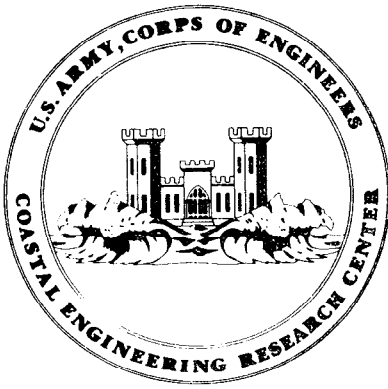




Coastal Engineering Technical Note

REVETMENTS - THEIR APPLICATIONS AND LIMITATIONS

PURPOSE: To describe the functional applications, limitations, and the general design concepts of revetments. This note is intended to provide a brief, general discussion of revetments for Corps personnel who do not have a background in the functional design of coastal structures, and to provide useful information for answering inquiries from the general public concerning the construction and use of revetments.

FUNCTIONAL APPLICATIONS: A revetment is a facing of armor placed on a sloping seashore or channel bank to protect it and the adjacent upland against scour by currents and waves. Unlike seawalls, revetments are not self-supporting and depend on soil beneath it for support. Revetments deflect waves up their sloped faces and dissipate wave energy on the faces, and their functional integrity is dependent on the structural stability of the armor comprising the face. The revetment may be built on the existing shore or bank slope if it is stable. An unstable slope must be properly graded before placing the various layers of the revetment material. Sloped faces, especially of rough material, do not reflect waves to the same extent as the vertical faces of bulkheads and seawalls; but a revetment may cause some loss of the beach fronting the structure due to wave reflection, unless the revetment is located so high on the beach that it will be exposed to waves only during extreme and rare storm surges.

FUNCTIONAL LIMITATIONS: Revetments protect only the land immediately behind them, offering no protection to adjacent areas up- or downcoast or to the beach seaward of them. On an eroding shore, recession of the surrounding shoreline will continue and may be accelerated in the vicinity of the revetment by wave reflection from the structure. If nearby beaches were being supplied with sand eroded from the area to be protected

by a revetment structure, the beaches will experience increased erosion resulting from the loss of this source of beach material. Revetment reflect wave energy, but to a lesser degree than vertical structures. This wave reflection could increase the height of waves, increase wave runup and overtopping, and scour the area immediately in front of the revetment. If a beach is to be retained adjacent to a revetment, additional structures may be required.

STRUCTURAL ASPECTS: A revetment is comprised of three components. The primary one, which determines the characteristics of the other two, is the armor layer. It must be stable under wave forces. The second component is the underlying filter layer which supports the armor against settlement, provides drainage of ground water through the structure, and prevents soil beneath it from being washed through the armor layer by waves or ground water seepage. The third component, toe protection, prevents settlement or removal of the seaward edge of the revetment.

1. Armor. Armor maintains its position under wave action due to its weight and, if the armor layer consists of individual units, the interlocking between the units. Armor may be classified as flexible, semi-rigid, or rigid. Flexible armor maintains its protective qualities when the structure is severely distorted, such as when the underlying soil settles or scour causes the seaward end of the revetment to sink. Quarrrystone (shown in Figure 1) and gabions (woven wire baskets and mattresses filled with stone and wired together as shown in Figure 2) are the primary examples of flexible armor. Quarrrystone is placed in differing numbers of layers depending on the uniformity of the stone size. Criteria for choosing quarrrystone weight and size distribution are given in CETN-III-1, "Riprap Revetment Design."

Semi-rigid armor can tolerate some distortion, but armor units may be removed if they are displaced too far to remain locked to surrounding units. Figure 3 shows a semi-rigid revetment of concrete blocks with shiplap joints. Other joint designs, which increase the mechanical interlocking between blocks, also increase resistance to wave forces but decrease the revetment's flexibility.

Rigid structures may be damaged and fail completely if subjected to differential settlement or loss of support by underlying soil. Figure 4 shows a

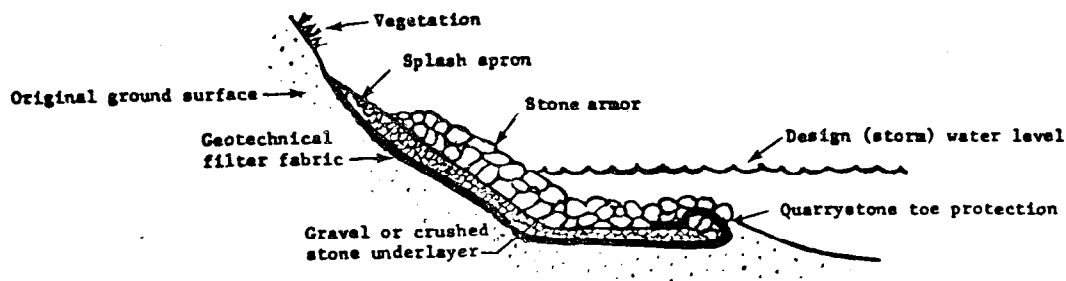


Figure 1. Quarystone Revetment

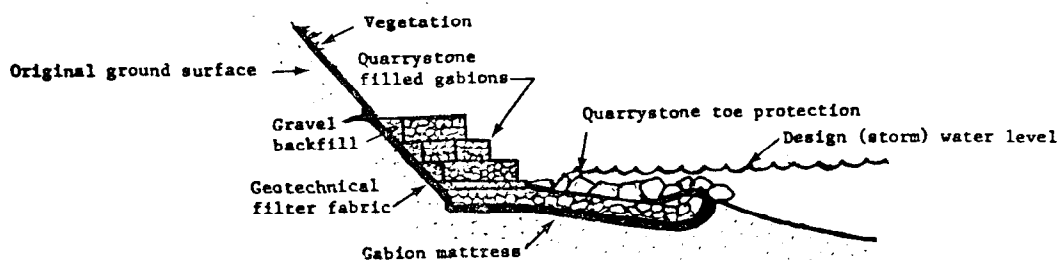


Figure 2. Gabion Revetment

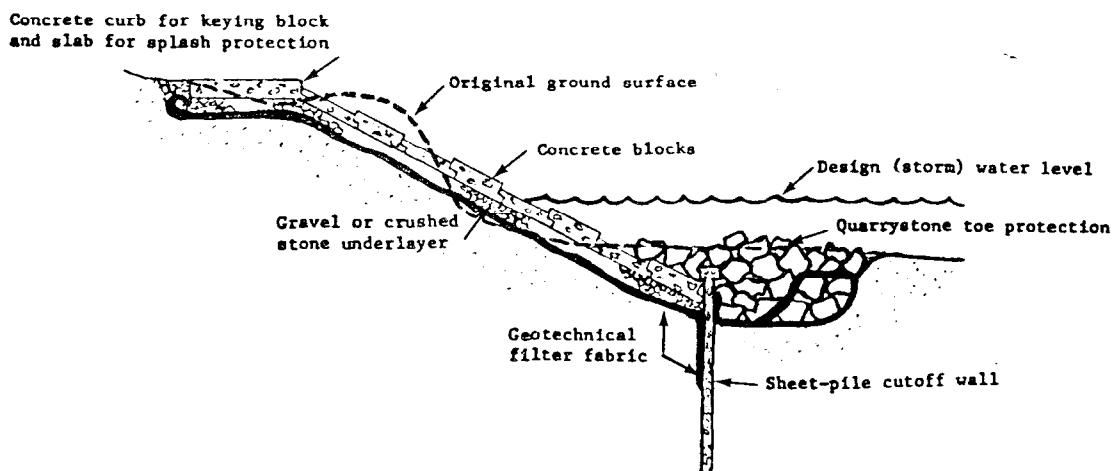


Figure 3. Concrete Block Revetment

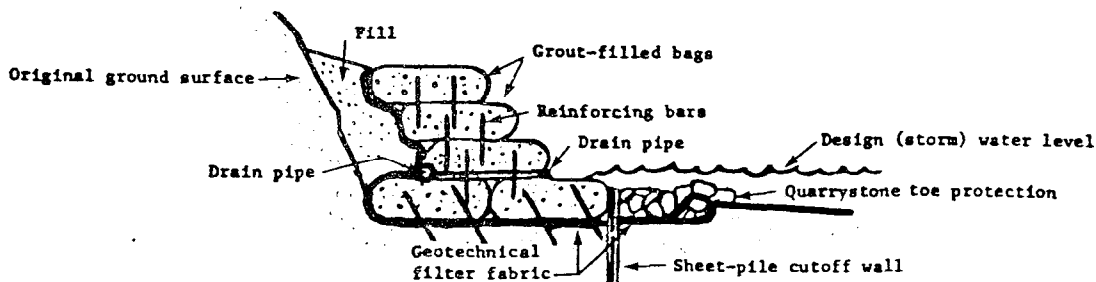


Figure 4. Grout-filled Bag Revetment

rigid grout-filled bag structure with reinforcing rods used to hold bags in place. Grout-filled mattresses of synthetic fabric and reinforced concrete slabs are other rigid structures similar in appearance to the block revetment in Figure 3. Revetments are discussed in the *Shore Protection Manual* (SPM) and McCartney, 1976.

The slope of the structure depends on the type of armor used. Gabions and bags may be stacked relatively steeply, but the types constructed on slopes should not be steeper than around 1 vertical on 2 horizontal. For these structures the natural bank, or any required backfill material, should be graded as shown in Figure 3 and compacted to provide an adequate foundation.

2. Filter Layer. A filter layer providing proper drainage is needed to maintain the foundation's slope. If the revetment traps ground water, it can flow down the interface between the revetment and the underlying soil, washing soil down the bank to form holes and mounds. If ground water can drain through the revetment, but soil is allowed to flow with it, piping occurs, also forming holes in the bank.

The simplest filter layer to use is a geotechnical filter fabric. Although the filter fabric will prevent individual components of a revetment from settling independently, it acts primarily as a filter, and should be carefully chosen to provide the necessary drainage while retaining the type of soil occurring at the revetment site. Figures 2 and 4 illustrate the use of fabric as a filter layer under gabions and bags. Uses of geotechnical fabrics with quarrystone are discussed in CETN-III-3, "Use of Geotechnical Fabrics."

A more complex filter uses a layer of gravel or crushed quarrystone over the filter fabric to protect the fabric or to facilitate construction. The angular edges of heavy rock may puncture the fabric, unless a layer of gravel or crushed rock (as shown in Figure 1) is used to protect the fabric by evenly distributing the load of the armor rock. This intermediate layer or underlayer will also contribute to the interlocking of the bottom course of rock. Block revetments must be built on smooth slopes to allow correct alignment of joints. If the bank material is difficult to grade, a gravel layer may be placed over the filter fabric and spread to the design's surface requirements.

In some cases it may be economical to replace the filter fabric with a layer of sand coarse enough to be retained by the overlying gravel or armor layer, yet fine enough to retain the underlying natural soil or fill. Both geotextile and mineral filters are designed by considering the sizes of retaining soil, as well as the size of openings in the quarrrystone that retain the filter materials. Criteria for choosing sand and gravel for filter layers are given in the SPM.

3. Toe Protection. Unless the toe of a revetment can be keyed into underlying rock, waves may scour a trough at the toe which may extend under the revetment if toe protection is not provided. If adequate drainage measures are not designed into low permeability armor, water trapped landward of the revetment will flow seaward under the toe, possibly scouring out soil. Typical protection (shown in Figures 1 to 4) consists of a layer of quarrystone, large enough to resist movement by wave forces, underlain by granular material and/or geotechnical fabric which prevents soil from being washed through voids in the quarrrystone. If the revetment is built on soft or sandy soil, a sheet-pile cutoff wall should be driven deep enough to protect the revetment against undermining by wave scour and to impede ground water flow past the toe. Examples of cutoff walls are shown in Figures 3 and 4. An apron may also be required in combination with a cutoff wall, depending on soil and wave conditions.

Toe protection also varies with the stability, permeability, and wave-dissipating properties of the armor used. The scour aprons for quarrrystone and gabion revetments, shown in Figures 1 and 2, respectively, can incorporate seaward extensions of the revetment. The seaward course of block in a block revetment must be set against some straight, well-anchored cutoff wall to insure proper joint alignment as well as to prevent undermining of the toe. Such a cutoff wall is the sheet-pile wall with quarrrystone toe protection shown in Figure 3. Structures armored with smooth concrete slabs or blocks, or with grout-filled fabric, will require more elaborate toe protection.

4. Other Protective Measures. Unless other design precautions are taken, the property landward of a revetment may be eroded by ground water flow, wave overtopping, or flanking. Ground water flowing out of the bank above the revetment can be controlled by installing proper drainage structures at the toe and within the bank. Overtopping may erode the area behind the

revetment, negating the structure's purpose; may remove soil supporting the top of the revetment, leading to damage by waves; and may increase the volume of water in the soil beneath the structure, contributing to drainage problems. The effects of overtopping can be limited by choosing a design height exceeding the expected runup height; or, as illustrated in Figures 1 and 3, by armoring the bank above the revetment. Flanking occurs when the erosion of shores adjacent to the revetment advances into the area landward of the revetment, leading to progressive destruction of the revetment from the ends toward the middle. Flanking can be prevented by tying each end into adjacent shore protection structures, or by extending each end back into the existing bank a sufficient distance.

ARMOR MATERIALS: Angular quarrrystone is the preferred material for revetment armor. Quarrrystone, that is selected in accordance with the specifications given in Section 6.104 of the SPM, is one of the most durable materials used in coastal structures. Quarrrystone armor layers are easily repaired. Quarrrystone armor may be uniform, fitting a narrow size range; or graded with a wider range, as discussed in CETN-III-1, "Riprap Revetment Design." Construction materials (debris), such as broken bricks, broken concrete, and cinderblocks, normally cannot provide the desired wave resistant characteristics required for revetment armor; however, they are sometimes used as emergency protection until more permanent measures can be taken.

Since gabions are filled with fist-sized or larger quarrrystone, they approach the surface roughness of quarrrystone. They can be filled with smaller and more rounded stones than the larger quarrrystones. This makes gabions useful where large stones are not available. Gabions are made of galvanized wire for freshwater use, and plastic-coated galvanized wire for saltwater use. The life of the structure depends on the integrity of its corrosion protection. The coating, and ultimately the wire, is subjected to abrasion caused by wave-induced movement of sand, and movement of the quarrrystone fill within the gabions if they are packed tightly. Holes can be repaired by wiring them shut, but periodic inspections are necessary to insure repair before filling is lost.

Concrete blocks are available in a variety of permeabilities and means of interlocking, providing different degrees of surface roughness and rigidity.

Blocks must be made of good quality concrete and must be manufactured with care to insure ease of interlocking and correct placement during construction. Some types of blocks may be glued to filter fabric to speed construction and to help anchor them.

The synthetic fabrics used for bags and mattresses are smooth, creating wave reflection and runup problems. They are vulnerable to damage from vandalism, exposure to sunlight, and impact with debris; thus making the filling material, usually grout or concrete for permanent revetments, provide all the structural integrity. The smooth, rounded contours of bags make interlocking a problem. Unless reinforcing rods or some other form of locking bags together are provided, the stability of a bag structure will be limited by the individual bag size. Since mattresses have no steel reinforcing, they may crack between weepholes until the mattress is broken up into small, easily removed blocks.

Concrete slabs generally are built with a smooth face, but a rough shape may be used. Adequate concrete cover must be provided over reinforcing steel to prevent its corrosion. Where the concrete is exposed to salt-water and/or freezing and thawing, a very high quality concrete will prevent spalling.

Lighter armor materials, than those discussed here, have been successful at sites exposed only to currents and very low waves; but on coasts exposed to more powerful waves, their behavior has either been unsatisfactory, or has not been sufficiently studied to determine their suitability for this use.

DESIGN CONSIDERATIONS:

1. To assure that there will be adequate beach seaward of the revetment, a beach fill and/or additional structures can be added. If unhindered access to the beach or water is desired, crossings should be provided.
2. The bank on which a revetment is to be constructed must be stable and have the proper slope to maintain the armor layer's stability. The bank may require grading to a flatter slope, possibly resulting in the loss of high ground landward of the revetment.
3. The armor must be stable against movement by waves. For flexible and semi-rigid layers, the shape and weight of armor units and the strength and flexibility of unit interlocking must be suited to the wave climate. Rigid bag, mattress, and slab structures must be sufficiently thick and/or

reinforced to prevent cracking and breaking up.

4. A filter layer, under permeable armor or under impermeable armor pierced by drainage pipes, must provide proper drainage while preventing the loss of underlying soil. Granular filter material must have the proper gradation to allow the free-drainage of ground water, yet prevent the loss of the supporting soil. This type filter also contributes to the stability of individual armor units by functioning as a bedding material. Filter fabric must have the correct pore size to retain the soil, yet allow the passage of water; in addition, it must be strong enough to support the armor layers without puncture or tearing, or have a sufficient thickness of gravel or crushed stone as an intermediate layer under the armor to protect the fabric.

5. The effects of scour in undermining the revetment toe can be controlled by providing quarystone toe protection and/or a cutoff wall.

Quarystone armor dissipates wave energy, and therefore reduces the wave reflection which is a contributing cause of scour. The use of granular filter material or geotechnical filter fabric can prevent the loss of the underlying foundation material caused by ground water flowing through the revetment. A sheet-pile cutoff wall can control the flow under the structure, as well as the undermining of the structure resulting from wave action.

6. Overtopping may be decreased by increasing the height of the revetment or by using wave-dissipating armor. The effects of overtopping may be mitigated by armoring the area landward of the revetment with quarystone or a concrete slab, and by providing means of draining overtopped water off of the surface of the slab or from beneath the quarystone.

7. Drains in the bank landward of the revetment will reduce the volume of ground water at the back of the revetment.

8. The revetment must be constructed to prevent failure due to flanking. The ends must be tied to adjacent structures or turned back into the shore or upland.

MATERIAL SELECTION FOR REVETMENTS:

1. Quarystone allows drainage, dissipates waves, and provides a good habitat for marine organisms. Stone of the required size and shape is not readily available everywhere in the United States. Gabions, which offer some of the advantages of quarystone, can use smaller, local stone. Concrete blocks containing voids lack the roughness and resulting favorable

performance of quarystone, but do promote better drainage and wave dissipation than highly reflective smooth, solid blocks.

2. The nature of, and access to, a site may dictate the construction methods possible and, in turn, limit the materials that may be used.

Grading with equipment ranging from bulldozers to shovels may be involved in the construction of quarystone, block, grout-filled mattresses, and concrete slab revetments which cannot be built on steep slopes. A filter of geotechnical filter fabric can be spread by hand, but lifting equipment is needed if blocks are attached to the fabric. If blocks are not previously attached to the filter fabric they can be placed by hand, but skill is required to keep the blocks properly aligned and interlocked. Filter material of any type generally is difficult to place underwater and in surf. Although light equipment can be used, heavy hauling equipment simplifies the handling of gravel and crushed rock. If necessary, empty gabions can be placed, wired together, and filled by hand. Concrete for slabs may have to be trucked to the site and may require placing equipment, but grout for bags and mattresses can be pumped into the fabric forms by small pumps.

3. Repairs are easiest for flexible armor layers. If the filter layer fails and settlement occurs, or the top or toe is undermined, only flexible structures can distort without cracking or losing armor units. If quarystone is removed it can be easily replaced by adding new rock in the damaged area. Gabions, which fail by leaking stone fill when wires break, are repaired by wiring holes shut and refilling with stone. Of the other types of armor, only concrete blocks without interlocking features, usually flat sided, have much possibility of fitting back together over a distorted foundation. Displaced interlocking blocks are difficult to key back into place, whatever the filter layer's conditions. Broken grout-filled bags might be replaced as units; but broken concrete slabs and grout-filled mattresses must be replaced in their entirety, or be covered with a new armor layer.

REFERENCES:

- McCARTNEY, B.L., "Survey of Coastal Revetment Types," MR 76-7, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, VA., 1976.
- U.S. ARMY, CORPS OF ENGINEERS, COASTAL ENGINEERING RESEARCH CENTER, "Riprap Revetment Design," CETN-III-1, Fort Belvoir, VA., 1979.
- U.S. ARMY, CORPS OF ENGINEERS, COASTAL ENGINEERING RESEARCH CENTER, "Use of Geotechnical Fabrics," CETN-III-3, Fort Belvoir, VA., 1980.
- U.S. ARMY, CORPS OF ENGINEERS, COASTAL ENGINEERING RESEARCH CENTER, *Shore Protection Manual*, 3d ed., Vols. I, II, and III, Stock No. 008-022-00113-1, U.S. Government Printing Office, Washington, D.C., 1977, 1,262 pp.