CHAPTER 109

DESIGN OF FILTER SYSTEM FOR RUBBLE-MOUND STRUCTURES

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ABSTRACT

The rubble-mound seawalls, groins, breakwaters and ripraps around ocean-fall pipelines are still the most common type of shore-protection structures currently in use. Major reasons include: easiness to construct and repair, flexible with respect to settlement, favorable wave-energy dissipation, fitness for any water depth and any foundation, and because of its economical nature if rubble-stones are readily available. However, the importance of a filter system in the stability of such structures must be emphasized. More recently, the submerged rubble-mound structures have become very popular due to aesthetic reasons. A filter system is considered a must to protect such a structure against erosion as a result of wave overtopping.

Following a brief review of the problems, general discussions are made of the specific causes of failures including piping, overtopping, and nonstability. The physical factors that would affect the filter design are discussed in detail. Methods for design of filter system is presented including those applicable to the gradation of filter layers and to the plastic filters. The design procedure involves (a) making mechanical analysis of the backfill and base material, (b) estimating sizes of voids in the rubble-stones, (c) designing filter by Terzaghi criteria as revised by U.S. Army Waterways Experiment Station.

A sample design of graded filter system behind rubble-mound seawalls is given.

The procedure for the selection of plastic filters is also included.

A comparison of the merits and demerits of these two types of filter systems will be made. This comparison will take into account the model test results conducted in the Look Laboratory. However, the readers are cautioned about the scale effects of the scour characteristics particularly on those tests with light-weight model sediments.

This paper is intended as a general guideline for practicing engineers who will be responsible for design and construction of rubble-mound marine structures.

INTRODUCTION

The rubble-mound seawalls, groins, breakwaters, and ripraps around ocean outfall pipelines and oil production structures are the most common types of marine structures currently in use. Major reasons are: (1) have good wave-energy dissipation characteristics thereby reducing wave run-up and bottom erosion, (2) easy to construct and to repair damages, (3) flexible in response to settlement, (4) suitable for use in any water depth or with any type of foundation, and (5) economical since rubble-stones usually are readily available near site. Unfortunately, many rubble-mound structures have failed due to faulty design and construction. In some instances, the interaction between waves, storm surges, wind-driven currents and the structure is not well defined and failures occur due to instability of the structure. In the past, emphasis has been placed on the effect of size or weight of the rubble-stones and/or armour units on the desirable stability. The importance of the foundation characteristics has been overlooked. Undoubtedly, many failures were caused by inadequate foundation protection. For example, a lack of proper rubble-stone gradation and filter system behind the seawall at the Sangley Point, Philippines has resulted in the leaching of the backfill behind the seawall, and in foundation erosion. More recently, the submerged breakwaters have become very popular in the United States due to aesthetic and environmental reasons. A filter system is considered a must to protect such a structure against erosion as a result of wave overtopping.

Most experimental studies on the stability of breakwaters have been conducted in a fixed-bed model without due consideration of the effect of foundation erosion on the stability of the armour units.

This paper is aimed to improve the design of the filter and rubble gradation system of a rubble-mount structure subject to a given critical ocean environment. Both graded and plastic filters will be discussed. It is intended as a general guideline for practicing engineers who will be responsible for design and construction of rubble-mound marine structures. The paper is also intended to call the attention of researchers to consider foundation erosion and protection by filter system in their future experimental studies on stability of rubble-mound type structures.

STATEMENT OF THE PROBLEM

A complete failure of the rubble-mound structure can be expected if the stone gradation is improper or if the filters are not provided, or are improperly constructed to specification. Many failures have been attributed to internal erosion wherein beach materials are removed by percolating water, such as that due to water waves, surface runoff, and tidal flow. As a wave and/or tide rises on a pervious wall, water fills all the voids back to the impervious section or until the soil is saturated. When the wave recedes, this water must be permitted to escape immediately or the hydrostatic pressure will cause the facing to be dislocated by piping action in the soil foundation unless a filter is provided. Washing-out of the backfills, settlement of the main structure and overtopping of the subsequent waves will follow eventually. Overtopping could also occur due to tsunami or hurricane wave effects.

To reduce the danger of piping, either a drainage filter system or an impervious membrane should be considered.

A drainage filter system consists of a narrow vertical or sloped layer or layers of graded stone, gravel, and sand behind the rubble-mound structure underneath the foundation toe. The impervious membrane or cutoff wall is composed of such materials as steel sheet piling or plastic blankets (Barrett, 1966). These impervious layers are designed respectively to penetrate into or to cover beach areas so as to lengthen the path of seepage. This tends to prevent the water from reaching the backfill or beach soil. The filter system is preferable. However, it should be noted that filters cannot function effectively unless they are free of fines.

Generally, four types of rubble-mound seawalls may be designed with graded filters as shown in Fig. 1. The size of stones is of primary importance. It may vary from top to bottom of the wall depending on such parameters as wave height, slope of wall and specific weight of stones. Design principles are presented by the Bank Protection Committee, California (1960), and by the U.S. Army Coastal Engineering Research Center (1966). If the seawall includes a hand-laid steep section, heavy face stones are generally required. For a flatter slope, the size of stone can be materially reduced. A slope of 1.5 on 1 is used generally but 1.2 on 1 is not uncommon.

DESIGN CRITERIA FOR GRADED FILTER SYSTEM

The gradation of the filter material depends on the characteristics of the backfill or beach materials and on the voids of rubble stones or armour units. The filter material should be uniformly graded from fine sands, coarse sands, gravels such that it will not wash into it. The material could be in two or more protective layers.

The design procedure involves (a) making mechanical analysis of the backfill and/or base materials, (b) estimating sizes of voids in the cover rubblestones, and (c) designing filter by Terzaghi criteria as revised by U.S. Army Engineer Waterways Experiment Station (Posey, 1961 and 1971). It stipulates that:

$$\frac{D_{15}\ \text{Filter}}{D_{85}\ \text{Base}} < 5$$

$$4 < \frac{D_{15}\ \text{Filter}}{D_{15}\ \text{Base}} < 20$$

$$\frac{D_{50}\ \text{Filter}}{D_{50}\ \text{Base}} < 25$$

$$\frac{D_{85}\ \text{Filter}}{D_{\text{voids,stones}}} > 2 \quad \text{(Seelye, 1965)}$$

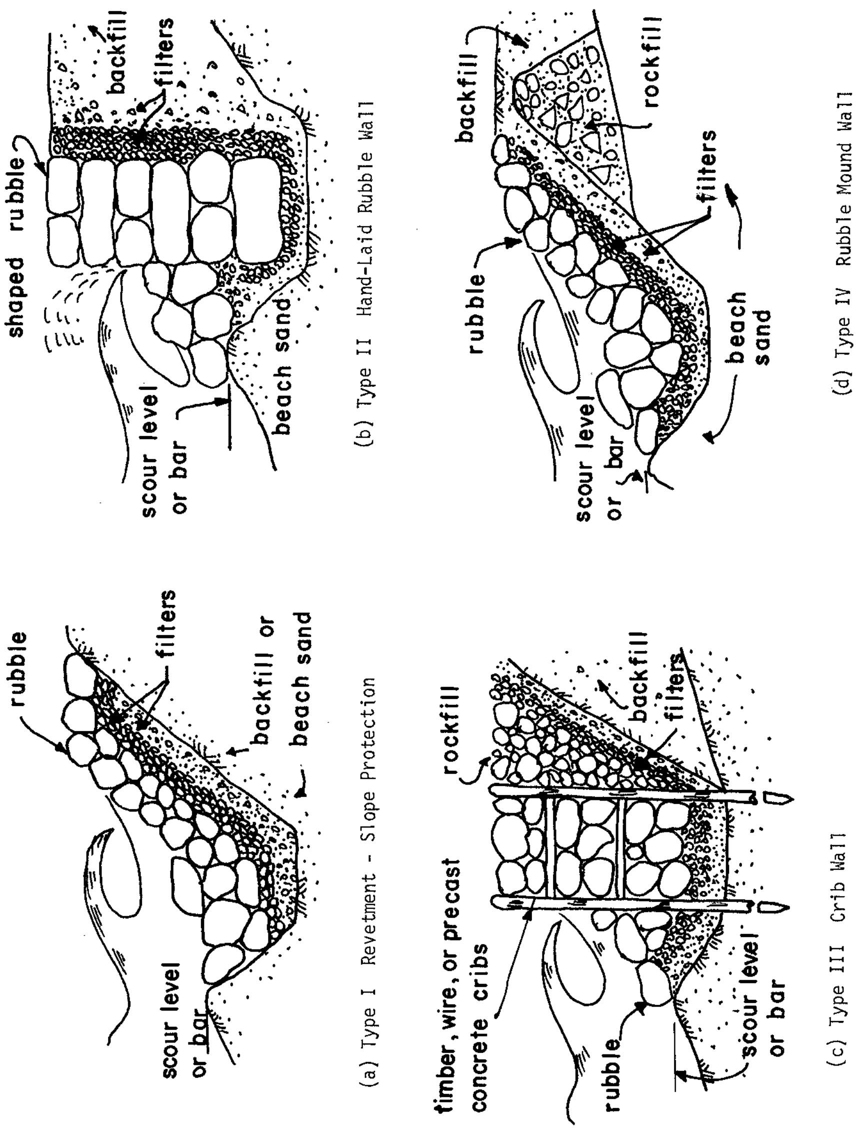


FIG. 1 TYPICAL RUBBLE-MOUND SEAWALLS WITH GRADED FILTERS

where D = nominal diameter of grain size usually in mm, and
for example D_{50} means 50% grain size

The thickness of the filter material should be adequate for a complete coverage of subgrade and backfill materials. In prototype, a layer of 6 to 12 inches is considered adequate. For rubble-mound structures with large voids, it is necessary to design a multilayer filter system. The first layer filter material is protected by another layer with its size distribution governed by the same design criteria as indicated above. This process is continued until filter material size is large enough to resist washing away through the voids formed in contact with ocean waves on the outermost layer of the rubble stones.

A sample design of a graded filter system behind rubble-mound seawalls is given in Figure 2.

DESIGN OF PLASTIC FILTER SYSTEM

In the event of unavailability of aforementioned graded materials suitable for local ocean conditions, a new type plastic filter has been found effective in increasing the stability of shore protection structures such as rubble revetments, seawall toe protection, bulkheads, rock groins, breakwaters, legged drilling platforms, and drainage systems (Fig. 3). The use of plastic filters as a replacement for graded filter systems and filter blankets in coastal structures was discussed by Barrett (1966, 1972).

In general, the plastic filter is woven of synthetic fibers such as polyvinylindene chloride resin monofilament yarns and polypropylene monofilament yarns which have higher tensile strength and higher resistance to abrasion than the former. Its filtering ability (permeability and soil particle retention) can be designed to meet individual requirements. Depending upon local soil conditions, the water volume and type of flow expected the permeability and filtration requirements of the plastic filter may vary from one project to another in an identical structure. In cases where thickness is required, this element would have to be realized by adding a layer of gravel or crushed stone. If the soil to be protected has an excessively high silt content, it would be advisable to place a sand pad beneath the plastic filter. Important design considerations include: the type of structure, weight and type of armour units, method of construction, and forces the structure is designed to withstand (wave action, water volume and hydraulic gradient oscillations, velocities). These variables determine the necessary abrasion resistance, tensile strength, puncture, and burst strengths of the plastic filter cloth, as specified. In all, the plastic filter must be so designed to be effective to retain soil and remain permeable to water under both laminar and turbulent flow conditions. If a particular plastic filter is selected, it is advisable that laboratory tests be conducted to determine permeability and filtration properties in the base materials to be protected, so as to ensure the filtering effectiveness as expected.

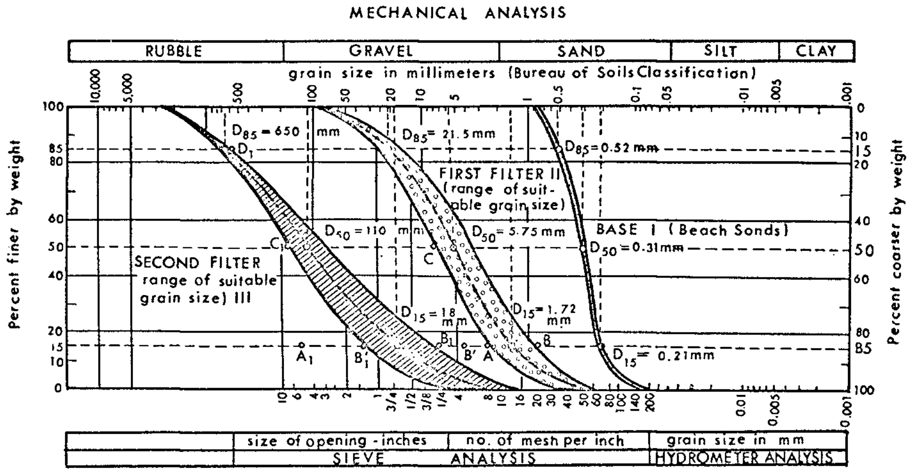
A comparison of the merits and demerits of these two types of filter systems is given in Table 1. This comparison takes into account the model test results

GIVEN

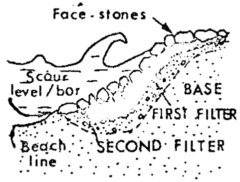
1. Mechanical analysis of a subgrade backfill or base material to be protected (Curve I): D_{15}=0.21 mm, D_{50}=0.31 mm, and D_{85}=0.52 mm; maximum
2. Maximum voids of face stones 300 mm.

REQUIRED

1. Gradation limits of 1st filter material (II) for protection of base material (I).
2. Gradation limits of filter material (III) for protection of filter material (II).



TYPICAL RUBBLE-MOUNTED SEAWALLS



SOLUTION

1. First filter layer:

Maximum 15% filter (II) size = 5x0.52mm
Criteria (1) = 2.60mm (Point A)
Minimum 15% filter (II) size = 4x0.21
Criteria (2) = 0.84mm (Point B)
or Maximum 15%=20x0.21 = 4.2mm (Point B')
Maximum 50% filter size = 25x0.31mm
Criteria (3) = 7.8mm (Point C)

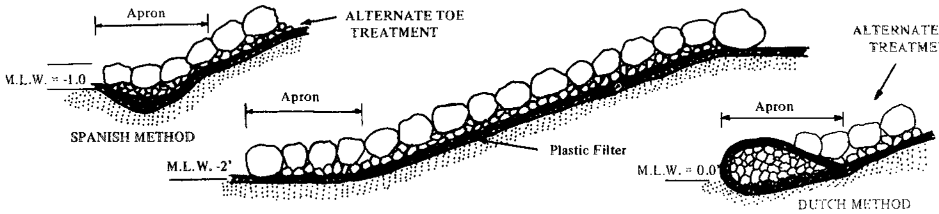
Answer: Selected first filter layer (II): D_{15}=1.72mm; D_{50}=5.75mm; D_{85}=21.50mm

2. Second filter layer (III):

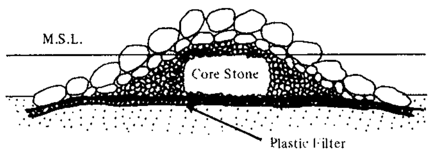
Maximum 15% filter (III) size = 5x21.5mm
Criteria (1) = 122.50mm (Point A_1)
Minimum 15% filter (III) size = 4x1.72mm
Criteria (2) = 6.88mm (Point B_1)
or Maximum 15%=20x1.72 = 34.40mm (Point B_1')
Maximum 50% filter (III) size = 25x5.75mm
Criteria (3) = 143.75mm (Point C)
Minimum 85% filter (III) size = 2x300=600mm (Point D_1)

Answer: Selected second filter layer (III): D_{15}=18mm; D_{50}=110mm; D_{85}=650mm

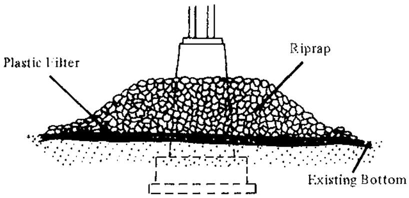
Fig. 2 A Sample Design of a Graded Filter System Behind Rubble-Mound Seawalls



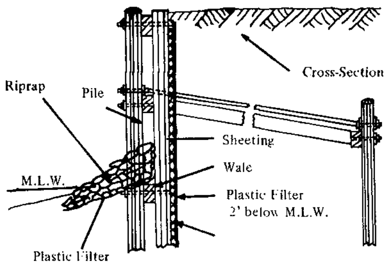
(a) Permeable rock revetment



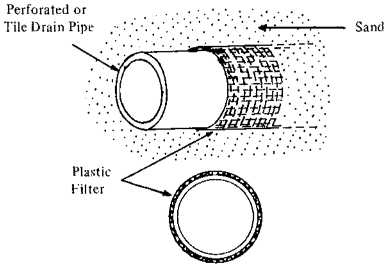
(b) Rock breakwater/jetty/groin



(c) Legged platform erosion protection



(d) Timber bulkhead



(e) Pipe wrapping drainage system

FIG. 3 TYPICAL APPLICATIONS OF PLASTIC FILTERS IN COASTAL STRUCTURES (Courtesy of R.J. Barrett of Carthage Mills, Inc.)

TABLE I A COMPARISON OF THE MERITS AND DEMERITS OF PRADED AND PLASTIC FILTER SYSTEMS

Filter Type	Merits	Demerits
Graded Filter System	1. most likely available 2. widely accepted practice 3. less effect of long-term operation on permeability and filtration may be expected. 4. the effectiveness will not be affected due to bio-deterioration	1. very difficult to construct to specification under water 2. difficult to determine the voids of the armour stones as required to design filter gradation 3. rock filter has not independent strength because it depends on soil condition for its stability
Plastic Filter System	1. filtering ability can remain the same during installation 2. have an independent tensile strength 3. eliminate screening process required for the graded filter 4. permit greater opportunity for consistency in filter design 5. plastic filter can be applied without too much concern on the geographic location and availability of graded materials	1. the plastic filter materials may not be readily available 2. initial cost may be higher than graded filter 3. more difficulty to maintain the permeability and filtration ability over long-term operations 4. the effectiveness may be reduced due to bio-deterioration

conducted in the Look Laboratory which will be described in the following paragraphs. However, the readers are cautioned about the scale effects of the scour characteristics particularly on those tests conducted with light-weight (walnut shells, ground) model sediments.

LABORATORY EXPERIMENTS IN DETERMINING THE STABILITY OF RUBBLE-MOUND BREAKWATER WITH FILTER SYSTEMS

An undistorted, two-dimensional hydraulic model study was conducted to test the stability and sensitivity of rubble-mound type jetty design with graded and/or plastic filter systems. Particular attention was given to the characteristics of the armour stone, secondary layers, core materials and characteristics of scour at the toe and under the foundation of the jetty. Model scales selected were: 1:24.5, 1:23.4, and 1:20 respectively.

A review of the considerable literature concerning hydraulic model studies on breakwater stability revealed that most study tends to neglect the effect of a movable bed on stability, including the characteristics of scour under the foundation, particularly under overtopping storm wave conditions. The scale similitude and significant findings were described previously by Lee (1970). The purpose of this section is to point out the importance of erosive type model and the phenomenon of permeability and filtration observed in the movable-bed model.

Two types of model sediments were used, i.e. fine sands and ground walnut shells. Their size distributions are shown in Fig. 4 respectively. The characteristics of jetty materials in model is shown in Table 2.

The general dimensions of final test sections of the jetty with and without plastic filters are shown in Fig. 5. The effectiveness of the graded or plastic filter are indicated in Fig. 6. Both are quite effective in reducing the scouring at the jetty toe, as compared with excessive scour depth when the jetty is designed with minimum or no toe protection.

It is interesting to note that the permeability and filtration characteristics are significantly different without toe protection and with protection by graded and/or plastic filters (Fig. 7). For the same duration of wave actions, the permeability and filtration is much greater for the jetty with no toe protection.

To demonstrate the effect of model sediment property on the scouring characteristics, tests were conducted for identical jetty design but two different sediments (sands and ground walnut shells) were used. The scouring at jetty toe are compared in Fig. 8. It should be noted that time scales for them must be taken into consideration in order to have a fair comparison. The permeability and filtration for the two different materials are similar as shown in Fig. 9.

It was found that: (1) To prevent scouring under the jetty, it is necessary: (a) to extend a layer of core materials beyond the armour-stone toe, and then place two layers of secondary stones over this core layer with proper gradation, or (b) as an alternative, a plastic filter may be placed under the jetty and

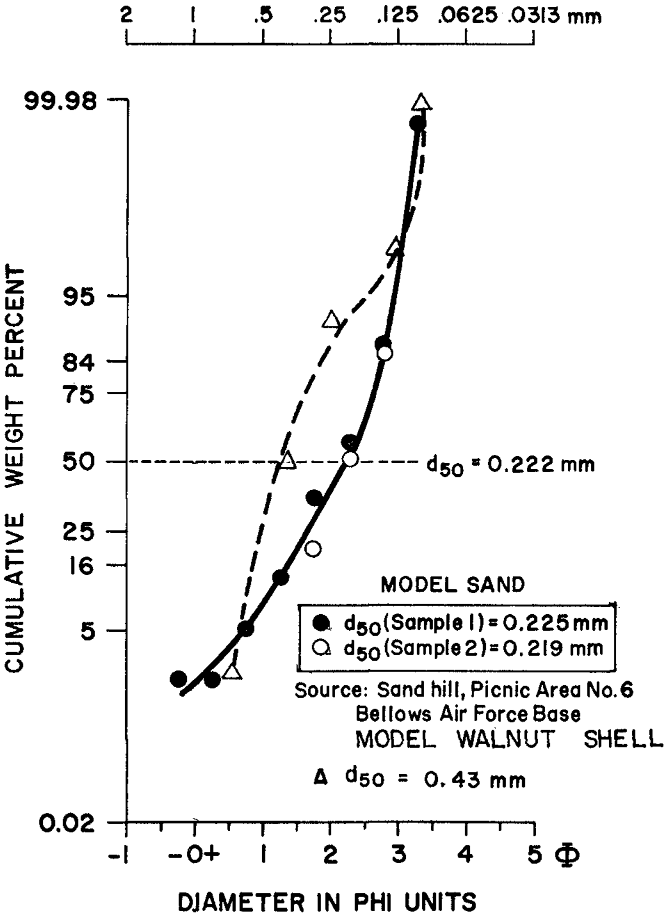


FIG. 4 SIZE DISTRIBUTION OF BEACH SANDS USED IN MODEL

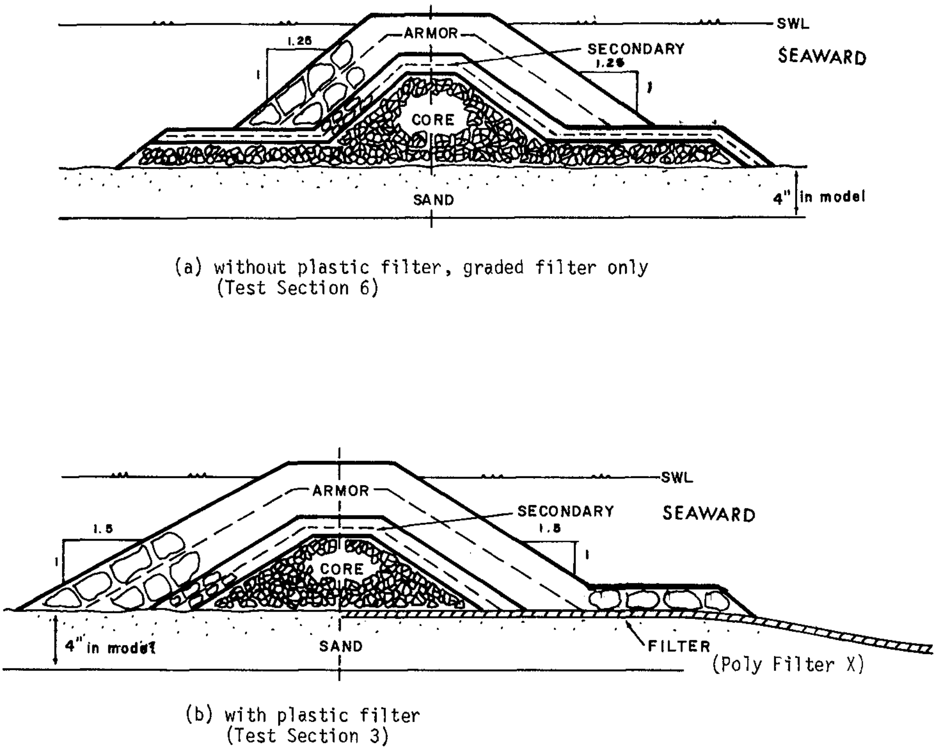


FIG. 5 GENERAL DIMENSIONS OF FINAL TEST SECTIONS OF THE JETTY WITH AND WITHOUT PLASTIC FILTERS

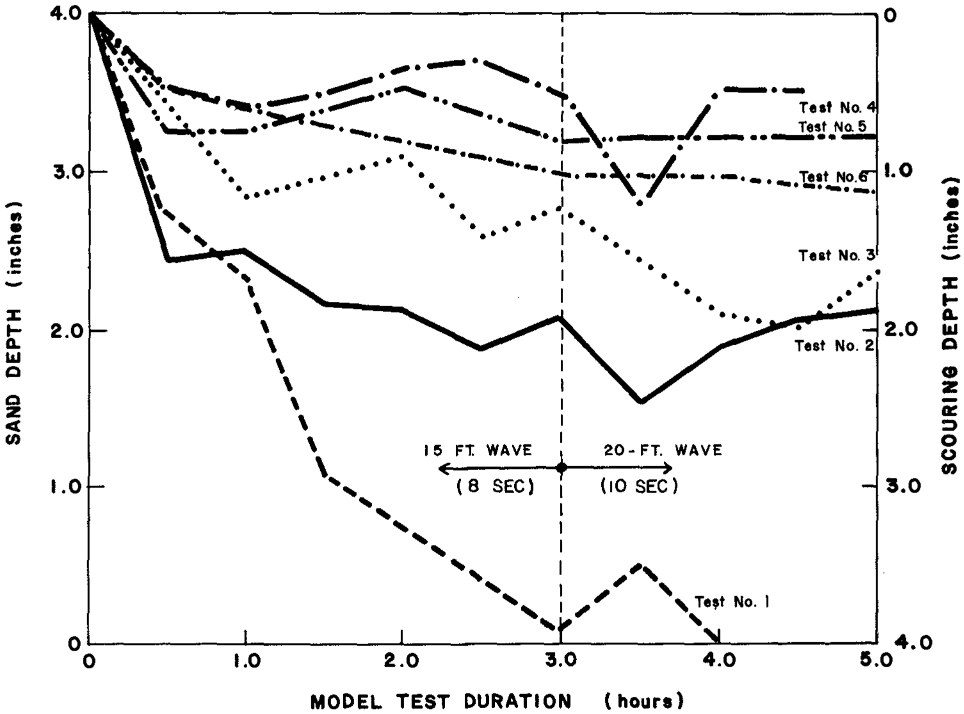
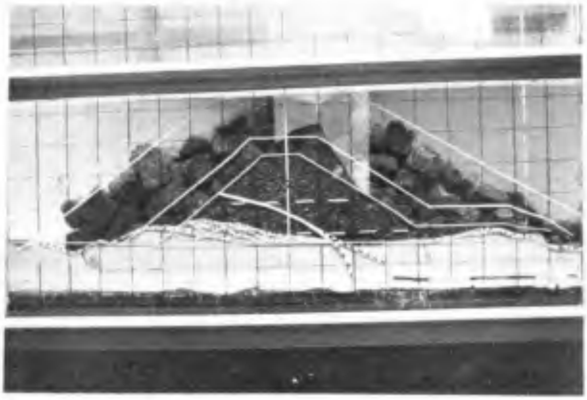
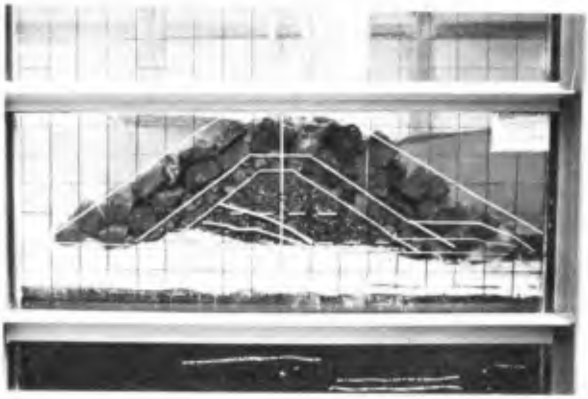


FIG. 6 SCOUR CHARACTERISTICS OF JETTY TOE AS A FUNCTION OF DEGREE OF PROTECTION



Without plastic filter
(15ft, 8 sec, 2 hr.)



With plastic filter
(15ft, 8 sec, 2 hr.)

FIG. 7

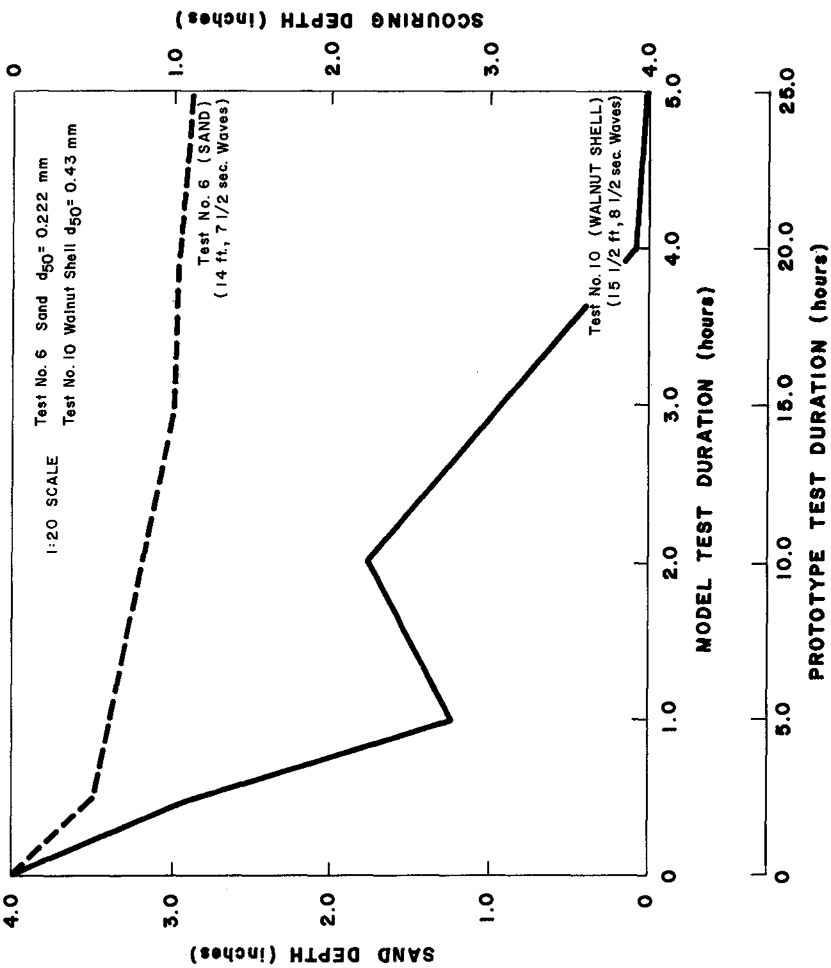
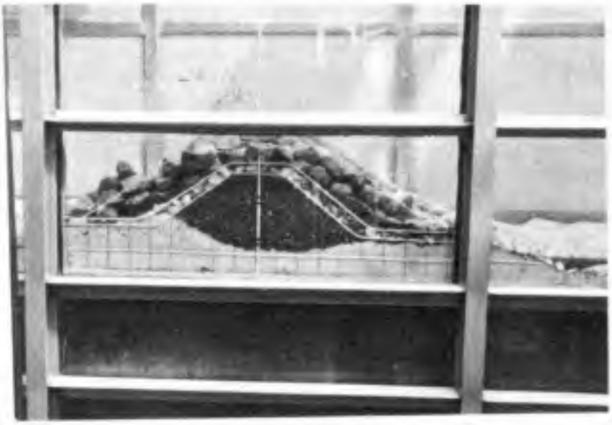
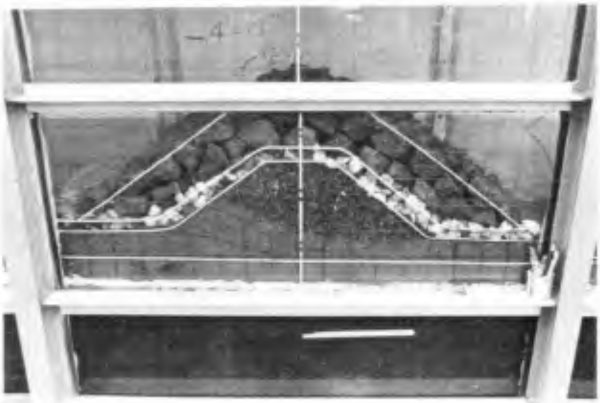


FIG. 8 SAND SCOURING AT JETTY TOE (TESTS 6 AND 10)



(a) Sands — 2 hrs of 20 ft, 10 sec waves
& 3 hrs of 14 ft, 8 sec waves
(TEST SECTION 5)



(b) Walnut shell — 5 hrs of 15 ft, 8 sec
waves (TEST SECTION 10)

FIG. 9

extend beyond the toe with secondary stones over it; (2) a filter layer, preferably plastic, is necessary in the prototype construction between the core material and the sandy beach; and (3) quantitative experiments on the scouring depth at the jetty with different model sediments need to be studied further.

The stability of the rubble-mound structure should be studied in a movable bed model, particularly the structure is founded in a depth shallower than the critical depth for sand movement. Otherwise, the designer should specify that the jetty bottom should either extend below scour depth yet to be determined, or it should be rest on a plastic filter. Also, the filter system for a jetty should be designed with extreme care, particularly if translatory currents induced by tidal and river flow along the longitudinal axis of the jetty are significant.

SUMMARY

The need for a properly designed and constructed filter system is obvious in the stability of rubble-mound marine structures. The design criteria given in this paper would be helpful to practical engineers to select either graded or plastic filters to suit local environmental and resources conditions. The gradation of filter materials is dependent on the characteristics of base sands and cover-stones of armour units. The plastic filter must be selected to meet the requirements of permeability and soil-particle retention, preferably determined from laboratory tests under a variety of flow conditions anticipated at site.

A movable-bed type test should be conducted for future studies on the stability of rubble-mound structures to determine the scouring characteristics with due consideration of model scale effects.

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