Chapter 35

SEAWARD PROFILE FOR RUBBLE MOUND BREAKWATERS

by

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ABSTRACT

For several years, some coastal engineers have been aware that the seaward face of rubble mound breakwaters of the common trapezoidal cross-section is conducive to relatively severe wave action and possible damage to the breakwaters. Further, it has been suggested that a preferable seaward profile would be that composed of three straight lines, with the middle line at a relatively small angle with the horizontal, to form what might be thought of as a broad berm.

In order to arrive at a more realistic knowledge of seaward profiles for which wave intensity and likelihood of breakwater damage are minimal, a laboratory study of shallow-water wave action on rubble breakwaters was initiated at Auburn University. It is hoped that such knowledge will lead to design procedures which will result in (a) less violent wave action, (b) less structural damage, and (c) the possible use of smaller stones.

Thus far, the study has been devoted to shallow-water waves of two types, steep, smooth waves and spilling breakers, acting, with normal incidence, upon breakwaters constructed of various materials and having an initial seaward slope of 1 on $1\frac{1}{2}$.

For each set of conditions, the stable seaward profile was determined. Through dimensional analysis and curve fitting, an effort was made to describe the stable seaward profiles in terms of physical quantities which influence the profiles. It is the authors' belief that the results of this study will be useful in leading to more rational design procedures.

INTRODUCTION

Judging from existing structures, one might say that the conventional cross-section for rubble mound breakwaters is trapezoidal in shape. It is probable that the principal influencing factors in establishing this conventional cross-section were simplicity of construction, initial volume of material, and insufficient knowledge of wave action upon breakwaters. However, it is now known that the seaward face of the conventional trapezoidal cross-section is not natural to the wave motion and results in relatively violent wave action and the need for extremely large, heavy stones to prevent damage to the structure. In recognition of this problem, a comprehensive study was conducted and reported by Barbe and Beaudevin[1]. Later, it was suggested by Beaudevin[2] that the seaward profile might be designed with a berm, thus reducing the violence of wave action.

Experimental studies by the authors, for shallow-water waves, have resulted in a clearer understanding of the seaward profile which is natural to the breakwater materials and the waves to which they are subjected. To the best of the authors' knowledge, this natural profile has not heretofore been adequately described. For the breakwaters studied in the laboratory, material was moved from the upper part of the seaward profile to the lower part of that profile, without significant change in cross-sectional area of the breakwater. However, practical considerations arising from the steepness of the upper part of the natural profile and from the need to preserve an adequate crest width may require a greater cross-sectional area and volume of material for the breakwater with the natural profile than for the conventional type. But, when one considers the possibility of using smaller stones than those indicated by conventional formulae, there may be instances in which the breakwaters with natural profiles will compare favorably, in an economic sense, with those of conventional profiles.

The continuing study initiated at Auburn University is for the purpose of determining means by which natural seaward profiles of rubble mound breakwaters may be described. The study is concerned with the relationship between particular breakwater materials, stillwater depths, wave characteristics, and profile coordinates for shallow-water waves at normal incidence. The initial phases of the study have been reported in theses by Pugh[3] and Singh[4]. Results of the study are described in generalized terms through dimensionless parameters involving quantities pertinent to the study.

EQUIPMENT

This study was made with facilities in the Hydraulics Laboratory of Auburn University, Auburn, Alabama. The primary item of equipment was a wave basin having an interior length of 44 feet, width of 2 feet, and depth of 2 feet, except for a depression in the vicinity of the generator. The wave generator is of the horizontal-plunger type with a vertical, plane face. Wave frequency is controlled through a variable-speed drive. The wave height is controlled through the setting of a crank arm. The basin is of rectangular cross-section with a horizontal bottom, except for the depression near the generator. A part of one wall in the vicinity of the test section is constructed of glass. A grid system was drawn on the glass to enable determination of coordinates describing the seaward profile of the test section. A hook-point gage was used to determine wave height and stillwater depth.

EXPERIMENTAL PROCEDURE

After the choice of shape, size, and specific gravity of material to be used in the test section had been made, the test section was constructed in the wave basin. The test section was located within that part of the basin having a glass wall along one side and far enough removed from the wave generator that the incident waves could be considered as reasonably stable. The axis of the test section was about 22 feet from the wave generator. Thus far, all test sections have been constructed with seaward faces that were initially plane, with a slope of one vertical on $1\frac{1}{2}$ horizontal. The height of the section was such that there was no significant overtopping. For all tests, the wave period was sufficiently great that each wave was more or less independent, approximating a solitary wave. This condition is considered to be representative of shallow-water waves. The distance between crests was 10 to 12 feet. Two types of waves were studied: smooth waves of such steepness as to be near instability and spilling breakers. After the water level in the basin had been brought to the desired elevation, an approximate setting of the crank arm for desired wave conditions was made and the wave generator operated for a period of time sufficient to make the necessary adjustments in wave height. Then, the seaward face of the test section was reshaped to its initial plane surface. The wave generator was put in operation and allowed to operate until the seaward profile of the test section had become stable. Operation of the generator was then stopped, and coordinates of the seaward profile were determined from the grid system on the glass wall of the basin. The same procedure was repeated for various shapes, sizes, and specific gravities of materials and for various water depths and wave conditions.

Each test section was constructed of a single material. The several test sections were constructed of the following materials:

Material	Specific Gravity	Size (inches)	Shape
Coal	1.30	1 - $1\frac{1}{2}$	Irregular
Granite	2.89	1 - $1\frac{1}{2}$	Irregular
Limestone	2.71	$\frac{1}{2}$ - 3/4 3/4 - 1	Irregular
Concrete	2.26	5/8 $1\frac{1}{4}$	Cube

Coal was included in the study because of its low specific gravity. The greater movement of the coal contributed to a better understanding of the phenomenon through observation and photography and through extension of the range of experimental data. It is not expected that coal would be used as a prototype material.

Limiting values of stillwater depth were 0.5 and 1.10 ft. The value of H/D for which the smooth waves were studied was between 0.4

and 0.5 and the value for which the breaking waves were studied was between 0.6 and 0.7.

ANALYSIS OF DATA

It was observed that the tendency of waves was to move material from the upper portion of the seaward face to the lower portion. This tendency is illustrated in Figure 1. It was found by Pugh[3] that the stable profile intersects the initial plane face at about 0.2 of the still-water depth below the still-water surface. This point was chosen as the origin for subsequent curve fitting. All coordinates determined from the grid system on the glass wall of the basin were converted to coordinates from horizontal and vertical axes through the adopted origin. Physical quantities necessary for describing the stable seaward profile resulting from either a smooth wave or a spilling breaker might be related through dimensionless parameters of the implicit function

$$\phi\left(\frac{x}{D}, \frac{y}{D}, \frac{d}{D}, S, \text{shape}\right) = 0 , \qquad (1)$$

where x and y are coordinates of the profile; D is still-water depth; d is a linear index to size of material; S is specific gravity of the material, and the word shape refers to shape of the unit of material.

Although it was desired to describe the seaward profile through a single functional relation, that has not, as yet, been accomplished. For the shallow water conditions of this study, the lower part of the seaward profile was affected by the presence of the solid boundary of the basin bottom. Also, it is possible that the upper part of the seaward profile was affected, in some instances, by the truncated nature of the crest. It was observed that the part of the profile above the origin usually exhibited different characteristics than the part below the origin. Consequently, it has been expedient to divide the curve fitting into two parts. However, either the upper part or lower part can be described satisfactorily through a power function such as

$$\frac{y}{D} = m\left(\frac{x}{D}\right)^n \qquad (2)$$

where m and n are constant for the upper part or the lower part of any particular profile, but, in general, would depend upon the type of waves and be functions of d/D, S, and shape. For either the upper part or lower part, x/D and y/D will be of like sign. For purposes of curve fitting, Singh[4] treated all measurements from the origin as positive.

For a material of particular specific gravity and unit shape and for a particular type of waves, Singh[4] has suggested that m and n might be expressed satisfactorily through a logarithmic function of d/D such as

$$m \text{ or } n = A \log\left(\frac{d}{D}\right) + B , \qquad (3)$$

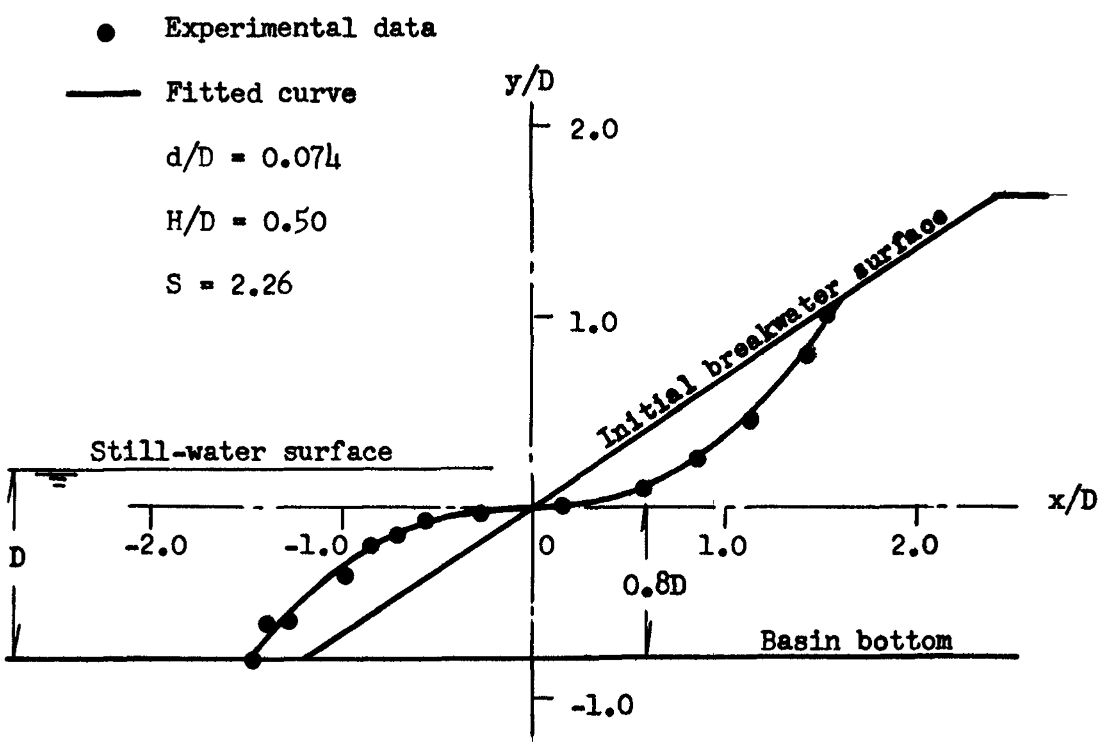

Fig. 1. Seaward profile for steep, smooth waves acting upon a breakwater of concrete cubes

where A and B are constants. In general, the values of A and B would depend upon the type of waves and be functions of specific gravity and unit shape of material. Values of A and B have been tabulated by Singh[4], using the logarithmic base 10.

SUMMARY AND CONCLUSION

It was apparent from the study that the conventional trapezoidal section results in relatively severe wave action coupled with a strong tendency toward movement of material on the seaward face. It was further noted that, after the breakwater material had been moved to form a stable section, the wave action was much less severe and there was no longer any general movement of the material except for very light weight material within a thin zone slightly below still-water surface.

In addition to the observations which have already been stated, Pugh[3] observed that, for particular breakwater material and type of waves, an increase in size of stones resulted in a decrease in volume of material moved and that, for particular size of stones and type of waves, an increase in specific gravity of material resulted in a decrease in the volume of material moved. Singh[4] concluded that, for particular breakwater material and type of waves, the use of cube-shaped units rather than those of irregular shape results in a decrease in volume of material moved.

The study leads to certain design considerations. It is not anticipated that a breakwater would be designed with the expectation that the material would be shifted to a stable section. However, the design could provide for a profile that would be stable for stones which would be more readily moved than those that will actually be used in construction. It seems that it would be practical to design such a section that would be stable for the design incident wave but with smaller stones than would be required by conventional formulae. Although the designer may not be inclined to call for curves such as those resulting from this study, it does seem reasonable to expect that such curves might be used as a guide for a profile composed of appropriate straight lines.

It has been the intent of the authors to point the need for design procedures which will result in a greater degree of compatibility between severe wave action and the rubble breakwater face than is achieved by procedures in common use. Although the study reported herein was limited to conditions which were of primary interest to the authors, such a study can be expanded to include other conditions which are peculiar to some geographical regions. In any event, it is hoped that this paper has served to create an awareness of the shape of the seaward breakwater face as an important design consideration.

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