cause considerable scouring of the bottom. If the waves approach at an angle, no standing waves form, but the resulting sea-state is choppy because the reflected waves cross the path of incoming waves. This could also contribute to bottom scour.

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.

The wave generation process depends on several important factors, the most prominent being wind, although the movements of pleasure craft and large vessels are also significant sources of wave activity. 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 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.

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.

Table 1

CLASSIFICATION OF SHORELINE MATERIALS

Size Description	Particle Size Range (Inches)	Particle Size Range (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

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 and the production of organic material (generally peat) by coastal 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, which form a beach. If no other littoral material is carried to the sit by waves, even the sand and fine gravel will eventually 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 most cases, littoral materials comprising beaches are derived from erosion of the shoreline itself.

Rivers and streams carry sediments eroded from mountain forests, and fields, particularly during floods. The sediment usually smaller than sand because coarser particles are not easily transported by most streams. Except where streams traverse san drainage basins, the contribution to beach building from this source is usually smaller than from the first source.

Coral reefs, shells, and other plant or animal matter are another material source. They gradually break and weather in carbonate particles, which are, for instance, the primary component of beaches south of Palm Beach, Florida. Swamps, marshes, a 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.

Littoral materials are transported along the shore as shown. Figure 3. As waves approach the shore, they move to progressive 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 face 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 in the downdrift direction. As long as waves approach from the same direction, the alongshore transport direction remains the same.

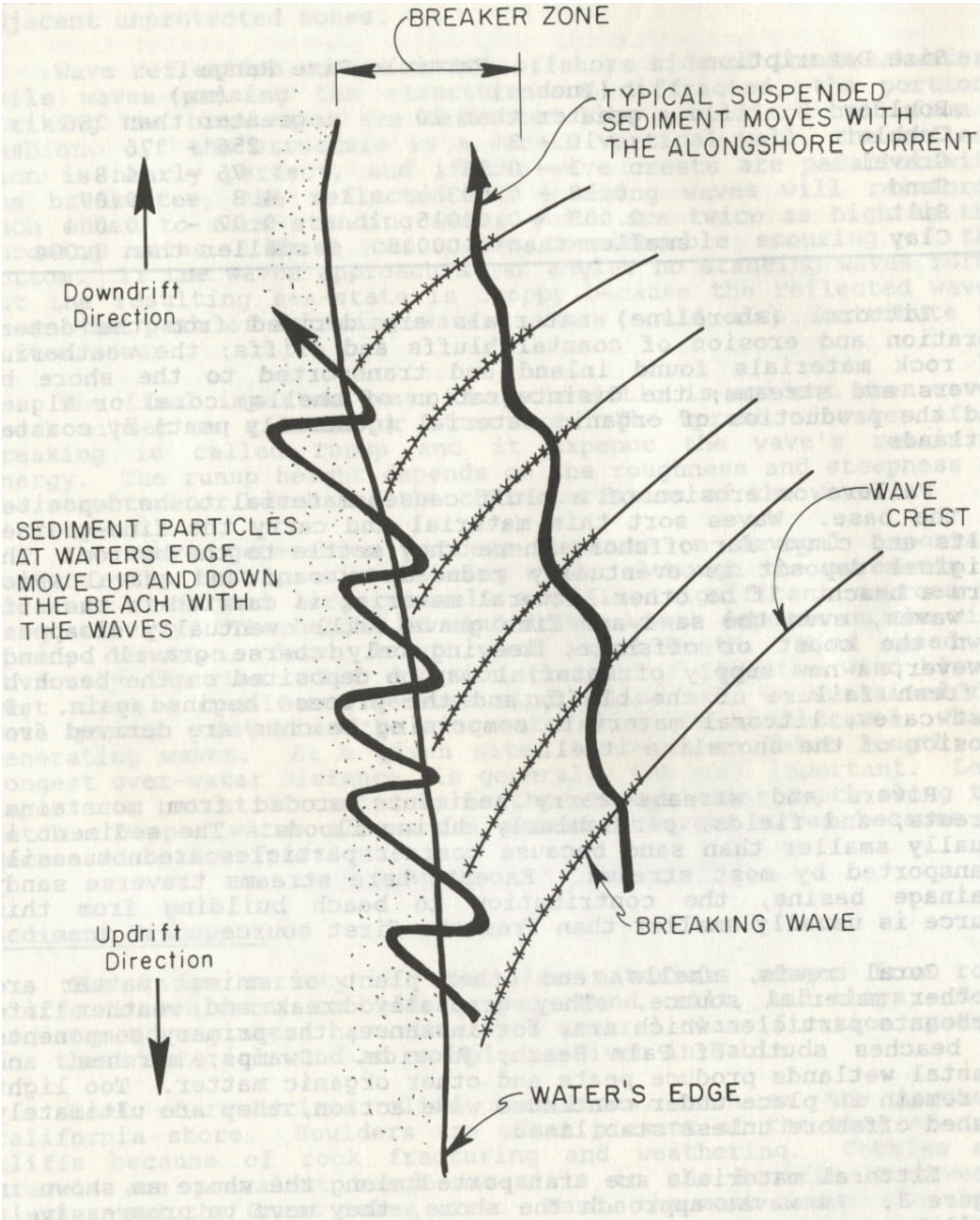


Figure 3 **Alongshore Sediment Transport**

Littoral materials are also moved by the longshore current. Arising from the action of breaking waves, this current is generally too weak, alone, to move sand. However, the turbulence of breaking waves places sand temporarily in suspension and permits the longshore current to carry it downdrift. The sand 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-zag motion up and down the beach, and the turbulence and action of the wave-generated longshore 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 Change

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. If the most severe winds striking a site are generally along the longest fetch length, structures should be built 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, the water level with no waves present, changes because of astronomical tides, storms, and periodic lake level variations. Tides are caused 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. 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 the two successive highs or two 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 tidal 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 moon are out of phase, somewhat canceling their individual effects and causing correspondingly smaller tidal ranges. Differences in tidal range are also caused by the varying distance to the moon as it orbits the earth, the declination of the moon's orbit, and the declination of the earth's orbit about the sun.

Tide levels are used as reference elevations on maps, charts, and engineering drawings. Key reference elevations or datums (Figure 4), which are important because of their wide use, are defined in the *Glossary.* Not shown are reference levels for the Great Lakes where all water levels are ultimately referenced to the International Great Lakes Datum (IGLD). Each lake 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.

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 flow back to a lower level. These high winds also generate large waves, which tend to pile water on shore as they break, 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 drive the water surface higher at the downwind end of a 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. 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 wind directions, and its relatively shallow depths lead to higher storm setup levels.

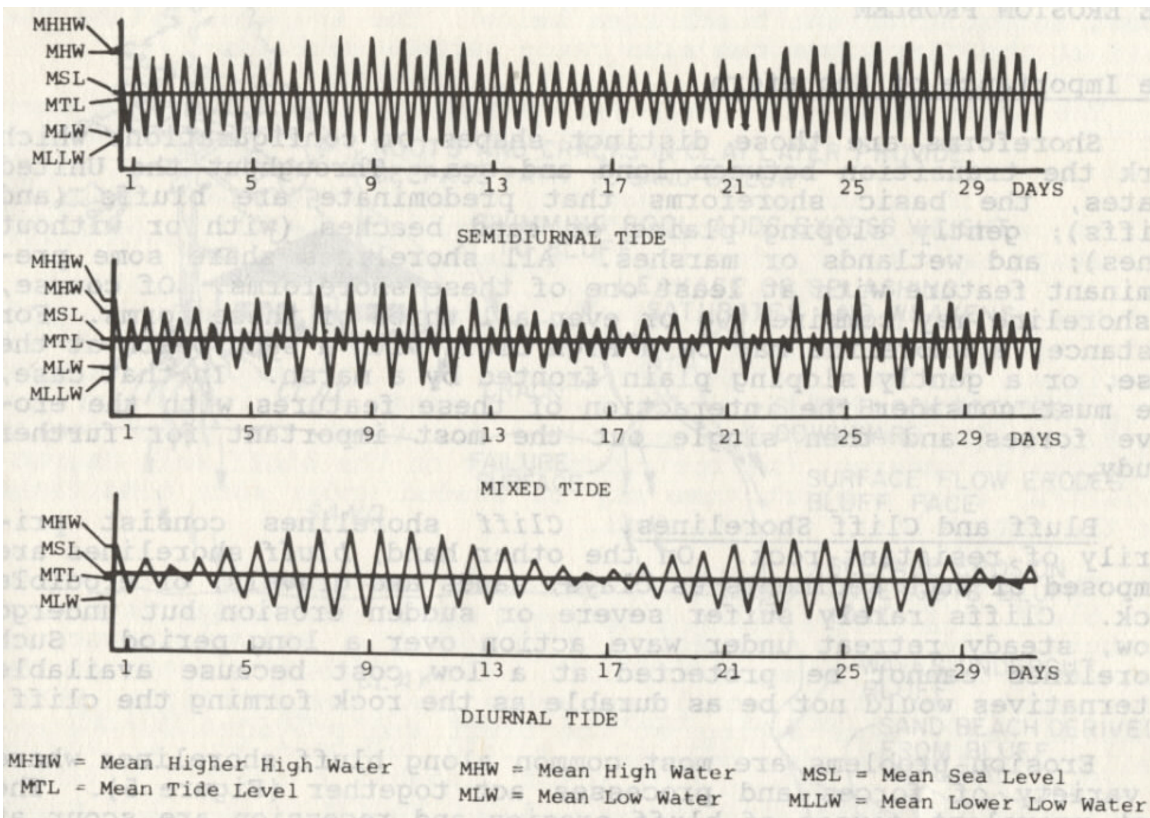


Figure 4 Tidal Reference Elevations

The Great Lakes are also subject to long-term 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 annually 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 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 conf igurations 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 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.

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. Slope stability problems are highly technical and can only be analyzed correctly using methods of geotechnical engineering. Therefore, 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. It is suggested that if a property is endangered by an apparent slope stability problem, a registered professional geotechnical engineer should be contacted.

As Figure 5 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.) Soils are not generally stable at a vertical face, but form a slope that varies with the soil and groundwater conditions. This slope forms as a result of 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, the soil moving downward as it rotates along the failure surface. Granular soils, on the other hand, fail when vertical-sided blocks drop to the bottom or when the soil suddenly flows 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.

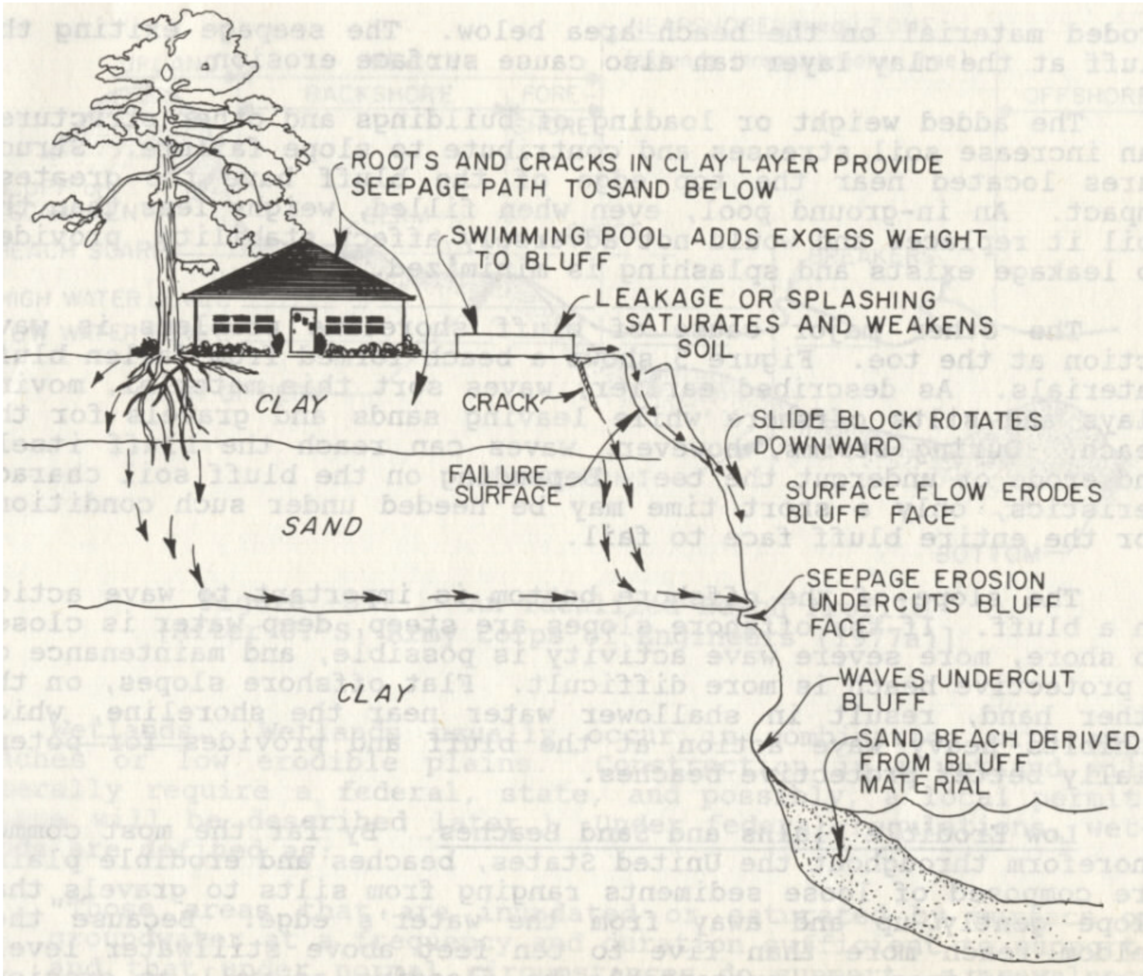


Figure 5 **Causes of Bluff Erosion and Retreat**

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 which provide 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 slope failure. In addition, surface runoff can erode the bluff face, causing gullies and deposits of eroded material on the beach below. The seepage exiting the bluff at the clay layer can also cause surface erosion.

The added weight or loading 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. An in-ground pool, even when filled, weighs less than the soil it replaces and 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 bluff materials. As described earlier, waves sort this material, moving clays and silts offshore while leaving sands and gravels for the beach. During storms, however, waves can reach the bluff itself and erode or undercut the toe. Depending on the bluff soil characteristics, 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.

Low Erodible Plains and Sand Beaches.

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 inaccessible 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 the 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 wave action on the beach, and helps re-establish equilibrium. At open coast sites, the process eventually reverses, and long-period swells again return the sand to the beach after storms. At sheltered sites where no exposure to oceanic swells exists, the recovery does not occur, and storm caused erosion becomes permanent.

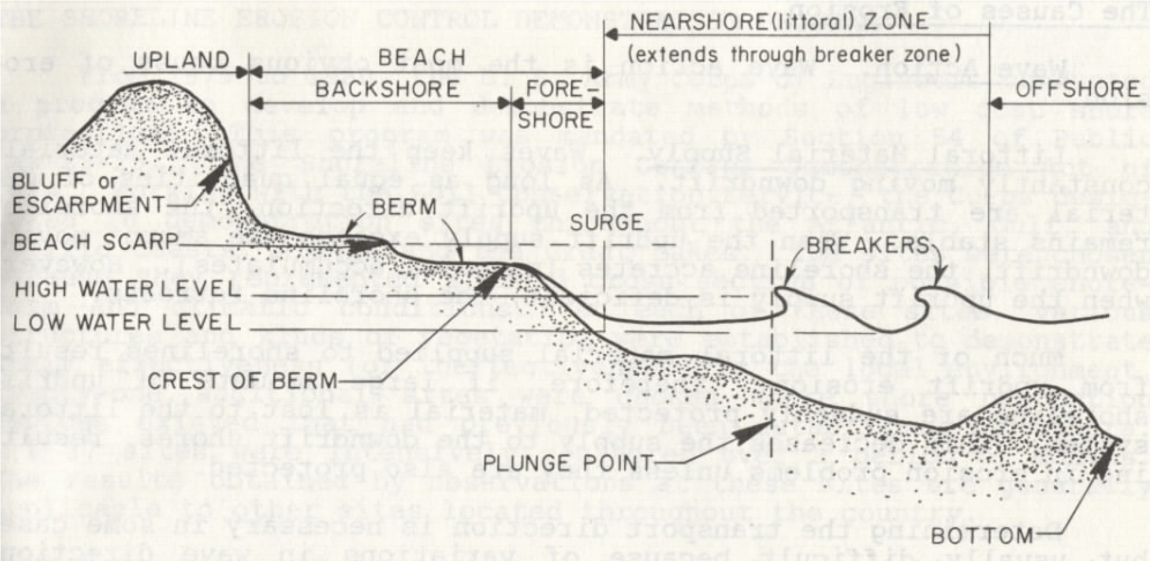


Figure 6 An Idealized Beach Profile
[After U. S. Army Corps of Engineers (1977a)]

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, wetlands are defined as:

> Those areas that are inundated or saturated by surface or 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 soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas" [U. S. Army Corps of Engineers (1977b).

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

Until recently, wetlands were regularly drained and filled for new development or agriculture. They are now recognized as a vital link 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 energy of approaching waves and trapping sediment carried along by currents.

The shore protection qualities of wetlands 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 backup protection.

The Causes of Erosion

Wave Action. Wave action 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 variations 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 longshore transport rate is the total amount of sand that annually moves past a point regardless of direction. The net transport rate is the quantity moved in one direction minus that moved in the other 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 mechanism seldom occurs along sheltered shorelines.

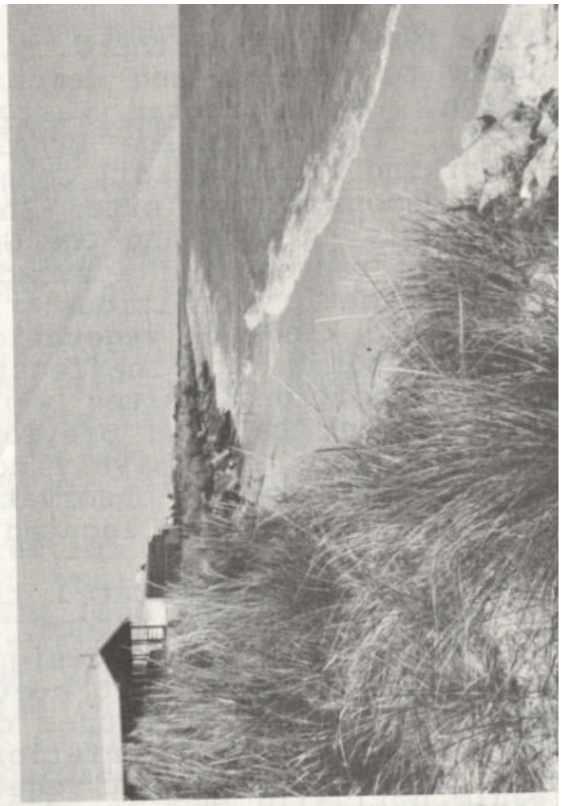
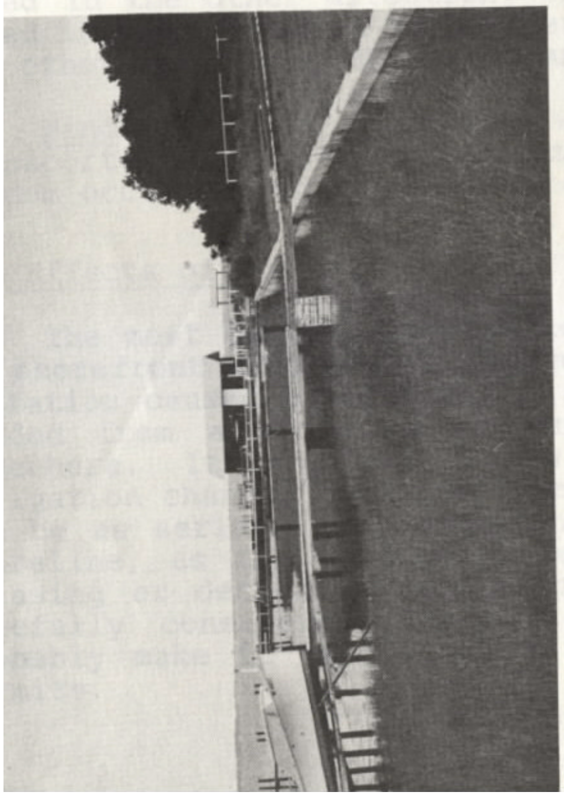
The Effects of Erosion

The most obvious and noticeable effect of erosion is the loss of shor6front property. Less apparent are the increases in sedimentation caused by erosion in adjoining areas since all materials eroded from a shoreline at one point are eventually deposited elsewhere. It is likely this will occur in deeper water such as a navigation channel crossing or closely paralleling the shore. This can be as serious a problem, in terms of total utilization of the shoreline, as the eroding property. All possible effects of increasing or decreasing sediment movement by any actions should be carefully considered. Significant effects of either kind, will probably make it impossible to obtain required federal and state permits.

THE SHORELINE EROSION CONTROL DEMONSTRATION PROGRAM

From 1975 to 1980, the U. S. Army Corps of Engineers conducts a program to develop and demonstrate methods of low cost shore protection. This program was mandated by Section 54 of Public Law 93-251, the Shoreline Erosion Control Demonstration Act of 1974. Working with the Soil Conservation Service, the Corps designated 16 demonstration sites throughout the Atlantic, Gulf, an Pacific coasts, Alaska and the Great Lakes. The sites were chose because they represented a broad cross section of possible shoreform and climatic conditions. At each of these sites, various structures and kinds of vegetation were established to demonstrate their effectiveness (or ineffectiveness) in the local environment. Twenty-one additional sites were chosen where shore protection devices existed that had previously been established by others. All 37 sites were intensively monitored over a period of months. The results obtained by observations at these sites are generally applicable to other sites located throughout the country.

The program demonstrated that commonly available material (e.g., timber, concrete, stone, etc.), when integrated in structures that adhere to sound design principles, can produce successful protective devices that meet the aforementioned criteria for low cost. Violation of proper design principles, or use of no durable materials, led to inferior performance in almost all cases The program also showed that vegetation can, at some sites, provide significant protection when used alone, or more often, when combine with other devices.


AVAILABLE OPTIONS

Three options are available when confronted with an erosion problem: take no action, relocate endangered structures, or take positive action to halt the erosion. The latter includes devices that either armor the shoreline, intercept or diminish wave energy offshore, or retain earth slopes against sliding.

Any alternative requires evaluation of the shoreform, planned uses of the land, money and time available, and other effects of the decision.

NO ACTION

The no action alternative is used to help evaluate different options. When confronted with an erosion problem, the first, reaction is to act immediately. 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), and in such cases, it may be advisable to wait for the erosion rate to slow before acting.

RELOCATION

No action is generally unacceptable, and in most cases, steps must be taken. Before investing in shore protection, however, physical relocation of endangered structures should be considered. This could involve moving them either to a different area or farther from the water on the same lot. Moving a building involves considerable expense which could be wasted if it is not moved back far enough. Therefore, it is necessary to evaluate the erosion rate (feet/year) and the likelihood that this rate will continue at or below historical levels through the required life of the setback.

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, large waves are 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.

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 marina and other structures, where water depth is needed directly at the shore (Figure 7).

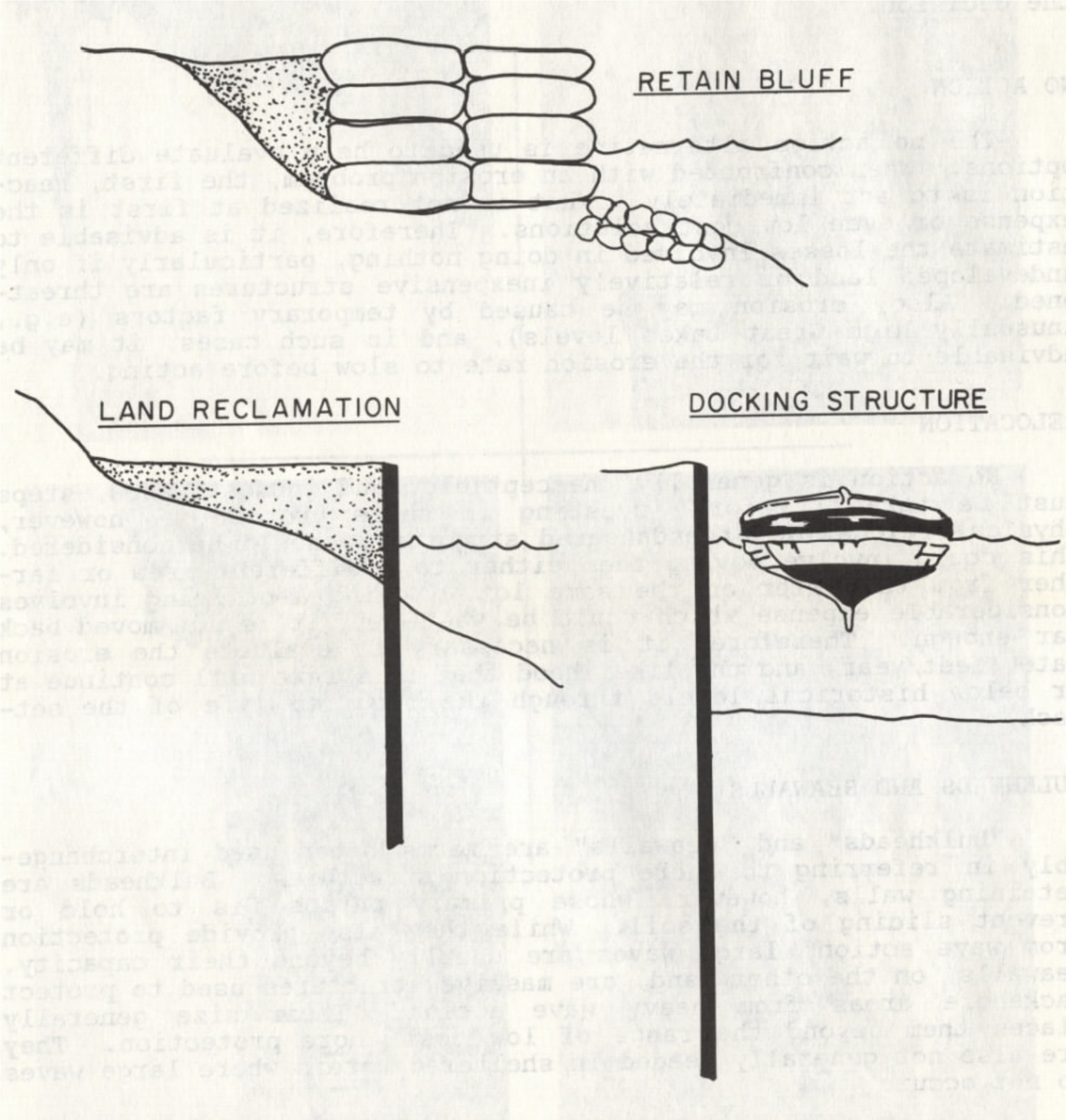


Figure 7 **Uses of Bulkheads**

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 the structure or moving it toward the water. To increase the chances of success, the bulkhead should be placed somewhat 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- or grout-filled bags). Sheet pile bulkheads require adequate ground penetration to retain soil. 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 generally penetrate the soil, they often cannot prevent slides where failure occurs beneath the surface. This limits their effectiveness to sites where the backfill and structure are low.

Bulkheads protect only the land immediately behind them and offer no protection to adjacent areas up and down the coast or to the fronting beach. In fact, because bulkheads normally have vertical faces, wave reflections are maximized, wave heights and overtopping may increase, and scour in front of the structure is more likely. In addition, if downdrift beaches were previously nourished by the erosion of land now protected, they may 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.

Since scour can be a serious problem, toe protection is necessary for stability. Typical toe protection consists of quarrystone large enough to resist movement by wave forces, with an underlying layer of granular material or filter cloth to prevent the soil from being washed through voids in the scour apron. Flanking (erosion of the shore around the ends of the structure) can also be a problem. This can be prevented by tying each end into existing shore protection devices or the bank.

Sheet Pile Bulkheads

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 8, 9, and 10). Sheet pile structures may be either cantilevers or anchored.

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).

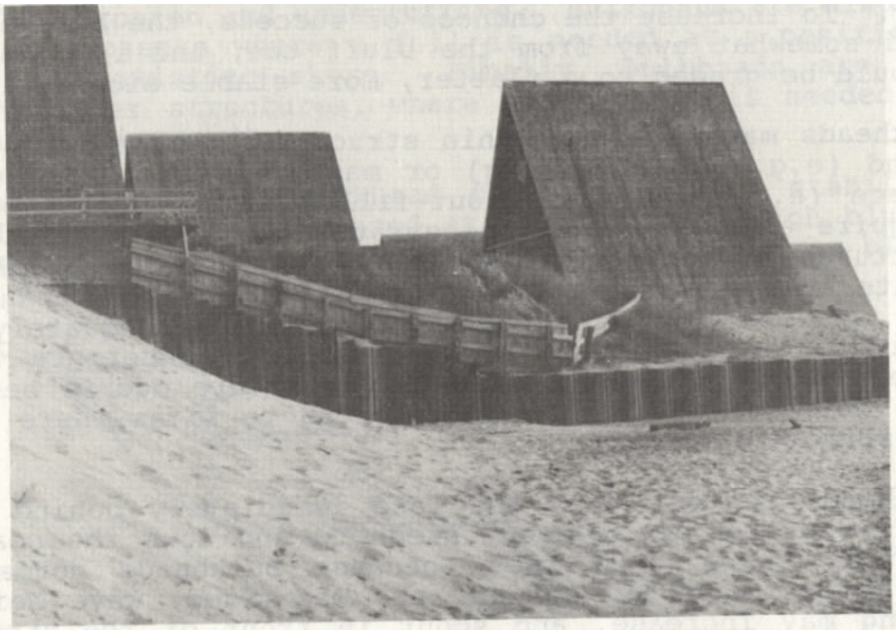


Figure 8 Steel Sheet Pile Bulkhead

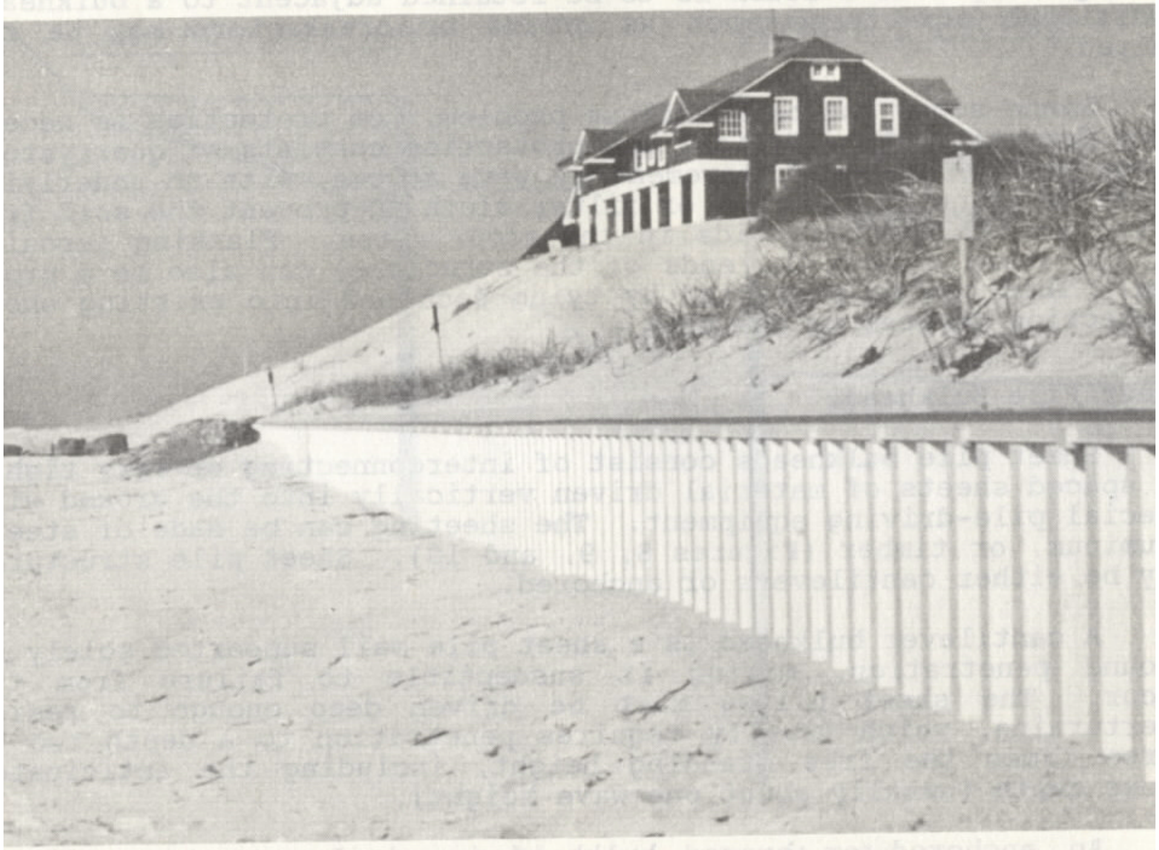


Figure 9 Aluminum Sheet Pile Bulkhead
(Photo Courtesy of Koppers Company, Inc.)

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, the piles generally only need to be embedded to a depth one and one-half to two time 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 corrosion-protected steel. Plain carbon steel should not be used for long-term protection. Horizontal wales at or near the top of the wall laterally distribute the anchor loads. 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 anchors. Figure 11 illustrates cross sections of cantilever and anchored sheet pile bulkheads.

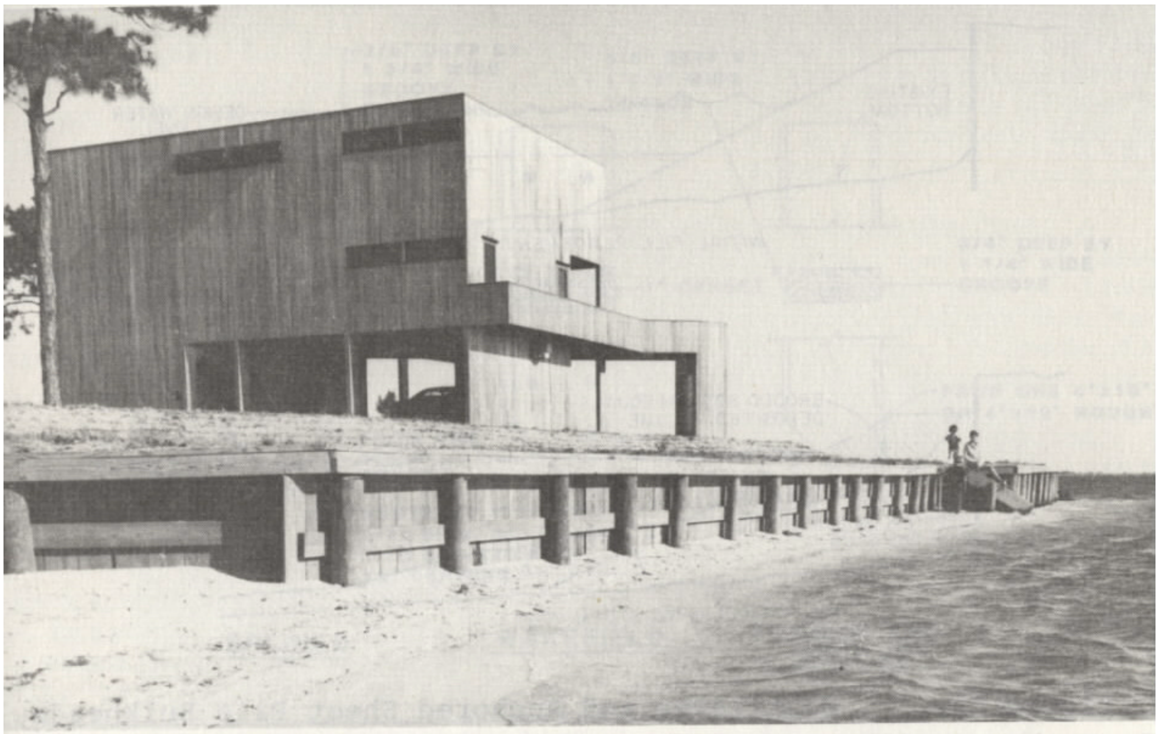


Figure 10 Timber Sheet Pile Bulkhead
(Photo Courtesy of Koppers Company, Inc.)

The type of soil at a site determines the type of sheet piling than can be used. Steel sheet piling can be driven into hard soil and some soft rock. Aluminum and timber sheet piling can be driven or jetted into softer soil. An analysis is required to determine the subsurface conditions at a site and 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 is noisy and requires a fairly wide access route with ample maneuvering room at the site

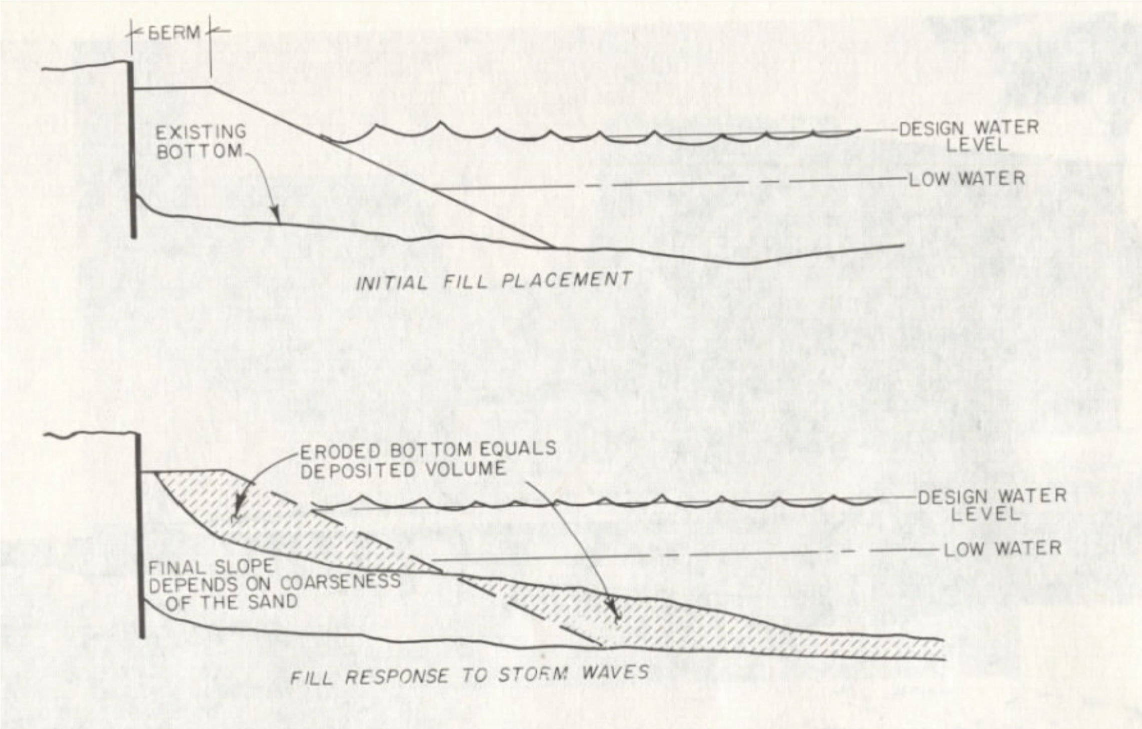


Figure 11 Cantilever and Anchored Sheet Pile Bulkheads

Treated Timber. Well designed and built timber structures have long been recognized as viable and economical for bulkhead construction. Figure 12 illustrates the common types of timber sheeting used. Only specially treated timber should be used for marine construction to prevent deterioration from marine borers. The joints between sheets should be kept as tight as possible and filter fabric should be used as an added precaution against loss of the soil through cracks. Only granular material should be used for backfill. Supplemental drain holes should be placed at regular intervals to further facilitate movement of water from behind the structure and these must always be backed with filter cloth or crushed stone filters. All hardware and fasteners should be corrosion-resistant or protected metal. In addition, washers should be provided under all bolts and nuts to insure that these bear evenly on the timber members.

Steel. Steel sheet piling is probably the most widely used bulkhead-material (Figure 13). The interlocking feature of sheet pile sections provides a sand-tight fit, generally precluding the need for filters. The close fit may also be essentially watertight, so regularly spaced weep holes are recommended. These, and lifting holes in the piling, should be backed with graded stone filters or filter fabric to prevent loss of backfill.

Aluminum. Aluminum sheet piling, which comes in sections similar to those in Figure 13, is designed and installed using 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 less* ruggedness when driven, so it usually cannot penetrate logs, rocks, or other hard obstructions.

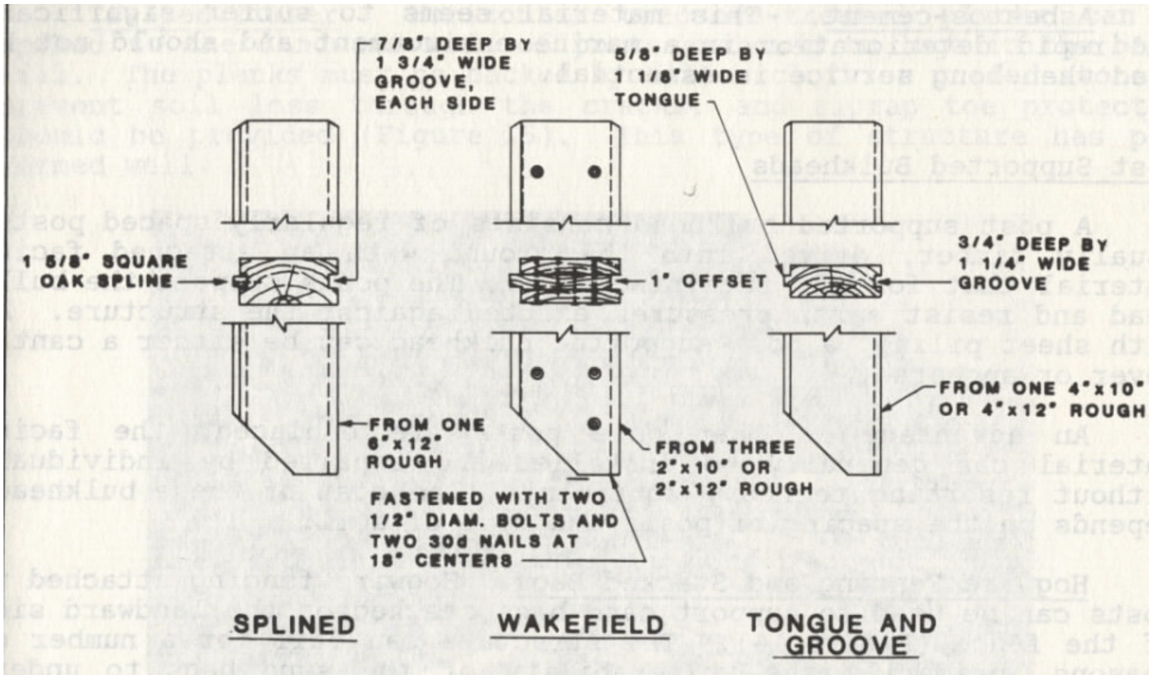


Figure 12 Typical Timber Sheet Sections [After Winterkorn and Fang (1975)]

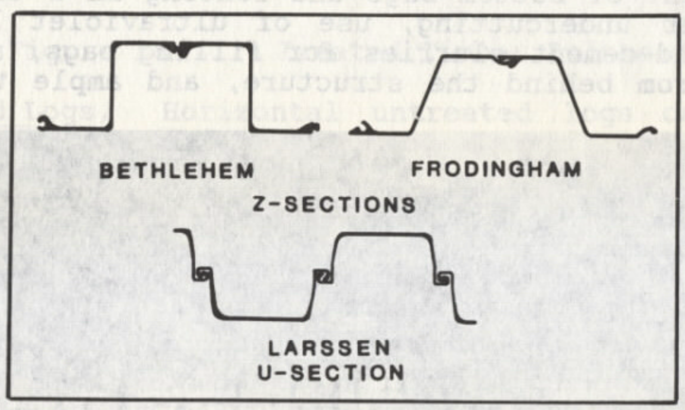


Figure 13 Steel Sheet Pile Sections [After Winterkorn and Fang (1975)]

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

Post Supported Bulkheads

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 earth pressures exerted against the structure. As with sheet piling, a post supported bulkhead can be either a cantilever or anchored.

An advantage is that once posts are emplaced, the facing material can generally be installed and repaired by individuals without resorting to heavy equipment. The cost of these bulkheads 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 14). The structure can fail for a number of reasons, primarily the vulnerability of the sand bags to undercutting by toe scour, which causes them to tear as they slide against the hogwire fencing. The structure is relatively inexpensive, however, and can be used when properly designed. This would include the use of PVC-coated, small mesh wire, deeply embedded posts, placement of bottom bags and fencing in a trench to eliminate toe scour undercutting, use of ultraviolet light-resistant fabrics or sand-cement slurries for filling bags, adequate relief of drainage from behind the structure, and ample toe protection.

Figure 14 Hogwire Fencing and Stacked Bag Bulkhead

Treated Timber. Horizontal creosote-treated planks can be spiked to he landward side of post anchored to logs in the backfill. The planks must be backed by filter cloth or graded stone to prevent soil loss through the cracks, and riprap toe protection should be provided (Figure 15). . This type of structure has performed well.

Figure 15 Treated Timber Bulkhead

Untreated Logs. Horizontal untreated logs can also be attached to the-landward side of posts. This is particularly advantageous 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. Filter cloth is vulnerable to damage or vandalism, however, which would jeopardize the entire structure with the resulting loss of fill. For that reason, the use of logs is probably more risky than use of treated timber.

Used Rubber Tires. Used tires can be strung over two rows of treated pos s 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 the backfill can then escape. Although used tires can generally be obtained free, the structure is probably comparable in cost to other post bulkheads because of the required close spacing of postholes. This kind of structure is generally not recommended.

Steel H-Piles and Railroad Ties. Steel H-piles can be used as posts with railroad ties placed between their flanges (Figure 16). The toe should be protected by armor stone, and proper filtering and granular backfill are needed behind the structure. A 12-inch steel channel, welded to the top of the H-piles, aligns the piles and protects 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 16 Steel H-Pile and Railroad Tie Bulkhead

<u>Miscellaneous Bulkheads</u>

<u>Lonqard</u> Tubes. A Longard tube is a patented, woven polyethylene fabric tube, tilled with sand at installation, and available in two diameters (40 and 69 inches) and in lengths up to 328 feet (Figure 17). Proper performance depends on the device remaining intact and completely filled, in which case, 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 10inch tube, factory-stitched to the seaward edge of the filter cloth, can settle into the bottom under wave action to provide toe protection.

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 work.

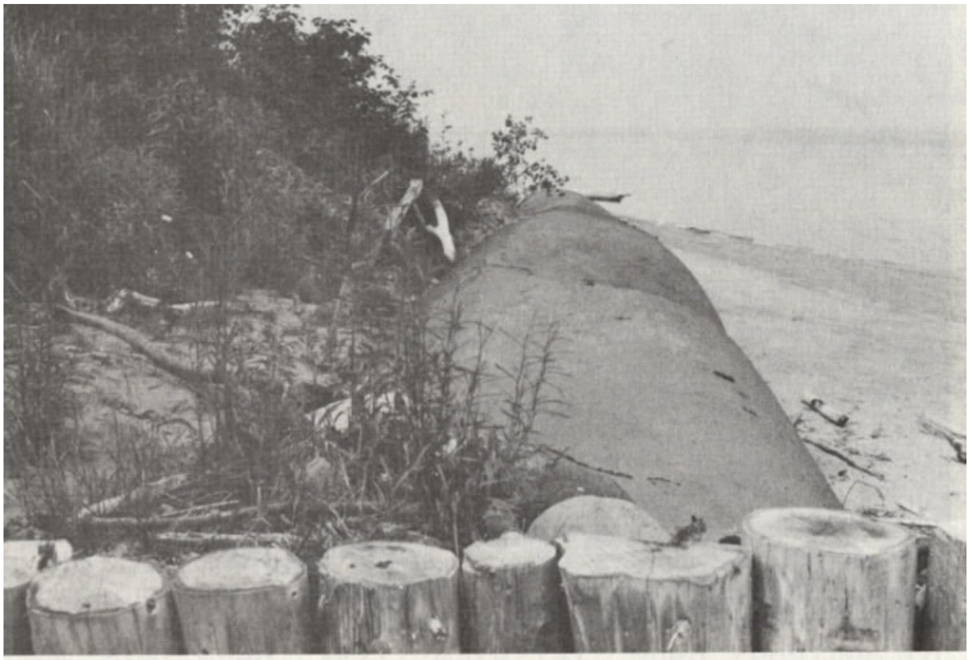


Figure 17 Longard Tube Bulkhead

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 the bank from wave action. The bank should be graded to a stable slope, therefore, or the tube should be placed seaward of the toe to prevent possible damage or movement due to slumping of the bank.

Stacked Used Tires. Because used tires are readily available at most sites at no cost, many people have tried to use them for shore protection devices. The bulkhead on Figure 18 was made with scrap tires interconnected (both vertically and horizontally) with 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 were used to secure 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.

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.

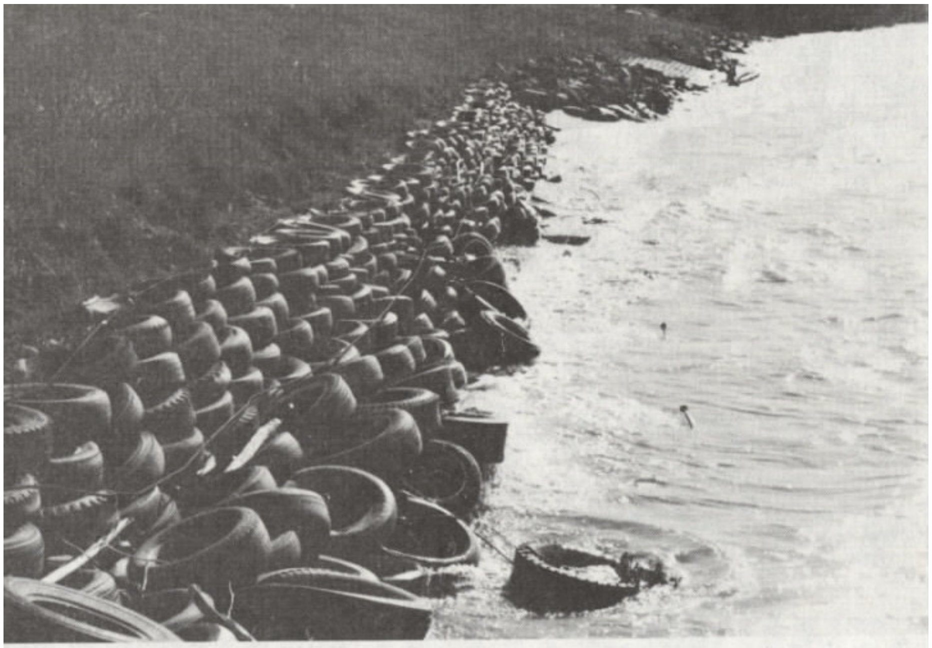


Figure 18 Stacked Used Tire Bulkhead

Used Concrete Pipes. This bulkhead is made by standing used concrete pipes on end, placing them side-by-side and then filling with granular soil (Figure 19). It is economical only when there is an available supply of used concrete pipes and where a low structure is adequate. 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 and bursting the cloth. The wall should not be more than two pipe diameters high without an anchoring system, and a continuous concrete cap (not pictured) could be cast across the tops of all pipes to insure performance as a unit. This type of bulkhead may not provide long service because of the potential deterioration of the concrete pipes.

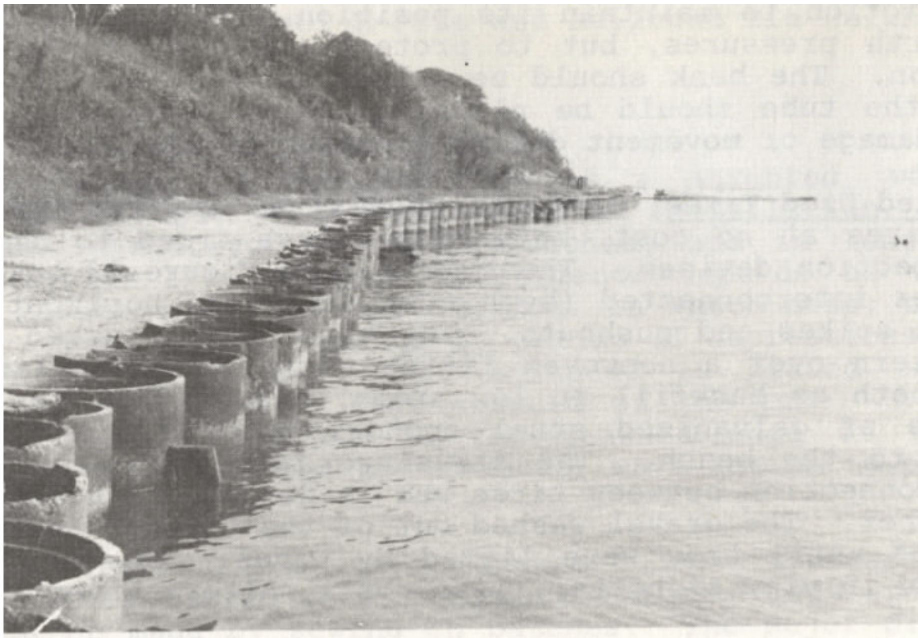


Figure 19 Used Concrete Pipe Bulkhead

REVETMENTS

A revetment is a heavy facing (armor) on a slope to protect it and the adjacent upland against wave scour (Figure 20). Revetments depend on the soil beneath them for support and should, therefore, be built only on stable shores or bank slopes. Slopes steeper than I on 1.5 (1 vertical on 1.5 horizontal) are unsuitable for revetments unless flattened. Fill material, when required to achieve a uniform slope, must be properly compacted.

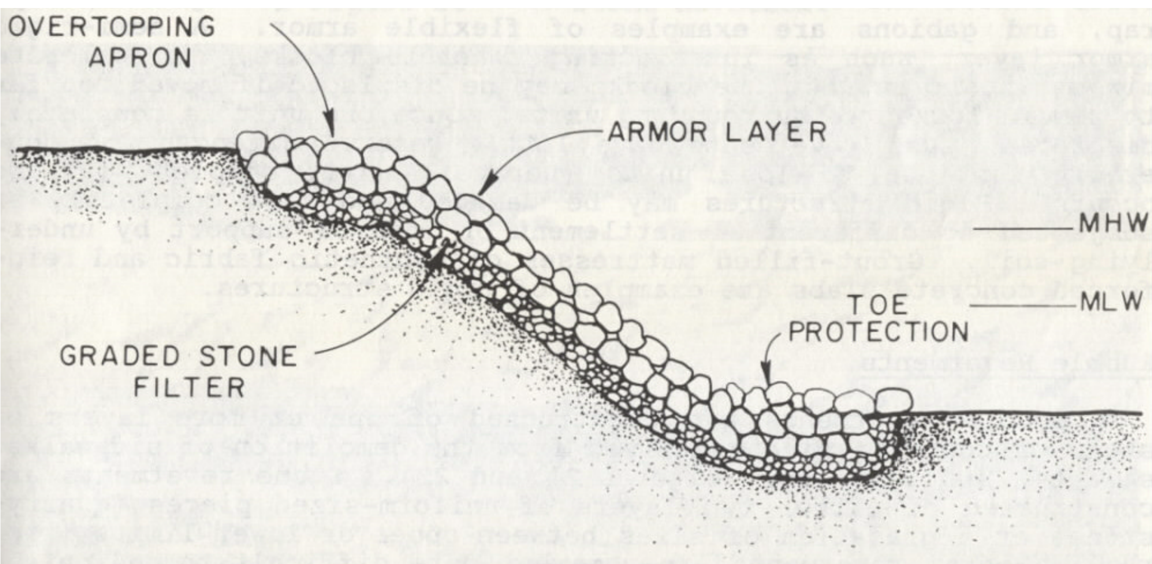


Figure 20 Typical Revetment Section

Like bulkheads, revetments protect only the land immediately behind them and provide no protection to adjacent areas. Erosion may continue on adjacent shores and may be accelerated near the revetment 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.

Of the revetment's three components, the primary one, which determines the characteristics of the other two, is the armor layer, which must be stable against movement by waves. The second component, the underlying filter layer, supports the armor against settlement, allows groundwater drainage through the structure, and prevents the soil beneath from being washed through the armor 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. As the bank retreats, however, the ends must periodically be extended to maintain contact.

The armor layer of a revetment 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 examples of flexible armor. A semi-rigid armor layer, 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.

Figure 21 Stone Revetment

Figure 22 Concrete Rubble Revetment

<u>Rubble Revetments</u>

Rubble revetments are constructed of one or more layers of stone or concrete pieces derived from the demolition of sidewalks, streets, and buildings (Figures 21 and 22). 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 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. They are, however, acceptable for the majority of low cost shore protection applications. In either **case,** stone revetments are time tested, highly durable, and often the most economical where stone is locally available.

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.

Prior to construction, the existing ground should be stabilized by grading to an appropriate slope. In most cases, the steepest recommended slope would be 1 vertical on 2 horizontal (1on 2). Fill material should be added as needed to achieve uniformity, but it should be free of large stones and firmly compacted before revetment construction proceeds. Properly sized filter layers should be included to prevent the loss of slope material through voids in the revetment stone. When using filter cloth, an intermediate layer of smaller stone below the armor stone may help distribute the load and prevent rupture of the cloth. The revetment toe should be located about one design wave height (but at least three feet) below the existing bottom to prevent undercutting. In lieu of deep burial, a substantial sacrificial berm of additional rubble (with filtering) should be provided at the toe.

Quarrystone. Stone revetments, a proven method of shoreline protection, are durable and can be relatively inexpensive where there is a local source of suitable armor stone. Such stone should be clean, hard, dense, durable, and free of cracks and cleavages.

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, may provide the necessary transition to the filter material.

Concrete. 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 water-borne 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.

Concrete Block Revetments

Concrete blocks, many of them patented, have various intermeshing or interlocking features (Figure 23), and the advantage of a neat, uniform appearance. Many units are light enough to be installed by hand once the slope has been prepared. Their disadvantage is that interlocking between units must be maintained. Once one block is lost, other units can dislodge, and complete failure may result. A good, stable foundation is required since settlement of the toe or subgrade can cause displacement of units and ultimate failure. Also, some concrete bl6ck revetments have smooth faces that can lead to significantly higher wave runup and overtopping.

For maximum effectiveness, concrete block systems should only be placed on a stable slope with the toe buried at least three feet below the existing ground line. Fill materials beneath the revetment should be uniform and well compacted and an adequate filter system, preferably with a properly sized woven filter cloth, should be provided. All concrete must be high quality; standard building blocks will probably deteriorate too quickly. Finally, blocks should not be used where they may be stolen or damaged by waveborne cobbles, ice, or debris.

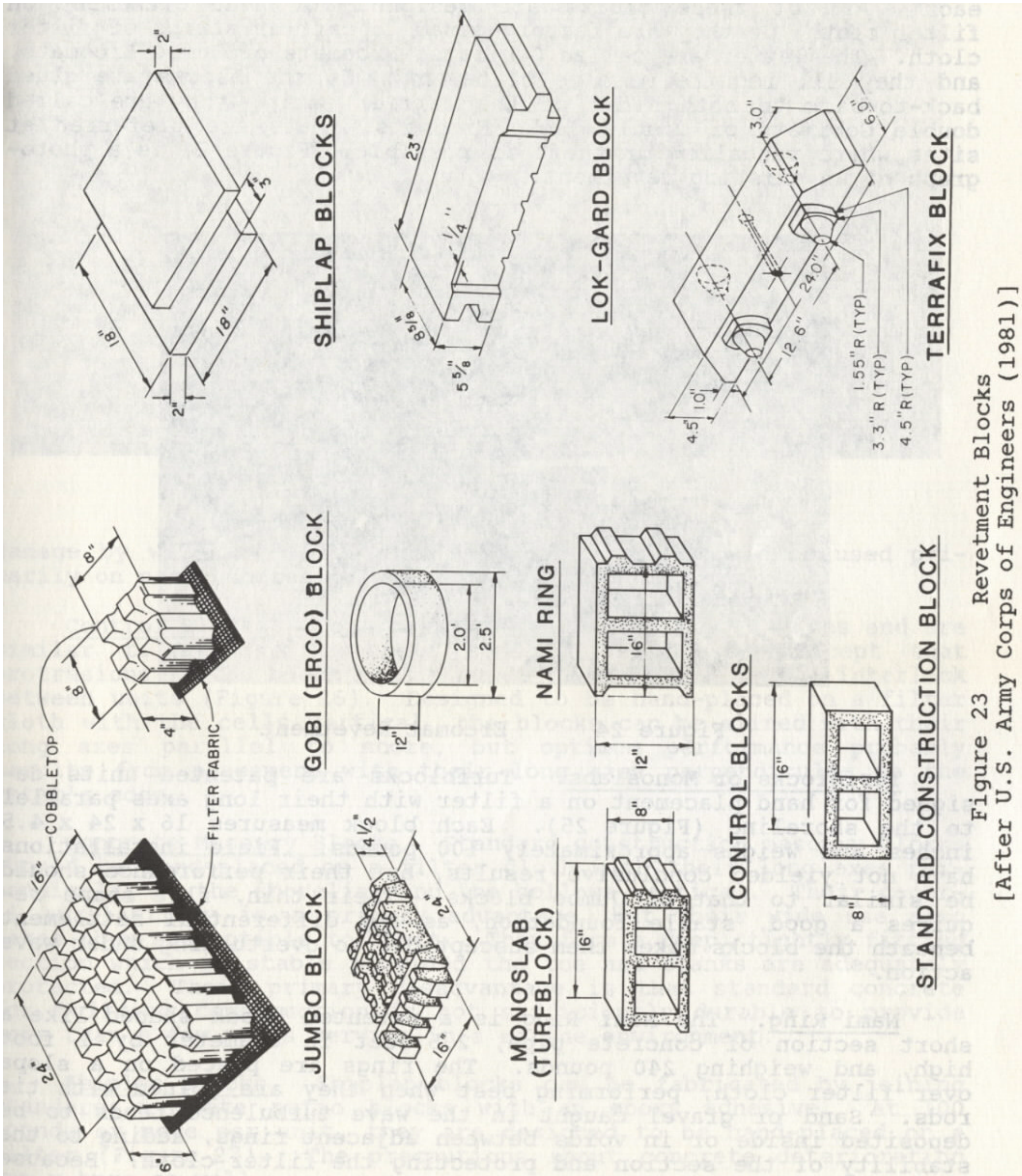


Figure 23 Revetment Blocks
[After U.S. Army Corps of Engineers (1981)]

Gobi (Erco) and Jumbo Blocks and Mats. Gobi blocks are patented units that weigh about 13 pounds each. Erco blocks are similar, but they are offered by a different licensed supplier. Jumbo blocks are large Erco blocks that weigh about 105 pounds each. All of these blocks are designed for hand placement on filter cloth, or they are factory-glued to carrier strips of filter cloth. The latter are called Gobimats, Ercomats or Jumbo Ercomats, and 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 or double Jumbo Ercomats. Mats are preferred at sites where vandalism or theft is possible. Figure 24 is a photograph of an existing revetment.

Figure 24 Ercomat Revetment

<u>Turfblocks or Monoslabs</u>. Turfblocks are patented units designed for hand placement on a filter with their long axes parallel to the shoreline (Figure 25). Each block measures 16 x 24 x 4.5 inches and weighs approximately 100 pounds. Field installations have not yielded conclusive results, 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 blocks makes them susceptible to overturning under wave action.

<u>Nami Ring</u>. 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, performing best when they are 3olned 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 on sandy shores.

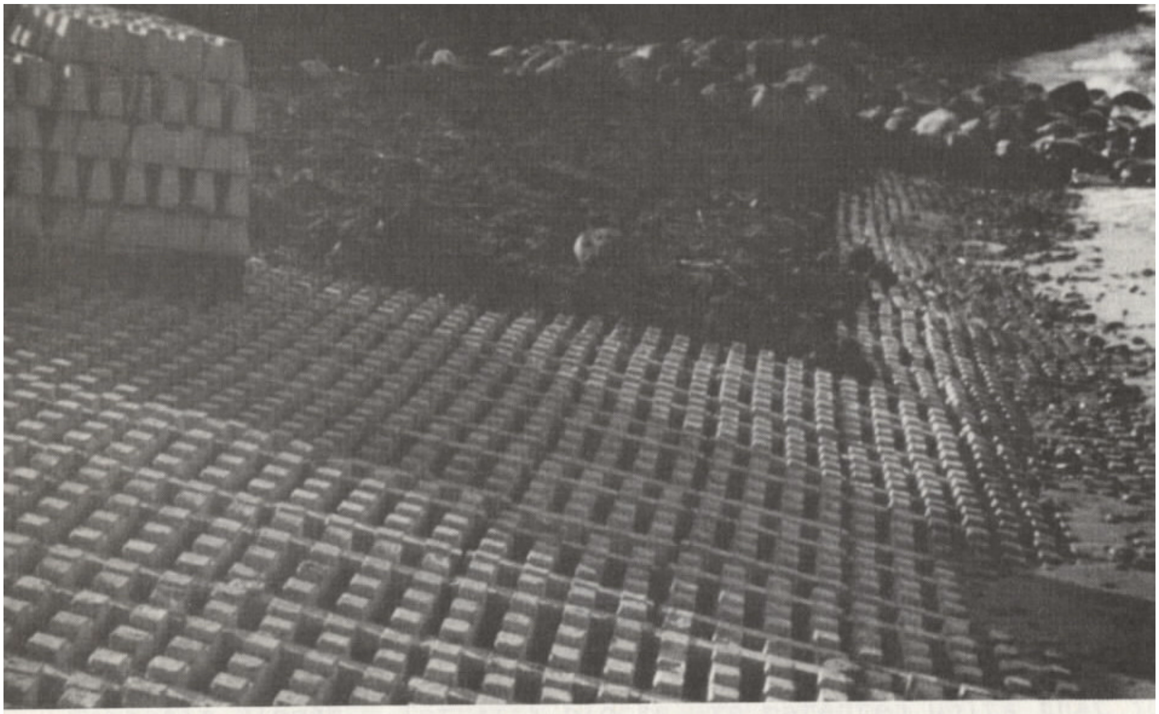


Figure 25 Turfblock Revetment

Control Blocks. 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 (Figure 26). Designed to be hand-placed on a filter cloth with the cells vertical, the blocks can be aligned with their long axes parallel to shore, but optimum performance probably results from placement with their long axes perpendicular to the water's edge.

Concrete Masonry Blocks. 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 their wide use also makes them susceptible to theft. 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.

Shiplap Blocks. Shiplap blocks can be fabricated by joining standard concrete patio blocks with an epoxy adhesive. At 100 pounds or more per unit, they are designed to be hand-placed on a filter (Figure 27). The precautions about concrete deterioration apply here as well.

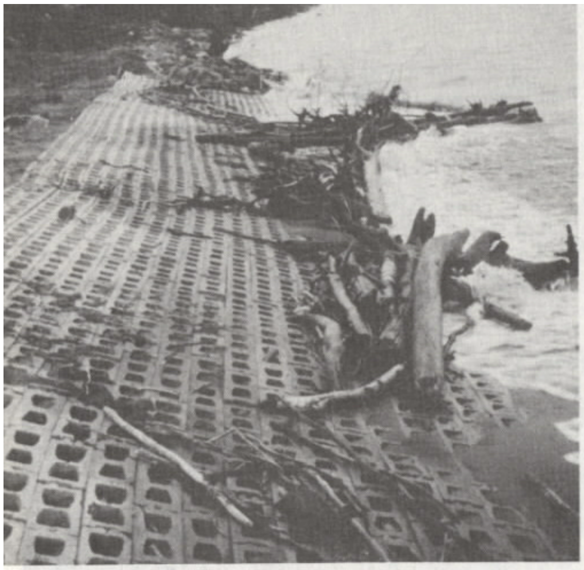


Figure 26
Control Block Revetment

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

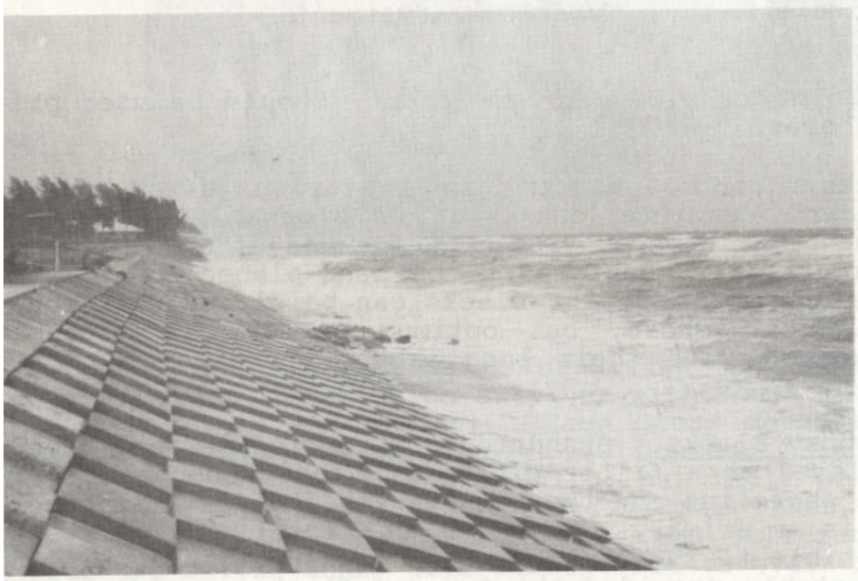


Figure 27 Shiplap Block Revetment

Lok-Gard Blocks.

Lok-Gard blocks join together with a tongue-and-groove system. The 80 pound, patented units are designed to be hand-placed on a filter with their long axes perpendicular to the shoreline (Figure 28).

Figure 28 Lok-Gard Block Revetment

Terrafix Blocks. Terrfix blocks are patented units that join together with a mortise and tenon system, having two cone-shaped projections, which fit similarly shaped holes in the bottom of the adjacent block. In addition, holes through the center of each block allow for stainless steel wire connection of many individual blocks to form a large mat. The uniform interlocking of the 50 pound units creates a neat, clean appearance (Figure 29).

Figure 29 Terrafix Block Revetment
(Photo Courtesy of Erosion Control Products, Inc.)

Stacked Bag or Mat Revetments

Several manufacturers produce bags and mats, in various sizes 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 and stacked against a prepared slope with their long axes parallel to the shoreline and joints offset as in brick work (Figure 30). Grout-filled bags can be further stabilized with steel rods driven down through the bags.

Figure 30 Stacked Bag Revetment

The advantage of a bag revetment is its moderate cost. Sand filled bags are relatively flexible and can be repaired if some are dislodged. 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 flatter and underfilled for stability.

Bags should form a large mass of pillow-like concrete sections with regularly spaced filter meshes for the passage of water.

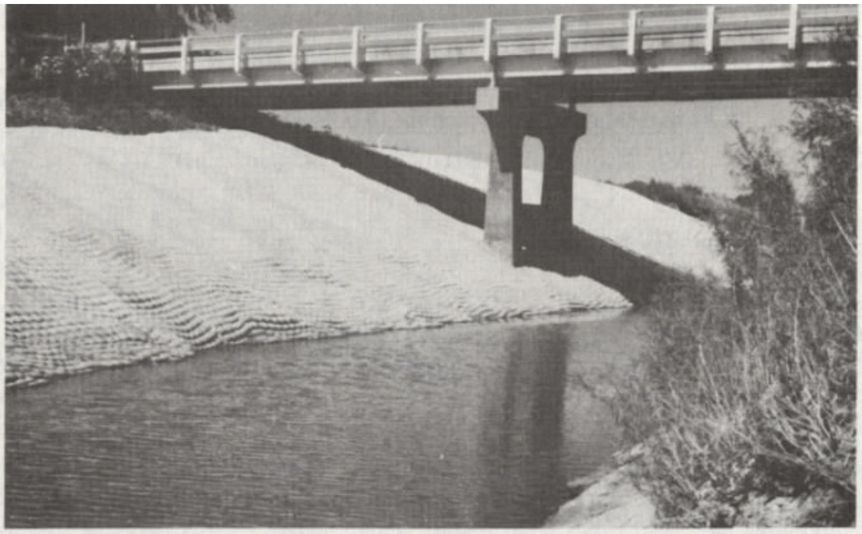


Figure 31 Concrete-Filled Mattress Revetment
(Photo Courtesy of Construction Techniques, Inc.)

Bags or mattresses should only be placed on a stable slope. While a stacked bag revetment can be placed on a steeper slope than a mattress, it should not exceed 1 vertical on 1.5 horizontal. Fill materials beneath the revetment should be uniform and well compacted and an adequate filter system should be provided. Some form of toe protection is usually required, or the toe should be buried well below the anticipated scour depth. A stacked bag revetment should be at least 2 bags thick, preferably outside layer concrete-filled, but the inner layer sand-filled. When sand is used as filler material, the fabric and its seams must be nondegradable (ultraviolet resistant). However, where vandalism or water-borne debris is likely, only concrete-filled units should be used. As with concrete block revetments, the structure's integrity depends on the stability of the individual units. Once units are lost or damaged, or settle unevenly, the structure loses its strength.

Burlap Bags. Burlap bags are recommended only when filled with concrete-because of their rapid deterioration and the ease with which they can be torn.

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

Dura Baqs. Dura bags are large (4 x 12 x 1.7 feet) and must be fi1led in 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 exposed installations.

Fabriform Nylon Mat. Fabriform is designed to be filled with a highly fluid mixture. The exterior cloth envelope serves primarily as a form 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 to the manufacturer's instructions.

Figure 32 Unassembled Gabions

Miscellaneous Revetments

Gabions. Gabions are rectangular baskets or mattresses made of galvanized, and sometimes PVC-coated, steel wire in a hexagonal mesh (Figure 32). 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-indh diameter stones. The use of interior liners or sand bags for small size material is not recommended. The lids are finally closed and laced to the baskets, forming a large, heavy mass (Figure 33).

The chief advantage of a gabion revetment 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 the baskets, refilling them, and then wiring them shut again. Depending on the local supply of stone, a gabion revetment can be a low cost option.

Figure 33 Gabion Revetment

The disadvantage of a gabion structure is that the baskets may open under heavy wave action. They should not be used where action by water-borne debris or cobbles is present. Also, since structural performance 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. For that reason, the baskets should be tightly packed and periodically refilled to minimize movement of the stone and subsequent damage to the wire. Rusted and broken wire baskets also pose a safety hazard where traffic across them is required. Gabion structures require periodic inspections so that repairs are made before serious damage occurs.

Steel Fuel Barrels. This type of revetment is limited to areas such as remote arctic regions where corrosion rates are slow and there is an abundance of used fuel barrels of little salvageable value (Figure 34). The barrels should be completely filled with coarse granular material to preclude damage by floe ice and debris, and seaward barrels must be capped with concrete. In addition, all barrels should be partially buried to increase stability.

Concrete Slabs. Structures of this type have 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, they can provide low cost protection when large slabs are available.

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

Figure 34 Steel Fuel Barrel Revetment

BREAKWATERS

In contrast to bulkheads and revetments, breakwaters are placed out in the water, rather than directly on shore, to dissipate energy of approaching waves and form a low-energy shadow zone on their landward side (Figure 35). Even a small decrease in wave height significantly 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 increased 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 in dissipating wave energy depends on their height and porosity (amount of voids). Floating breakwaters function at or near the water's surface and must be firmly anchored to the seafloor to prevent their displacement. They are generally effective in sheltered waters where wind-generated waves with short periods (less than 5 seconds) are vulnerable to dissipation in passing a floating structure. Such waves have short wavelengths that may be less than the structure width, while their energy is concentrated near the surface and not distributed down through the water column as with long-period waves.

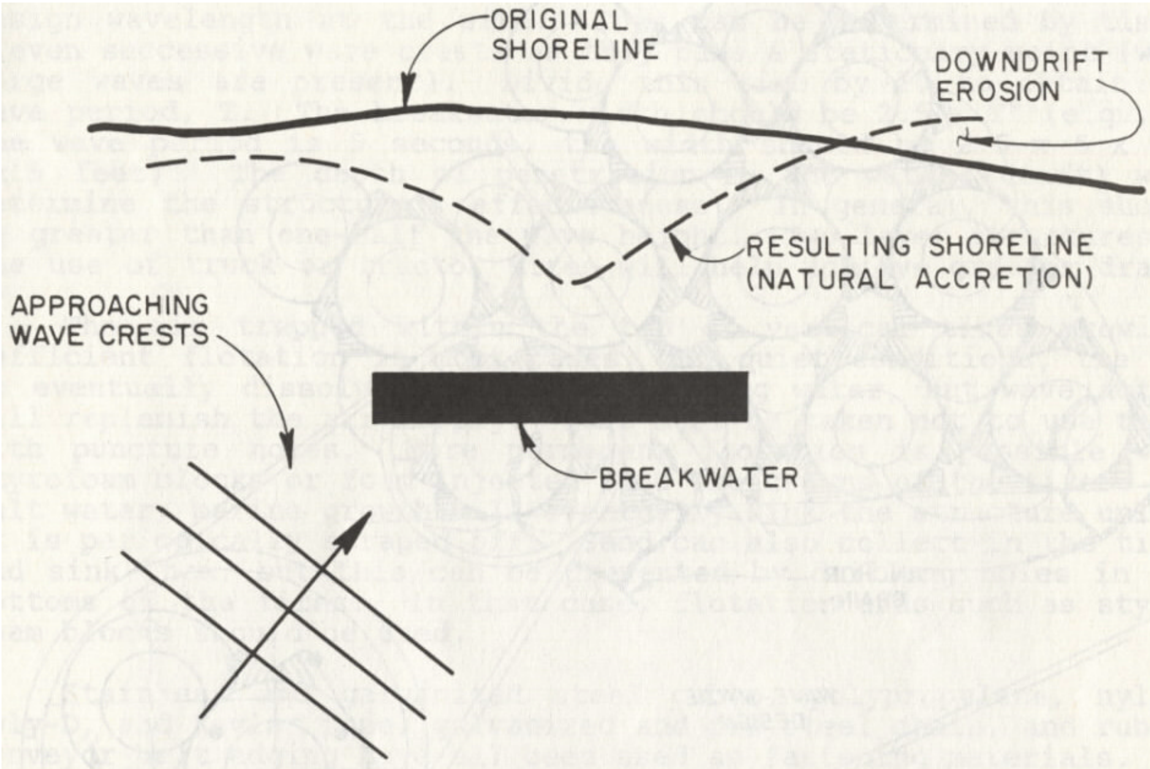


Figure 35 Plan View of a Breakwater

Floating Breakwaters

Floating breakwaters can be constructed of virtually any buoyant material, such as rubber tires, logs, 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.

A disadvantage is that floating breakwaters may be regarded as eyesores in some areas. They also tend to collect floating debris and often require more maintenance than fixed breakwaters.

Two possible arrangements of scrap-tire breakwaters are shown on Figure 36. The upper configuration, known as a Wave-Maze, is patented and cannot be used without payment of royalties. (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.

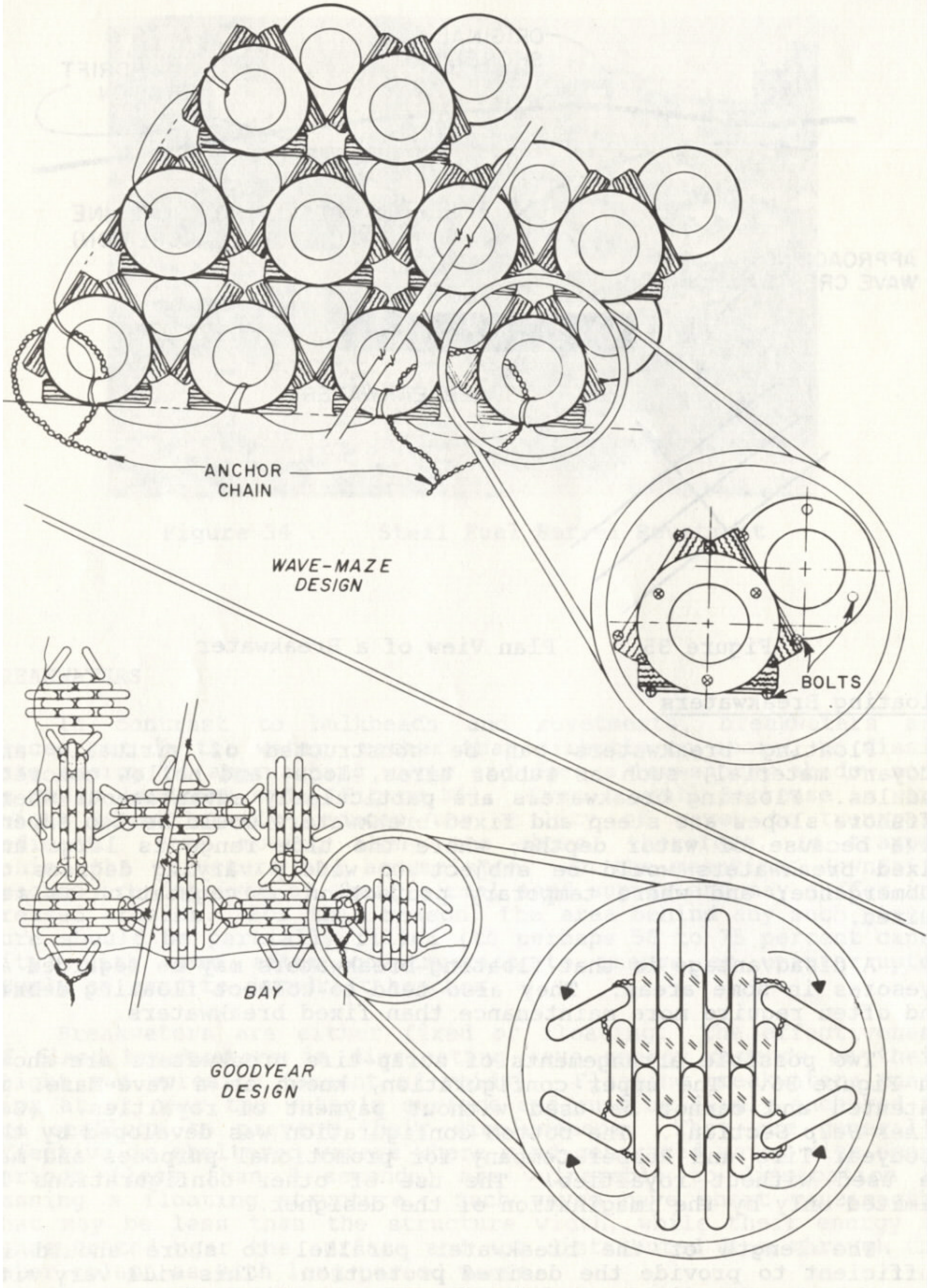


Figure 36 Floating Breakwater Modules
[After U.S. Army Corps of Engineers (1978)]

The length of the breakwater parallel to shore should be sufficient to provide the desired protection. This will vary with the structure's distance from shore. The width depends on the design wavelength at the site. This can be determined by timing eleven successive wave crests as they pass a stationary point (when large waves are present). 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. In general, this should be greater than one-half the wave height. Two-layer structures or the use of truck or tractor tires will help achieve greater draft.

The air trapped within the top of vertical tires provides sufficient flotation in most cases. In quiet conditions, the air is eventually dissolved by the surrounding water, but wave action will replenish the air supply. 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.

Stainless and galvanized steel cable, polypropylene, nylon, Poly-D, and Kevlar rope, galvanized and raw steel chain, and rubber conveyor belt edging have all 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 the manufacture of conveyor belts, is available from several rubber companies in a wide range of widths and thicknesses.

Floating breakwaters must be securely anchored 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 usually the best means of stable anchorage over long periods. Pile driving" of course, adds considerably to total installation costs.

Floating breakwaters can also be constructed using other materials. For instance, 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, 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. Moderate, but uniform, settlement may not necessarily adversely affect performance, but if one portion of the breakwater sinks significantly below the others, there will be increased wave transmission over the low section.

Longard Tubes. The same advantages and disadvantages mentioned for a Longard tube bulkhead apply. An added disadvantage is that the protective epoxy coating cannot be applied to a wet tube so that damages are more likely. Therefore, a tube should not be used at a location where it will be exposed to vandalism or waterborne debris. Figure 37 shows before and after views of a Longard tube slashed by vandals. The damage eventually caused the entire tube to deflate.

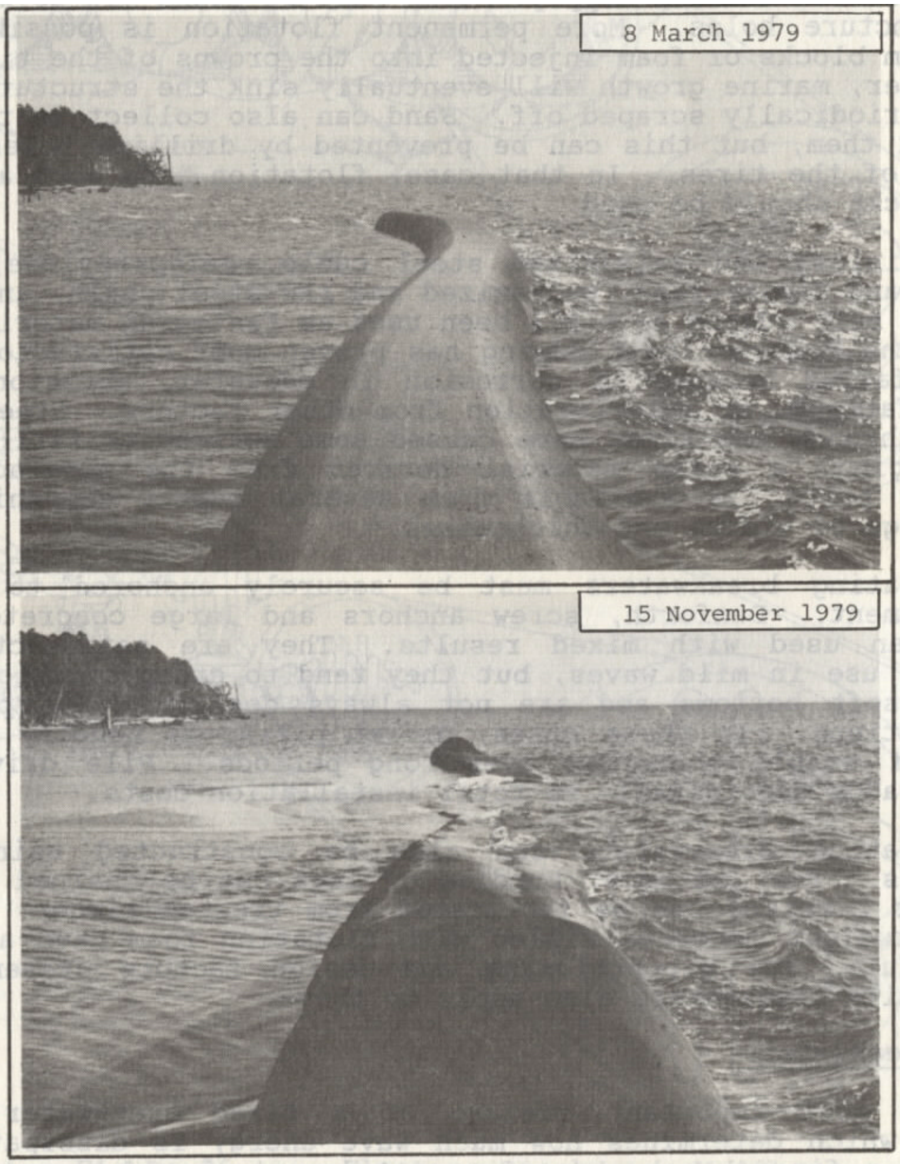


Figure 37   Before and After Views - Longard Tube Breakwater

<u>Sand-Filled Bags</u>. This breakwater is built using stacked bags in a staggered pattern (Figure 38). The structure's performance depends on whether the individual bags remain in place and intact. The bags and seams must be resistant to ultraviolet light to preclude deterioration from prolonged sunlight exposure. The lighter bags (100-pound range), such as those used for revetments, are displaced when exposed to even moderate wave heights. Larger bags, therefore, such as Dura Bags are recommended for breakwaters even though they are more difficult to handle and must be filled in place. A filter cloth should be placed under the bags to reduce settlement in soft bottoms. During construction, bag-to-bag abutment should be insured to preclude wave transmission through gaps.

Figure 38   Sand-Filled Bag Breakwater

Grout-Filled Bags. 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 apply to grout-filled bags, except that vandalism is not a major concern.

Gabions. The same basic design considerations given for gabion revetments 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 photograph of a gabion breakwater is shown in Figure 39.

Figure 39 Gabion Breakwater

Z-Wall. A Z-Wall is constructed with patented, steel-reinforced concrete panels set on edge in a zigzag fashion and joined with large threaded connectors (Figure 40). The structure is

Figure 40 Z-Wall Breakwater

Z-Wall. A Z-Wall is constructed with patented, steel-reinforced concrete panels set on edge in a zigzag fashion and joined with large threaded connectors (Figure 40). The structure is designed for placement close to shore on the existing bottom without use of a filter. Heavy construction equipment and trained personnel are required for installation. A single bolt acts as a hinge to connect adjacent panels and allow them to settle nonuniformly but with limited tolerance, which makes Z-Walls 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 nut on the bolt also tends to loosen and unwind under wave agitation. Eventually, an end unit may fall away if the nut unwinds completely.

The structure performs best at a site with a firm bottom and generally not only protects the shoreline from high waves, but also 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.

Surgebreaker. A Surgebreaker is a modular device constructed with 3,700-pound, precast, reinforced concrete modules with vent holes to release wave pressure buildup. The patented triangular modules are 4 feet high x 7 feet wide. 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 41). Installation must be performed by a franchised contractor.

Figure 41 Surgebreaker Breakwater

Sandgrabber. 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 42). 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 42 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 high quality standards are met. Block breakage can eventually lead to complete structural failure.

Quarrystone. A rubble breakwater is structurally similar to a rubble revetment (Figure 43). 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 may have to be barge-mounted, resulting in higher costs.

Timber Piles and Brush. A brush breakwater is constructed with 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 alignment. Not suitable for permanent protection, it can be used as an energy absorber for temporary sheltering of new vegetation.

Used Tires and Timber Piles. Timber piles can be driven into the bottom so that every t ree piles form a triangular pattern, and used automobile tires can then be stacked on the piles. Just above the top tires, the triangularly grouped piles should be interconnected with planks bolted to the piles (Figure 44). The structure, whose stability depends on the depth of pile penetration, has proven effective against mild wave action.

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. 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.

Figure 44   Used Tires and Timber Pile Breakwater

When first built, the sand trapped on a groin's updrift side is no longer available to replenish downdrift beaches, resulting in erosion. 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. If downdrift erosion is unacceptable (it usually is), an alternative is to build more than one groin and fill the area between with sand (Figure 45). This will minimize downdrift damages and limit scour at the groin's shoreward end.

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 their height, length, and spacing (for a groin field). Height determines how much sand can pass over the structure; groins can be built either high or low with respect to the existing beach profile. Low groins, which essentially follow a foot or two above the natural beach profile, are widely used because they stabilize the beach but do not trap excessive amounts of sand and cause downdrift damages. High groins effectively block the supply of sand to downdrift beaches provided sand doesn't pass through them.

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 waves break (breaker zone), sediment moving around the structure may be forced too far offshore to be returned to the downdrift beach. Therefore, the groin 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 sufficiently landward to prevent their detachment from shore (flanking) if severe erosion occurs.

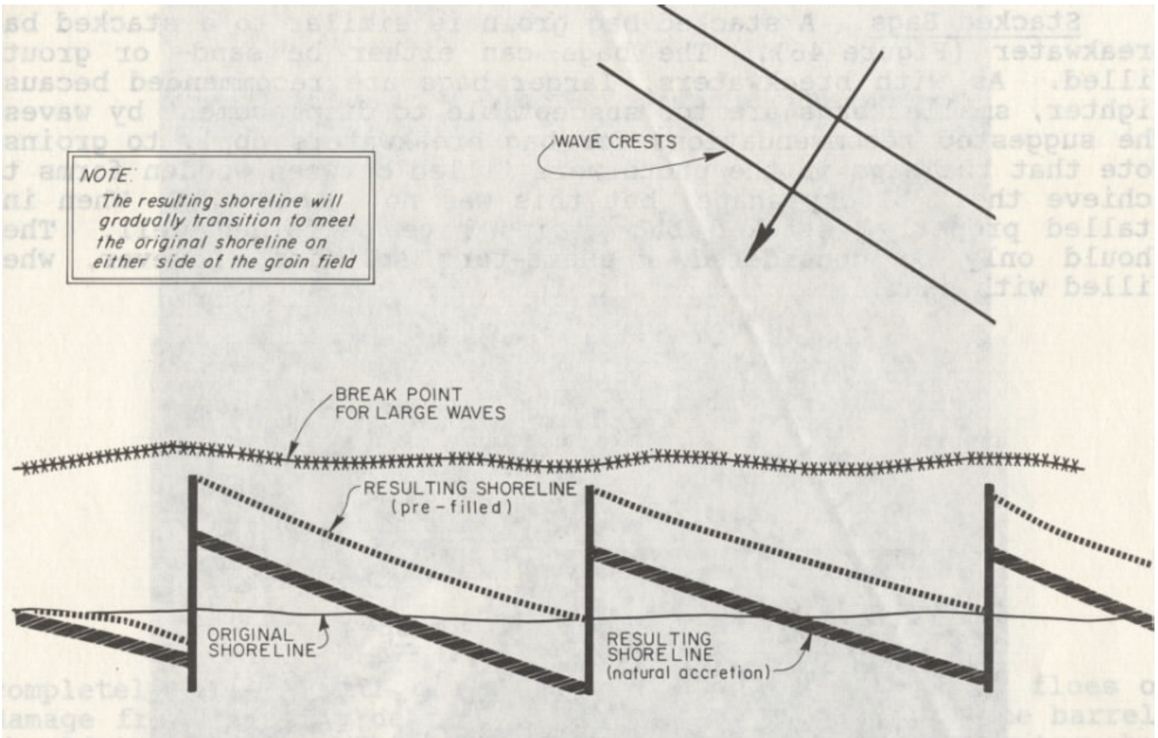


Figure 45 Effects of Groins

The correct spacing of groins depends on their 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 again before being forced seaward by the next downdrift groin. A common rule is to provide 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.

Stacked Bags. A stacked bag groin is similar to a stacked bag breakwater (Figure 46). The bags can either be sand or grout filled. As with breakwaters, larger bags are recommended because lighter, smaller bags are too susceptible to displacement by waves. The suggested recommendations for bag breakwaters apply to groins. Note that the bags in the photo were filled between wooden forms to achieve their blocky shape, but this was not necessary. When installed properly, stacked bag groins have performed well. They should only be considered a short-term solution, however, when filled with sand.

Figure 46   Stacked Bag Groin

Gabions. Gabions were described earlier in the revetment section. When used to construct groin, the gabions should be underlain with filter cloth to inhibit settlement and all baskets should be made from PVC-coated wire mesh. They must be tightly filled to eliminate deformation and possible breakage, and the tiers of baskets should be wired together to prevent shifting of the upper tiers over the lower tiers. As with other structures, adequate toe protection is required to prevent settlement and basket distortion. Thin gabion mattresses are ideal for this purpose.

Steel Fuel Barrels. The use of steel fuel barrels for construction is economical only in remote arctic areas where corrosion rates are low, and 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. When used to construct a groin, the barrels should be completely filled with gravel to prevent crushing by ice floes or damage from floating debris. For additional strength, the barrels should be capped with concrete. Also, they should be entrenched sufficiently to prevent undermining by scour on the downdrift side.

Figure 47 Gabion Groin

Quarrystone. 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(Figure 48).

Longard Tubes. Longard tubes have performed fairly well as groins as long as they nave remained intact (Figure 49). Failure has usually resulted from 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 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 49 Longard Tube Groin

Sheet Piling. Sheet pile groins (Figure 50), an old and proven means of shore protection, can employ timber, steel, or aluminum sheeting. Toe protection or adequate penetration is required to insure the structure's stability. Recommendations for sheet pile bulkheads and breakwaters also apply to groins.

Timber and Rock. Many structural forms are possible for timber and rock groins. Figure 51 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 with long wrought-iron or coated steel rods that are threaded at the ends to accommodate washers and nuts.

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.

Figure 50 Timber Sheet Pile Groin

Figure 51 Timber Crib Groin

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 these large incoming waves to break farther offshore. The useful life of a fill, 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 regular maintenance cost of adding new fill (periodic renourishment).

The rate at which new f ill 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 the fill material is coarser than the native material, the fill will erode more slowly and if it is finer, it will erode more quickly.

Figure 52 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. A portion of the fill which is very fine material is lost almost immediately after placement, requiring an initial supply of material somewhat over expectations. The beach should be overfilled by 50 percent the first time and this ratio adjusted as experience dictates. For instance, if 100 cubic yards of sand is needed for the required berm width, 150 cubic yards should be initially placed to compensate for the high initial losses of fine material.

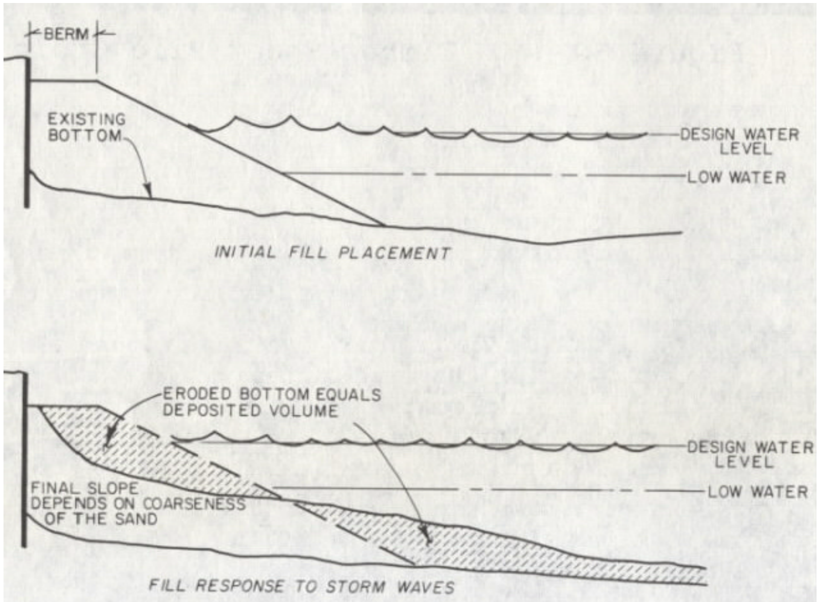


Figure 52 Beach Fill

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 the new beach will eventually assume a similar shape. Equipment can shape the beach fill profile 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.

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 general groups should be selected to insure adequate growth.

Species of grasses, sedges, and rushes are suited to marshes along moderate- to low-energy shorelines that are periodically flooded by brackish water. Upland species (shrubs and trees but particularly grasses) are especially adapted to the low-nutrient, low-moisture environment of the higher beach elevations, where they are subject to abrasion by wind-blown 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.

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 53). 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.

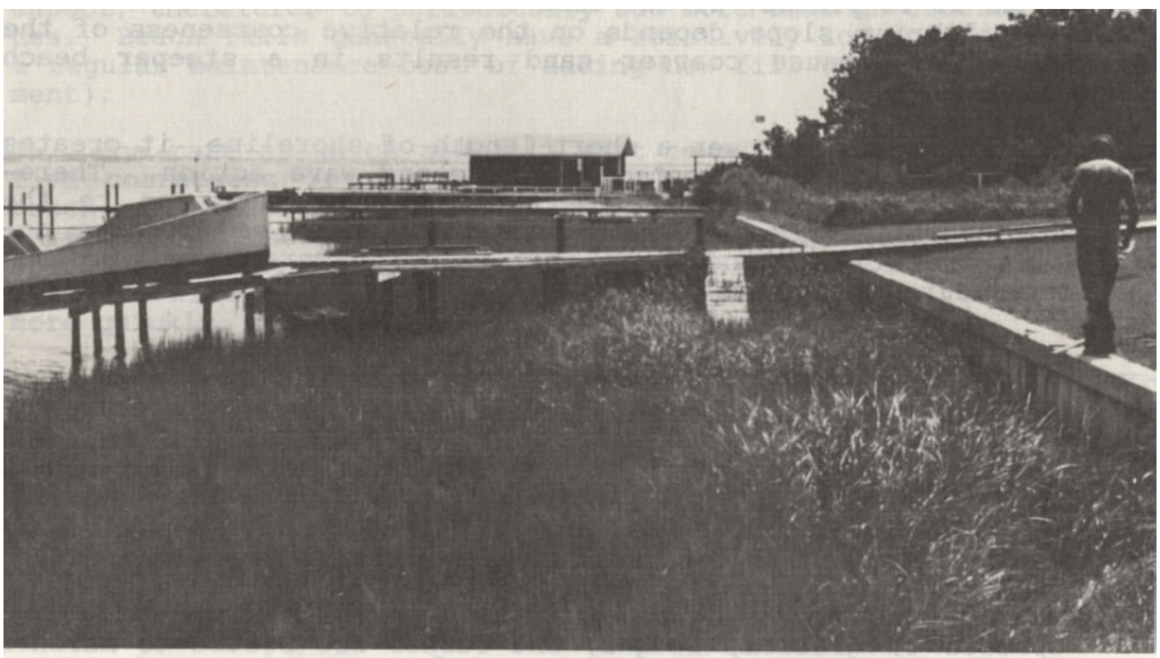
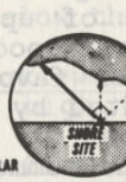


Figure 53 Marsh Vegetation

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.

The suitability of a site for marsh plantings can be evaluated by using Figure 54.

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) 1 15	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 54 Site Evaluation Form for Marsh Plants
[After U.S. Army Corps of Engineers (1980)]

Atlantic Coast Marshes. Common vegetation found in Atlantic coast marshes is describ@d 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.

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).

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.

Black Needle Rush *(,Tuncus 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 winddriven 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 communes).* The common reed grows 4.5 to 12 feee- 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 germinans), red (Rhizophora angle),* and white *(Laguncularia racemosa)*—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 mature cordgrass stands, which provide stability until the mangroves are established.

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 best above the mean high water level, and it is propagated like saltmeadow cordgrass.

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 foliosa).* It is similar to smooth cordgrass, but it takes longer to establish. It dominates below the mean tide level of intertidal marshes.

Pickleweed *(Salicornia spp.).* From mean high water to extreme high tide, various species of pickleweed can be used upslope of Pacific cordgrass. It will spread both by seeds and vegetatively (by rhizomes and tillers), but because it is shallow-rooted, 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 lyngbvei).* 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 i 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.

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 *(Ph.ragmites communis), rushes (Scirpus spp.*) such as spike rush, bulrush, and great bulrush, and, in some instances, upland grasses such as reed canarygrass *(Phalaris arundinacea).*

Beach and Dune Plants

The protection of the upland portions of sandy shorelines can be accomplished through the creation of barrier dunes and the stabilization of present dunes. Vegetation used to initiate the building of barrier dunes is specially adapted to the more severe environment of the beach area (Figure 55). Barrier dune formation can occur naturally, but it is usually slow and in some areas does not happen. Utilization and proper management of the natural processes can accelerate the development.

Figure 55 Beach and Dune Vegetation

The beach provides a generally harsh environment for plant growth. Plants must tolerate rapid sand accumulation, flooding, salt spray, sandblasts, wind and water erosion, wide temperature fluctuations, drought, and low nutrient levels. Plants capable of stabilizing coastal dunes, however, occur in most coastal regions where there is sufficient rainfall to support plant growth. These regions and several of the most successful species are discussed below.

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.

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.

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.

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.

Bermuda Grass *(Cynodon dactglon).* 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.

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 pescaprae).* 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 applicable 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.

American Dunegrass *(Elvmus mollis).* Although this grass is native to 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.

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 *(Carpobrotus edulis and C. aequilaterus).* These are effective for sand stabilization but are not good dune builders.

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 1000 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.

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.

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, these should be filled with compacted 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 56), which combine a low breakwater or sill and a fill, are beaches elevated (perched) above the normal level. They are suitable where offshore slopes are gradual enough to permit sill construction in reasonably shallow water at a distance from shore. The perched beach provides a broad buffer zone against wave action, while offering a potentially excellent recreational site.

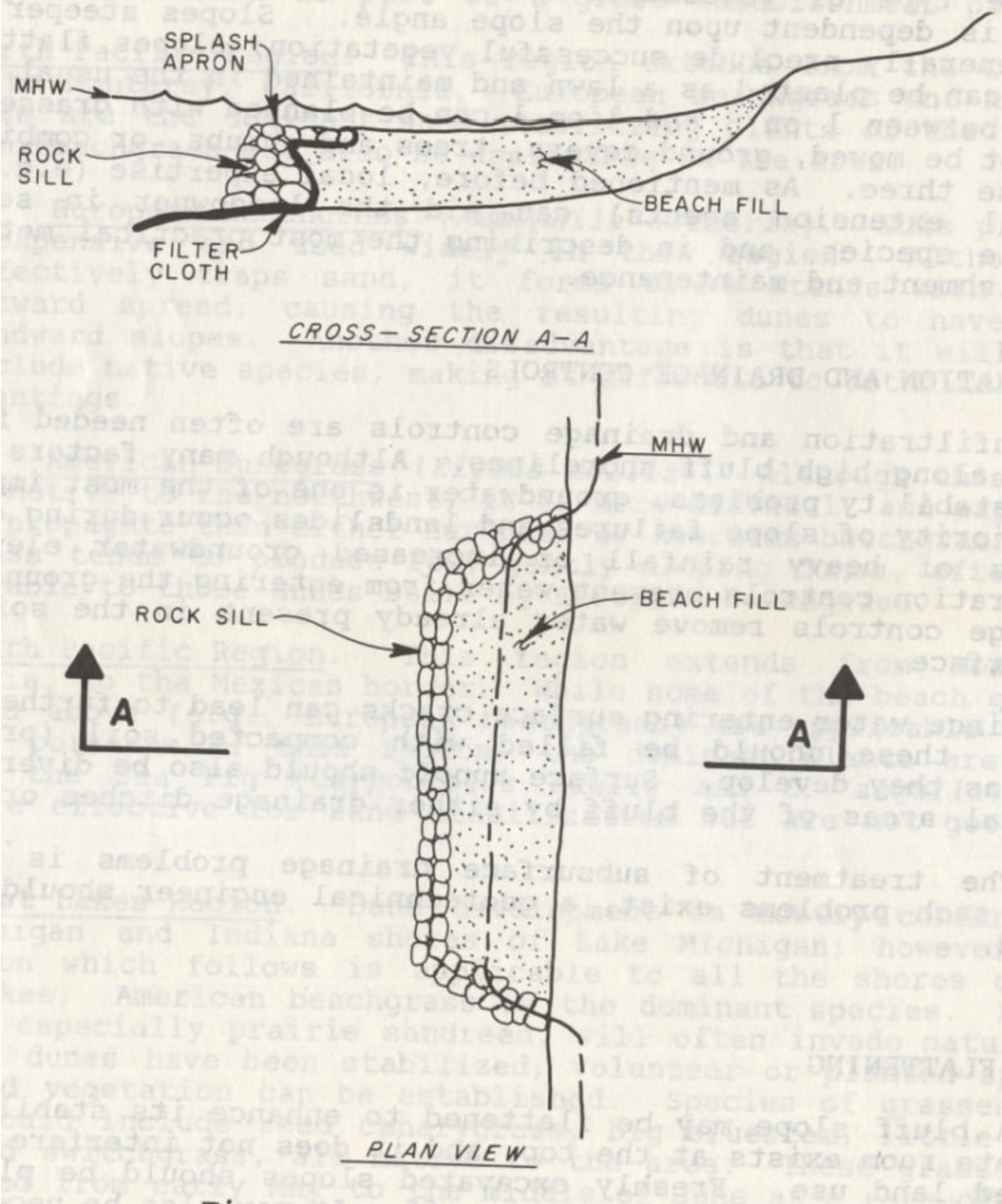


Figure 56 Perched Beach

Perched beach sills can be built using most of the materials described for fixed breakwaters. They must be made sand-tight to retain the beach fill, however. Proper filtering should be provided beneath and behind the sill to prevent settlement and loss of the retained fill.

Sheet Piling. Sheet pile sills are similar to bulkheads. 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.

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 57). 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 57 Concrete Box Sill

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 if 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. By placing it in the shelter of a structure such as a breakwater, however, vegetation can be used in areas experiencing considerably heavier wave activity. The use of a temporary structure is particularly appealing because it protects the plants while they become established and it can be removed when the plant mature.

SELECTION AMONG AVAILABLE OPTIONS

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 the 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. The property, however, 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 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 not work in a clay or silt bluff area unless sand were imported. *Beach fills* only dissipate 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 infiltration adversely affect slope stability. They provide no toe protection against wave action and can be expensive. Also, they are difficult to properly design, and may require the efforts of a qualified professional 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 is needed, such as a promenade or parking lot. Vertical bulkheads induce toe scour and wave reflections, and could cause a total loss of beach. 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 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. Drain*age controls* and *slope flattening* are not applicable to beach shorelines. *Perched breaches* 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 of 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.

EFFECTS ON COASTAL PROCESSES AND ADJACENT PROPERTIES

Table 2 lists the effects of various options on shoreline processes.

Table 2

EFFECTS ON COASTAL PROCESSES AND ADJACENT PROPERTIES

Option	Effect
No Action	Eroding shoreline will continue to supply material for transport to adjacent shores.
Relocation	Eroding shoreline will continue to supply material for transport to adjacent shores.
Bulkheads	Protect eroding shorelines that may have been supplying material to downdrift areas, which may then experience accelerated erosion. The fronting beach may experience increased erosion due to wave reflections.
Revetments	Protect eroding shorelines that may have been supplying material to downdrift areas, which may then experience accelerated erosion.
Breakwaters	Diminished wave energy behind such structures induces deposition. If the amount of sediment accumulation is significant, the downdrift shore may experience accelerated erosion. If wave energy is significantly reduced, the area behind the breakwater may not have sufficient circulation to maintain water quality.
Groins	Impede longshore transport and induce sedimentation. The downdrift shoreline may experience accelerated erosion due to lack of material supply-
Beach Fills	Provide a new supply of material to the littoral transport system. Increased suspended sediment loads could shoal adjacent navigation channels.
Vegetation	If some material is retained that previously was transported alongshore, it is possible that the downdrift shoreline may experience minimal erosion damages.
Drainage Controls	No significant effects.
Slope Flattening	No significant effects.
Perched Beaches	See "Beach Fills".
Structures and Fills	By filling the structures to near capacity with sand, the longshore transport may pass around the structure and continue to supply the downdrift shore.
Structures and Vegetation	The vegetation helps the structure more effectively retain sand, which could cause increased downdrift erosion.

EFFECTS ON SHORELINE USES

Table 3 lists the significant effects of the various options on shoreline uses.

Table 3

EFFECTS ON SHORELINE USES

Option	Advantages	Disadvantages
No Action	o No consistent positive or negative effects on shoreline uses.	
Relocation	o No consistent positive or negative effects on shoreline uses.	
Bulkheads	o When used for wharves, provide direct boat access to the shore. o Unless placed high on a beach, they may hinder swimming, jogging, walking, or fishing.	o Can limit access to beach so that stairs may be required. o Tend to cause erosion of existing fronting beach and possibly adjacent shores.
Revetments	o Unless fronted by a sufficient beach width, they may hinder swimming, jogging, walking, or fishing.	o Certain designs (e.g., gabions or quarrystone) limit access to the beach so that stairs may be needed. o If the fronting beach is normally submerged at high tide, partially submerged revetments may pose a hazard to swimmers.
Breakwaters	o Provide a partially protected area for swimmers and for mooring boats. o Do not obstruct access to and from or along the beach. o Stone structures may provide a habitat for aquatic life. o Deposited sand increases available beach area.	o If submerged, and not sufficiently marked, could be a navigatio[n] hazard. o Rock structures can be hazardous to climbers. o Choppy water conditions on the seaward side may cause navigation problems and bottom scour. o High structures may block the view of the water or spoil an otherwise scenic vista.
Groins	o Rubble structures may provide a habitat for aquatic life. o Can provide access to deeper water for fishing. o Trapped sand fillets increase the available beach area. o Do not obstruct access to and from the beach.	o May limit travel along the beach. o Low groins, when submerged, can be a hazard to boats if not appropriately marked. o Rip currents may be induced along groins which may be hazardous to bathers.
Beach Fills	o Provide more beach area for swimming, jogging, walking and fishing. o Do not restrict access to and from or along the beach.	o Increased turbidity during placement may cause temporary impairment of fishing.
Vegetation	o Provides a habitat for aquatic life. o Creates an opportunity for nature study.	o Restricts beach use because plantings cannot be subjected to traffic.
Drainage Controls	o When a fronting beach already exists, the potential for swimming, boating, jogging, etc., is unaffected.	o No impairment of shoreline uses.
Slope Flattening	o When a fronting beach already exists, the potential for swimming, boating, jogging, etc., is unaffected. o Access to the beach is enhanced.	o Reduces the land available at the top of the slope.
Perched Beaches	o Provide more beach to be used for swimming, jogging, walking, and fishing. o Do not restrict access to and from or along the beach.	o The sudden drop off the end of the beach at the sill can pose a hazard to bathers. o If not properly marked when submerged, the sill can be a hazard to boaters.
Structures and Fills	o Provide more beach area for swimming, jogging, walking, and fishing.	o Increased turbidity during fill placement may cause temporary impairment of fishing.
Structures and Vegetation	o Marsh plants provide a habitat for aquatic life.	o Plantings may restrict beach use because they cannot be subjected to traffic.

EFFECTS ON THE ENVIRONMENT

The environmental effects of low cost devices, because of their limited extent, will generally be minimal. Such impacts as may occur are summarized in Table 4.

Table 4

EFFECTS ON THE ENVIRONMENT

Option	Effect
No Action	No consistent positive or negative effects.
Relocation	No consistent positive or negative effects.
Bulkheads	Impacts will be almost nonexistent. Bulkheads that stabilize eroding clay bluffs may decrease turbidity and enhance water quality. Construction operations may temporarily increase suspended sediment loads.
Revetments	Same as for bulkheads. In addition, stone structures with submerged lower portions may provide an improved habitat for certain fin and shellfish species.
Breakwaters	Stone and similar materials will improve habitat to an even greater degree than revetments. Decreased wave action and current strengths behind breakwaters may inhibit circulation and exchange and could impair water quality.
Groins	Similar to breakwaters except that water circulation problems are not likely to be as troublesome.
Beach Fills	Increased quantity of sand will result in greater turbidity, especially during initial placement. Sand lost from the fill may deposit elsewhere such as in shellfish beds, etc.
Vegetation	Vegetation provides a superior habitat for many important species in the food web. Well-established stands of vegetation also filter the water and decrease the amounts of suspended sediment and pollutants. Marshes enhance the ecological value of almost any shoreline.
Drainage Controls	No significant impacts except where they stabilize clay bluffs. In those cases, turbidity will be decreased locally.
Slope Flattening	Same as "Drainage Controls".
Perched Beaches	Same as "Breakwaters" and "Beach Fills".
Structures and Fills	Same as "Beach Fills"; also depends on the structure.
Structures and Vegetation	Same as “Vegetation”; also depends on the structure.

IMPLICATIONS FOR COASTAL ZONE MANAGEMENT

As can be seen from the information already presented, the selection of proper alternatives for protecting shorelines requires trade-offs among many advantages and disadvantages. No single alternative will apply in every case and each has to be considered on its own merits.

Consistency in the planning or review of low cost shore protection systems requires an encompassing set of guidelines or goals that should be established by each local jurisdiction. The desire is to satisfy a community's development plans without risking property or life, while simultaneously protecting its ecological resources. Each community has its own set of attitudes, social goals, and political styles which will determine the policies it develops.

The purpose of proper shoreline management is to look beyond each individual site to the whole community. Uncontrolled development may adversely affect the shoreline in a number of ways. Management policies should, therefore, be concerned with minimizing changes in patterns of drainage and runoff, preserving ecologically valuable areas such as dunes and wetlands, preserving natural protective forms such as dunes and beaches, avoiding adverse alternation of coastal configurations, protecting coastal waters from pollution, and restoring damaged areas to former conditions. [The Conservation Foundation (1980)]. These policies would be applied to the earlier identified shoreforms in relation to low cost shore protection as follows.

Bluff Shorelines

Adverse uses of lands adjacent to the tops of banks or bluffs should be avoided. Clearing of trees and undergrowth, constructing buildings, or plowing could all destabilize existing slopes by increasing seepage and surface erosion or by adding extra weight (surcharge) which the bluff must support. surcharges, in particular, should be avoided. changes in surface drainage patterns should be planned to divert the flow away from the bluff face.

Zoning regulations should be instituted to restrict development to areas landward of setback lines. These should be established based on projected shoreline recession amounts over a specified future time period. In fact, in localities threatened with erosion, these setback lines are required for endangered structures to qualify for insurance under the National Flood Insurance Program.

Activities should be discouraged that will alter or disturb the bluff face or toe. Stable bluffs should not be stripped of vegetation, nor should they be unnecessarily excavated, as this could lead to slides and slope failures. This does not eliminate slope flattening or drainage controls as alternatives, because these are used when the bluffs are inherently unstable and must be treated to restore stability. Plantings and other uses of vegetation should be encouraged on all excavated or natural slopes to increase stability and reduce erosion.

Toe protection should be provided in all cases where wave attack undermines the bluff. Any appropriate device outlined within this report, subject to other engineering, shoreline use, or environmental criteria, would be acceptable.

Beach Shorelines

Activities should be discouraged that remove sand from the active beach zone, whether for fill at other areas, or for placement elsewhere on the beach profile. This would include dredging for beach fills, as a source of concrete aggregates, or as fill for bag structures.

New development should be located inland from the active beach to preclude the need for future shore protection. Setback lines should be established and observed. In most states, public domain is maintained as the area up to the mean high water line (MHHW on the west coast). In some states (e.g.,Texas) public domain extends higher, to the point of permanent vegetation. In addition, local Governments in some areas have zoned additional setbacks of 30 feet or more from the MHW line, with the area designated for community recreational purposes.

Actions that adversely affect the littoral system should be discouraged. Accretion devices such as breakwaters and groins interfere with sand transport and may cause downdrift erosion. Sand permanently trapped behind such structures is also unavailable during transport reversals and could cause updrift erosion damages. Supplemental fill (preferably from inland sources) should be placed in the shadow zone of all such structures to minimize adjacent property damages.

Restoration of eroded beaches should be encouraged as part of any shore protection plan. Vegetation may be useful in some locations to further assist stability.

Excavation and removal of dunes should be discouraged because dunes serve as the natural front line of defense for the shore. Control should be exercised through local zoning ordinances or building codes that require special permits for excavation in dune areas. All new development should be located landward of dunes.

Existing vegetation, particularly on dunes, should be protected, primarily by restricting pedestrian or vehicular traffic. Special roads or walkways may be required in some cases.

Dunes should be restored and stabilized whenever possible as part of a comprehensive shore protection plan. Vegetation and snow fencing are principal means of accomplishing this.

Wetlands and Marshes

Alterations to the surface of marshes by excavating, filling, clearing, paving or grading should generally be prohibited. The value of marshes for shore protection and as ecological resources has been stressed. In cases of essential development, marsh areas that are destroyed may be replaced by newly developed marshes elsewhere as compensation and as a requirement for development. As an alternative, adjacent damaged marshes may be restored to their full function to replace those taken by development.

Diking or draining of marshes is generally harmful and should not be permitted. Permanent structures that would impair marsh functions should be discouraged. Placement of buildings on piles is often an acceptable alternative, as are elevated walkways, shelters, footbridges, and boat houses.

Discharge of pollutants should be restrained. Marshes serve a valuable water purification function but their ability to absorb pollutants is finite and limited.

Marshes should be restored to full function as part of any comprehensive shore protection plan.

PERMIT REQUIREMENTS

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 are coordinated by the applicant and the states through division and district offices of the U. S. Army Corps of Engineers. The authority for the Corps' permit program is derived basically from two laws: Section 10 of the River and Harbor 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 shoreward of the mean high water line, and inland waters that have been used, are now used, or may be used in the future for interstate or foreign commerce. 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 dredged or fill material in waters of the United States. In this case, "waters of the United States" includes navigable waters as under Section 10 permits, as well as tributaries and wetlands adjacent to navigable waters of the United States. Jurisdiction extends to the high water line, except that where wetlands are present they are included also.

A standard application form (ENG Form 4345) must be obtained from the local Corps district office. The application must include a description of the proposed construction, including "necessary drawings, sketches, or plans; the location, purpose, and intended use of the proposed activity; scheduling of the activity; the names and addresses of adjoining property owners; the location and dimensions of adjacent structures; and the approvals required by other federal, interstate, state or local agencies for the work, including all approvals received or denials already made" [U.S. Army, Corps of Engineers (1977b)].

When the District Engineer receives the application, he will check it for completeness and will generally issue a public notice inviting comments on the application. The comment period is generally 30 days, although it may be longer or shorter depending on the circumstances. Permit applications are generally coordinated with the appropriate federal, state, and local agencies as well as adjoining property owners. As a result of that coordination, comments may be presented which would 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 would then be approved and a permit issued. Although it may vary considerably, a routine permit application normally requires 75 to 90 days for approval.

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 local areas is available -through Corps of Engineers' district offices or through certain state and local agencies.

OTHER HELP

CORPS OF ENGINEERS OFFICES

Permits are coordinated through district of f ices of the Corps of Engineers. Corps offices are also possible sources of information on water levels, wave climate, and other physical site conditions. Mail addresses, office locations, and phone numbers for Corps personnel familiar with coastal processes are given 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

Address	Phone	Jurisdiction
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

Address	Phone	Jurisdiction
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
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

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

Device or Material	Manufacturer

Device or Material	Manufacturer
	DuPont Company Room 38095 Wilmington, Delaware 19898 (Nonwoven)

Device or Material	Manufacturer
	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 (Woven and Nonwoven)
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

Device or Material	Manufacturer
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
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

Device or Material	Manufacturer
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. These provide information on water depths and fetch lengths to determine exposure of a site to wave action. Identification of a specific chart and important information about the available chart series are in the following Nautical Catalogs.

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 at 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

RECOMMENDED ADDITIONAL 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 goverrment reports include their NTIS or GPO accession numbers. Use the NTIS number to order documents from:

National Technical Information Services **(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)
http://www.gpo.gov

The references given below are recommended for local government officials to enhance their ability to assist property owners seeking advice and direction involving local erosion problems.

SHORE PROTECTION (GENERAL)

Consumer Investment in Shoreline Protection, Braden, P., Michigan Sea Grant Program, 2200 Bonisteel Boulevard, Ann Arbor, Michigan 48109.

HarmonV With the Lake: A Guide to Bluff Stabilization, Division of Water Resources, Illinois Department of Transportation, Room 1010, Marina City Office Building, 300 North State Street, Chicago, Illinois 60610, (free).

Help Yourself, North Central Division, U. S. Army Corps of Engineers, 536 South Clark Street, Chicago, Illinois 60605, (free).

Low Cost Shore Protection: Final Report on the Shoreline Erosion Control Demonstration Program, office, Chief of Engineers, U. S. Army Corps of Engineers, Washington, D. C. 20314, 1981.

The Michigan Demonstration Erosion Control Program in 1976, Brater, E. F., et al., University of Michigan Coastal Zone Laboratory, Michigan Sea Grant Technical Report No. 55, February 1977.

Shore and Beach, American Shore and Beach Preservation Association, P. 0. Drawer 2087, Wilmington, North Carolina 28401, (published quarterly; $20 annually).

Shore Erosion Control: A Guide for Waterfront Property Owners in the Chesapeake Bay Area, Baltimore District, U. S. Army Corps of Engineers, P. 0. Box 1715, Baltimore, Maryland 21203, 62 pp., (free).

Shoreline Erosion Control, Philadelphia District, U. S. Army Corps of Engineers, Attention: NAPEN-P (SECDP), Custom House, Second and Chestnut Street, Philadelphia, Pennsylvania 19106, (free).

Shore Protection Guidelines: National Shoreline Study, Office, Chief of Engineers, U. S. Army Corps of Engineers, Washington, D.C., August 1971, 59 pp. *Shore Protection Manual (Vols. I, II, and III), U.* S. Army Corps of Engineers, Coastal Engineering Research Center, 1977, (GPO Stock No. 008-022-00113-1).

Waves Against the Shore: An Erosion Manual for the Great Lakes Region, Lake Michigan Federation, 53 West Jackson Boulevard, Suite 1710, Chicago, Illinois 60604, January 1978.

What You May Need to Know About Owning Shore Property, Great Lakes Communicator, Volume II, No. 5, February 1981.

SHORE PROTECTION DESIGN

AWPI Technical	*Guidelines for Pressure-Treated Wood (1970).*
S2 Bulkheads:	*Design and Construction - Part I*
S3 Bulkheads:	*Design and Construction - Part II*
S4 Bulkheads:	*Design and Construction - Part III*
S5 Bulkheads:	*Hardware and Fasteners*
Pl Timber Piling	American Wood Preservers Institute, 1651 Old Meadow Road, McLean, Virginia 22101.

Building Salt Marshes Along the Coast of the Continental United States, Woodhouse, W. W., Special Report 4, U. S. Army Coastal Engineering Research Center, May 1979, (GPO #088-022-00133-6).

Concrete Shore Protection, Portland Cement Association, 33 West Grand Avenue, Chicago, Illinois, 1955.

Designing for Bank Erosion Control with Vegetation, Knuston, P. L., Reprint 78-2, U. S. Army Coastal Engineering Research Center, February 1978, (NTIS #AO51 571).

Designing Retaining Walls, Bulkheads and Seawalls of Treated Timber, American Wood Preservers Institute, (address given above).

Factors Affecting the Durability of Concrete in Coastal Structure. Mather, B., Technical Memorandum 96, U. S. Army Beach Erosion Board, June 1957, (NTIS #158 634).

How to Build a Floating Scrap Tire Breakwater, Kowalski, T., Ross, N., Marine Advisory Service, University of Rhode Island, Narragansett Bay Campus, Narragansett, Rhode Island 02882.

Planning Guidelines for Residential and Path Development in Michigan's Sand Dunes and Wetlands, Michigan Coastal Zone Management Program, Water Development Services Division, Michigan Department of Natural Resources, Lansing, Michigan.

Planting Guidelines for Marsh Development and Bank Stabilization, Knuston, P. L., Coastal Engineering Technical Aid 77-3, U. S. Army Coastal Engineering Research Center, August, 1977. (NTIS #AO46 547).

The Role of Vegetation in Shoreline Management, Great Lakes Basin Commission, P. 0. Box 999, Ann Arbor, Michigan 48106, (single copies, free).

PERMITS, REGULATIONS AND PLANNING GUIDELINES

Coastal Ecosystem Management: A Technical Manual for the Conservation of Coastal Zone Resources, Clark, J., John Wiley and Sons, New York, 1977.

Coastal Environmental Management: Guidelines for Conservation of Resources and Protection Against Storm Hazards, The Conservation Foundation, Washington, D. C., 1980, (Available through GPO).

Permit Program: A Guide for Applicants, EP 1145-2-1, U.S. Army Corps of Engineers, Washington, D.C.

Regulations to Reduce Coastal Erosion, Wisconsin Coastal Zone Management Program, State Office of Planning and Energy, GEF II, 101 South Webster Street, Madison, Wisconsin 53702, (free).

Shore Management Guidelines: National Shoreline Study. Office, Chief of Engineers, U.S. Army Corps of Engineers, Washington, D.C., August 1971, 56 pp.

Wetlands Protection Guidebook for Local Governments, Kusler, J. A. and Harwood, C., Environmental Law Institute, Washington, D. C., 1977.

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 travelling 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.

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U.S. Army Corps of Engineers, "Regulatory Program of the Corps of Engineers," *Federal Register,* Vol. 42, No. 138, Washington, D. C., 19 July 1977b.

U. S. Army Corps of Engineers, "Pickering Beach, Delaware: Preconstruction Report", Engineer District, Philadelphia, January 1978.

U.S. Army Corps of Engineers, "Erosion Control With Smooth Cordgrass, Gulf Cordgrass, and Saltmeadow Cordgrass on the Atlantic Coast," Coastal Engineering Research Center, TN-V-2, Washington D.C., March 1980.

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Winterkorn, H. F., and Fang, H. Y., *Foundation Engineering Handbook*, Van Nostrand Reinhold Company, New York, 1975.

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