CHAPTER 146

EFFECT OF BROKEN DOLOSSE ON BREAKWATER STABILITY

by

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Introduction

Although the use of rubble-mound structures for protection of coastal areas is common throughout the world and considerable hydraulic design data have been developed to aid the designer, very little data are provided on the structural integrity of individual armor units and the effect of broken units on the stability of such structures. The forces to which such structures are subjected are complicated and vary with type and geometry of the structure, depth of water, bottom configuration seaward of the structure, water level relative to the crown of the structure, and wave dimensions. Since all of these parameters are involved, accurate determination of wave forces cannot be calculated; and although it is not impossible to model the structural strength of armor units or measure forces on individual armor units, there are physical limitations which make the tasks extremely difficult. There is one way, however, that a breakwater stability model, as it exists today, can provide useful information on this subject and that is to purposely break given numbers of armor units and observe the effect on the overall stability of the structure. Such tests have been conducted at the U. S. Army Engineer Waterways Experiment Station for the Atlantic Generating Station (AGS) Breakwater in which specific answers were desired; thus, the data are limited to the dolos armor unit. The data do provide, however, significant indications regarding the type and extent of breakage (cluster or random) that is most detrimental to the overall stability of the structure; whether costly reinforcing steel is warranted to assure reduced armor breakage; and where necessary, data from this type study can be used as a basis for setting maintenance criteria that will prevent deterioration of the breakwater due to armor unit breakage.

Background

The AGS Breakwater is a 104-ft high, horseshoe-shaped, rubble-mound breakwater proposed for construction about three miles off the coast of New Jersey in about 30-40 ft of water (Figure 1). The purpose of the breakwater is to provide protection for two floating nuclear power plants. Initial tests conducted with unbroken dolosse indicated that for a selected condition of 16-sec, 40-ft waves at a still water level of +16.3-ft mean low water (mlw), 37-ton and 62-ton dolosse would be completely stable (practically no movement) on the trunk and heads of the breakwater, respectively. The broken-unit tests evolved from the question that if for some reason (i.e., reinforcing steel were not used,

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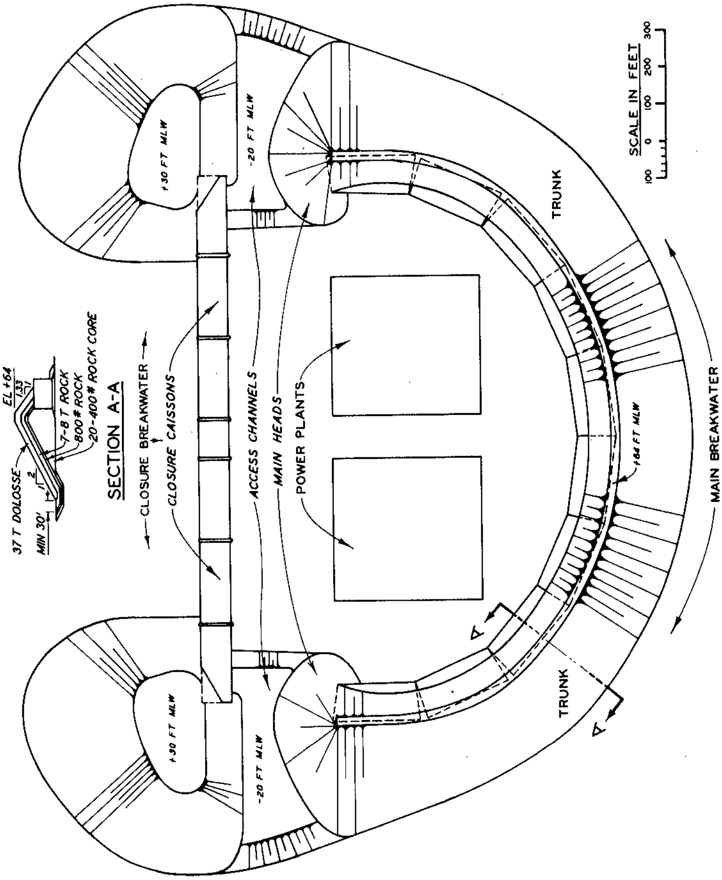


Figure 1. Layout of the Atlantic Generating Station

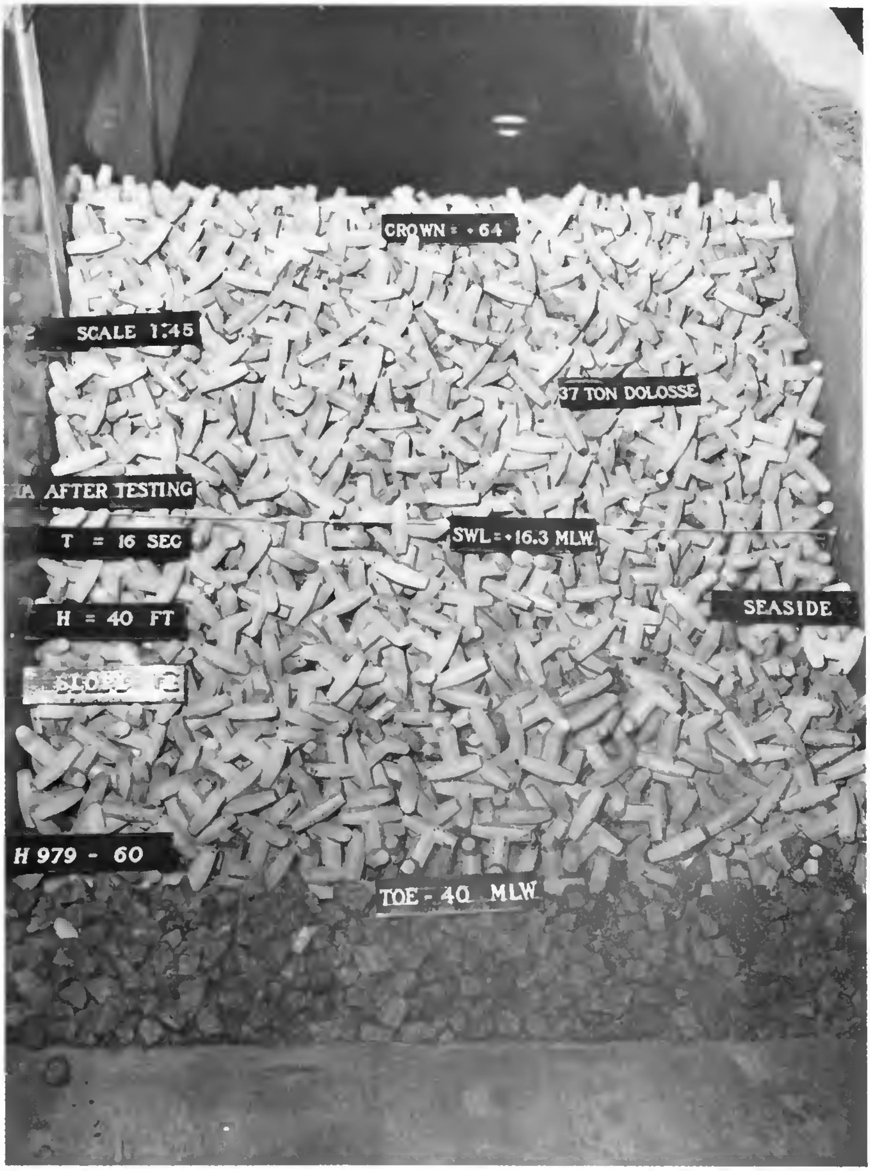
higher storm conditions, etc.), the armor units experienced breakage, what number of dolosse could be broken without having a detrimental effect on stability of the breakwater. Actual field experience for most projects throughout the world indicates that not over 2 percent of the total number of primary armor units are broken during the process of armor curing, placement of armor units, and exposure to wave attack not exceeding the design conditions. Therefore, if it can be shown that a significantly higher percentage of the armor units can be broken without deteriorating the stability of the structure, there is no need to use costly reinforcing steel to prevent breakage; or if the breakage should approach the critical percentage predicted by the model, proper maintenance can be initiated to preclude serious damage to the structure.

Two-Dimensional Model Tests

Normal Design Condition, Uniform Breakage

Several set of broken unit tests were conducted for the AGS Breakwater; however, only two sets of these tests are addressed in this paper--normal design condtions and extreme wave conditions. Both sets of tests used, for their respective water levels, the worst breaking wave condition that could occur on the structure. The first set of two-dimensional broken unit tests were conducted at an undistorted scale of 1:45 for the 16-sec, 40-ft wave condition at a swl of +16.3 ft mlw (condition for which model tests had already determined that unbroken 37-ton dolosse were completely stable on the trunk section of the structure, see Photograph 1). Using the unbroken unit test results as a base condition, up to 25 percent (in 5-percent increments) of the top layer of dolosse were broken and uniformly distributed (represents random breakage) over the test section.

The test section was constructed in the model in the same manner as two-layer unbroken unit test sections were constructed, which on the average requires about 55 percent of the total number of dolosse in the bottom layer and about 45 percent in the top layer. Once the unbroken unit test section was completed and the number of dolosse in the top layer determined, the number of broken dolosse specified for that test was determined and randomly placed in the top layer by removing an unbroken dolos and dropping a whole dolos in two parts in its place. Individually broken dolosse were never represented by more than two pieces. It is believed the model procedures used yield conservative results, since the disruptive action of replacing the unbroken armor unit with pieces does not occur in the prototype (i.e., most unbroken armor units simply break in place). Tests of each percent broken dolosse were conducted at least twice and sometimes three times with each repeat test verifying the original results. Test waves for all the tests were monochromatic and were subjected on the test sections in specific cycles (i.e., given time duration of about 30-sec increments with about 7-10 minutes between cycles to eliminate wave reflection effects). Each breakwater section was tested until stabilization (no progressive damage with time) or until damage had progressed to an unacceptable level.



Photograph 1. Test section of whole dolosse after testing with a design condition of 16-sec, 40-ft waves at a swl of +16.3 ft mlw.

Results

Observed results of the 5 and 10 percent broken unit tests indicated that individual dolosse were not displaced or did not move in place any more than that which occurred with a test section of whole dolosse. Photograph 2 shows an after testing view of a test with 10 percent of the top layer of dolosse broken and uniformly distributed (dots on the photo represent the breakage density). Tests with 15 percent of the top layer of dolosse broken indicated that there was a slight readjustment of a few of the units in the top layer of dolosse (Photograph 3). This readjustment was not significant to the overall stability, but one could tell some renesting had occurred. It is believed that 15 percent uniform breakage is the upper limit in which this type breakage can be allowed without initiating small areas of spot damage. After testing, results of the tests with uniform breakage of 20 percent (Photograph 4) and 25 percent (Photograph 5) substantiates this belief in that spot damage tends to increase with breakage above the 15 percent level. During the 5 to 15 percent uniformly distributed broken dolos tests, it was observed that the individual broken pieces of dolosse were not significantly displaced up and down the slope but tended to nest into the void areas nearest their initial position. As the broken percentage increased (20-25 percent breakage), the half pieces reached such numbers that they began to break down the interlocking characteristics of the whole units and displacement of both the whole and half dolosse was more evident.

Extreme Wave Conditions, Uniform Breakage

The second set of two-dimensional broken dolos tests, in which only 10 and 15 percent of the top layer of dolosse were broken and uniformly distributed, were conducted at the 1:45 scale to compare with the same basic armor protection provided in test series one (whole 37-ton dolosse) but with an extreme storm condition* of 15-sec, 48-ft waves at a swl of +27.4 ft mlw. In this series, both the whole dolos and uniformly distributed broken dolos tests accrued a higher degree of damage than test series one (16-sec, 40-ft waves), but neither progressed beyond repairable damage.

Results

Photographs 6, 7, and 8, respectively, show a whole dolos test section, a test section with 10 percent of the top layer broken and uniformly distributed, and a test section with 15 percent of the top layer broken and uniformly distributed after testing with the extreme wave conditions. Again, the results show that uniformly distributed breakage up to about 15 percent of the top layer of dolosse did not show significant change in stability relative to that for unbroken units.

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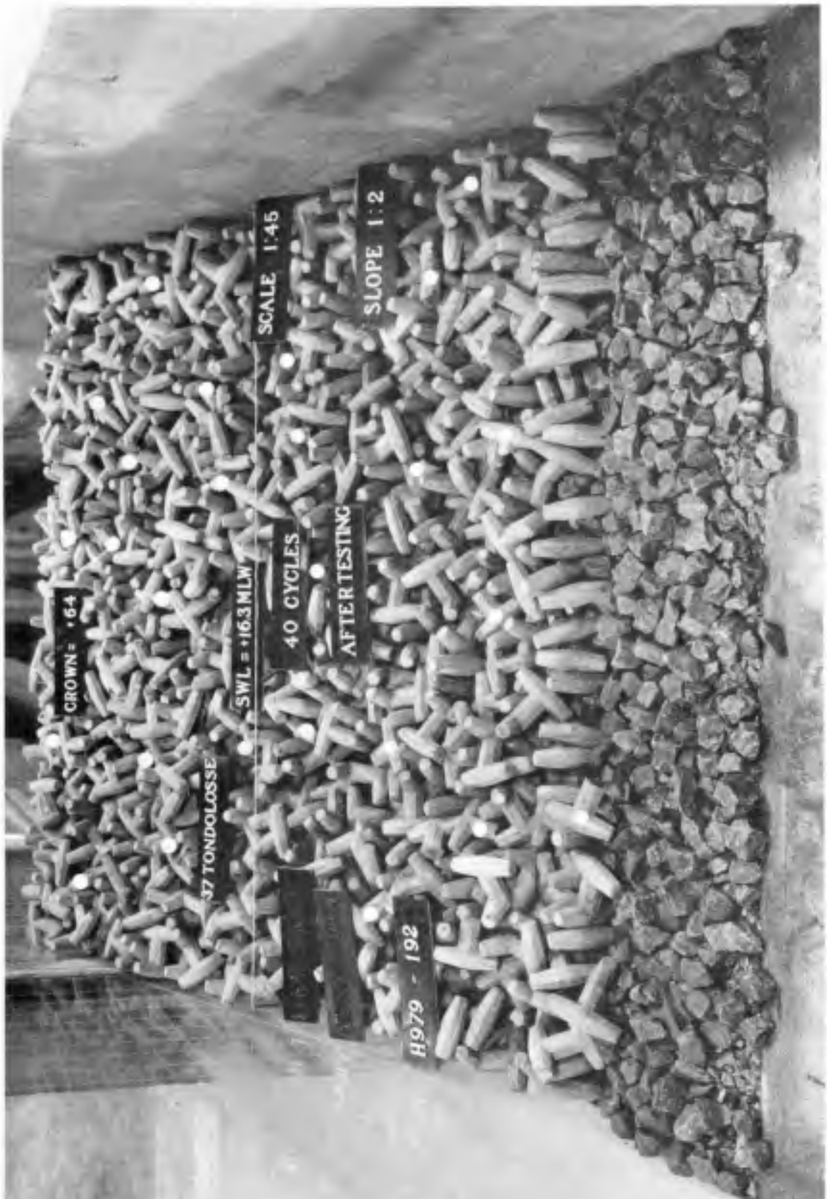
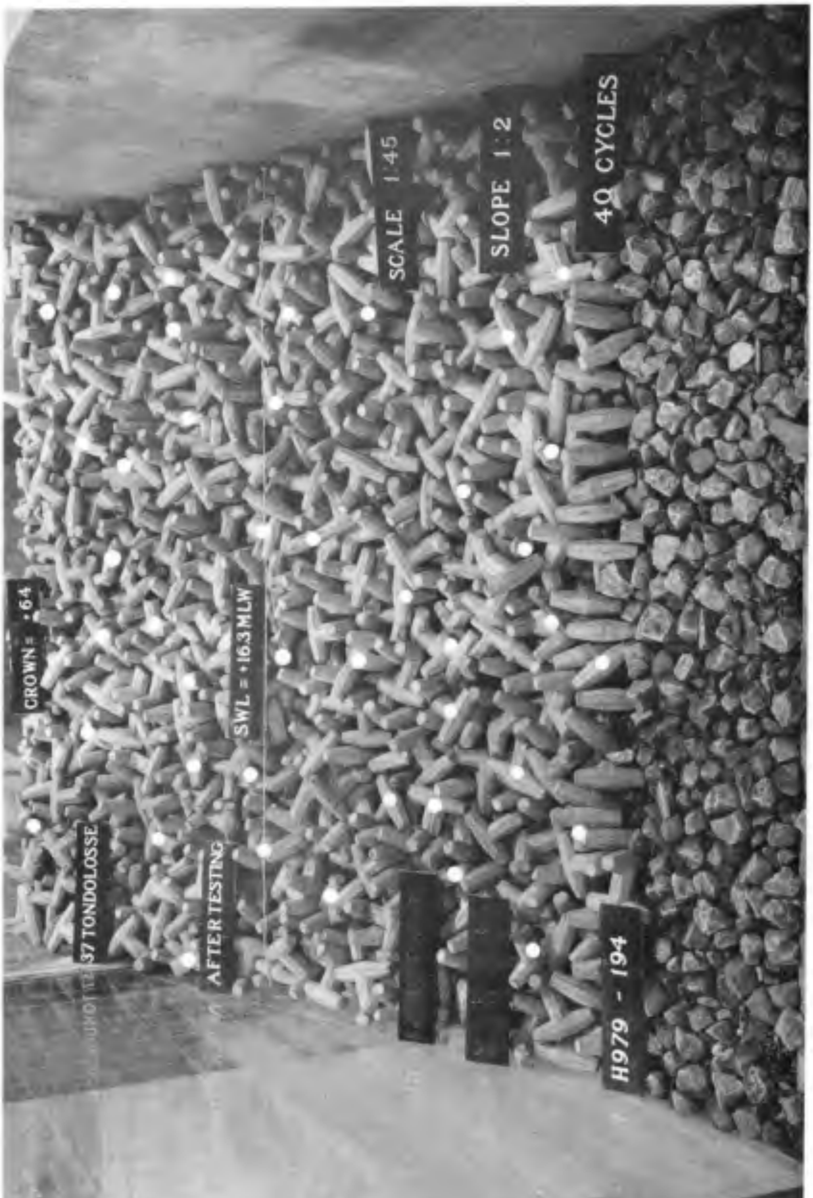
* The extreme wave condition described herein was a first estimate of a Probable Maximum Hurricane that could occur in this area but was deemed unreasonably high and subsequently has no relation on the selection of the final design condition.

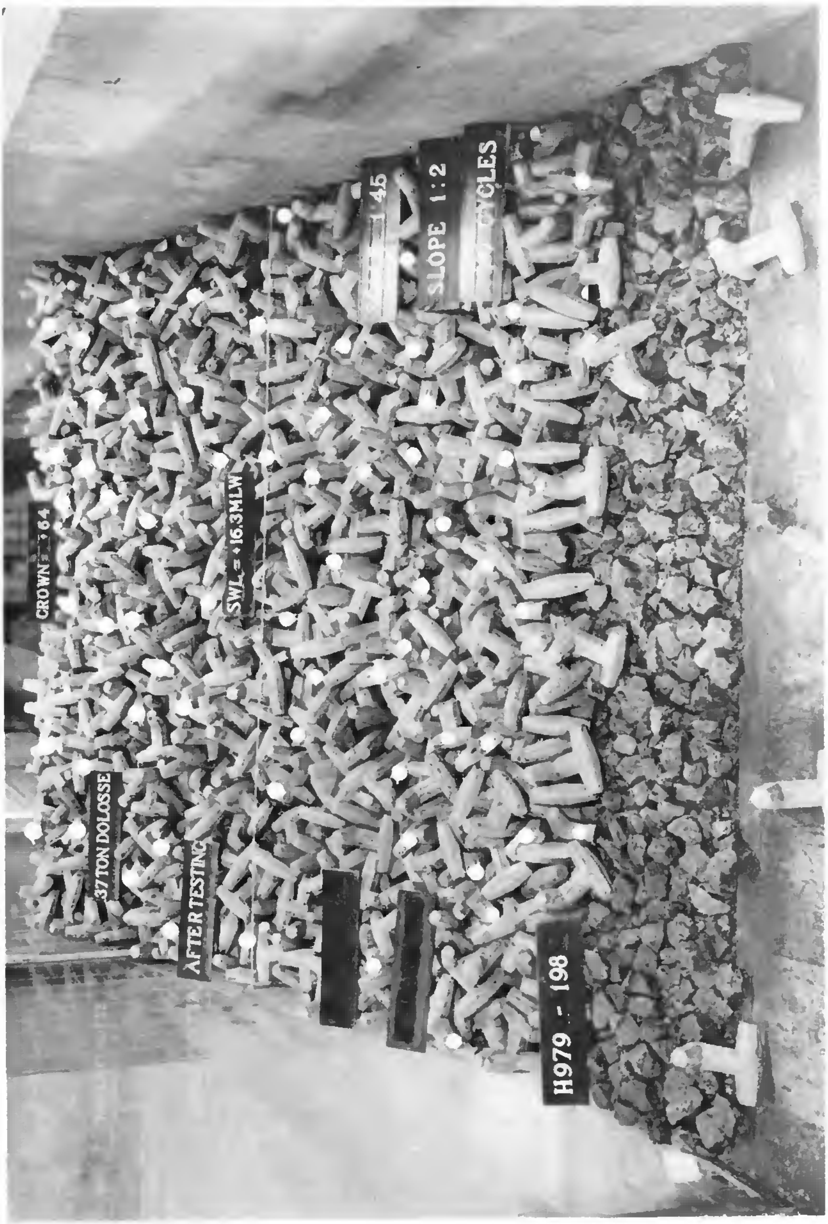


Photograph 2. Test Section with 10 percent of the top layer of dolosse broken and uniformly distributed after testing with a design condition of 16-sec, 40-ft waves at a swl of +16.3 ft mlw.

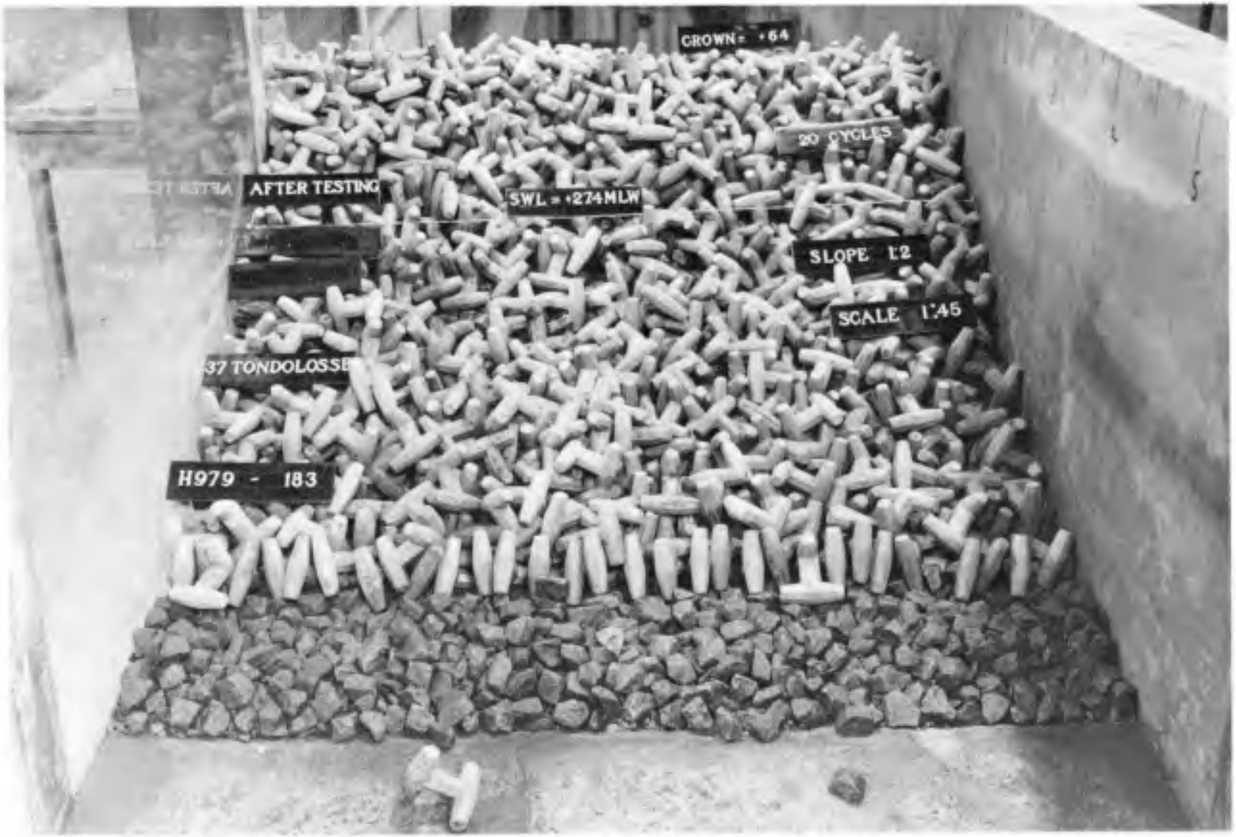


Photograph 3. Test section with 15 percent of the top layer of dolosse broken and uniformly distributed after testing with a design condition of 16-sec, 40-ft waves at a swl of +16.3 ft mlw.

Photograph 4. Test section with 20 percent of the top layer of dolosse broken and uniformly distributed after testing with a design condtion of 16-sec, 40-ft waves at a swl of +16.3 ft mlw.



Photograph 5. Test section with 25 percent of the top layer of dolosse broken and uniformly distributed after testing with a design condition of 16-sec, 40-ft waves at a swl of +16.3 ft mlw.



Photograph 6. Test section of whole dolosse after testing with an extreme wave condition of 15-sec, 48-ft waves at a swl of +27.4 ft mlw.

Photograph 7. Test section with 10 percent of the top layer of dolosse broken and uniformly distributed after testing with an extreme wave condition of 15-sec, 48-ft waves at a swl of +27.4 ft mlw.

Photograph 8. Test section with 15 percent of the top layer of dolosse broken and uniformly distributed after testing with an extreme wave condition of 15-sec, 48-ft waves at a swl

Extreme Wave Conditions, Cluster Breakage

Since prototype armor breakage could occur in concentrated numbers as well as ramdomly, two-dimensional tests of the extreme wave condition were extended to include units broken in clusters. These tests consist of 10, 5, and 3 dolos units broken in a cluster. For each set of cluster breakage, individual broken clusters were positioned on the structure at the swl, about halfway between the swl and the toe of the structure, and about halfway between the swl and the structure crown (Photograph 9). Similar to the uniform breakage construction procedure, it is believed these tests present a certain amount of conservatism since the test sections were constructed with unbroken dolosse, then for each cluster the respective number of dolosse were removed through both layers and the correct number of broken dolosse dropped into the hole. Even though this was done as gently as possible, these procedures could not help but disrupt the interlocking action of the armor units.

Results

Results of this type of cluster breakage indicate that clusters of 10 broken units would allow deterioration of the cover layers (Photograph 10, dashed circles represent initial positions of clusters) and could, with extended storm duration, cause major damage that might or might not be repairable. The results of tests using the 5 broken unit clusters also indicate deterioration (Photograph 11); however, it is not as severe and takes longer for the damage to occur, thus the more likelihood the area influenced by the cluster breakage can readjust to interlocking. During the 5 and 10 broken unit cluster tests, the failure of the breakage area seemed to occur in the following manner. The first few waves settled the broken units into rather tight clusters and the unbroken dolosse surrounding the clusters did not have any place to interlock; consequently, the unbroken dolosse around the clusters were displaced. This caused a loosening of the armor units in the area of the cluster until such time that the broken units had no "pocket protection" and were themselves displaced, which added to deterioration of the cover layer. Test results for the cluster of 3 broken units (Photograph 12) do not show this characteristic; and, in fact, indicate that clusters with three broken units are similar in stability to that of the unbroken dolos tests.

Three-Dimensional Model Tests

Extreme Wave Conditions, Uniform Breakage

Although the data are limited, a three-dimensional stability test (waves at an angle of 60 degrees to the trunk and end portions of the breakwater) using 15 percent of the top layer of dolosse broken and uniformly distributed was conducted at a 1:55 scale to compare with the results of similar unbroken unit tests. This particular test, which was conducted twice, used 62-ton dolosse on the heads of the breakwater which had been determined by previous tests to meet the no-damage stability criterion for the normal design condition (16-sec, 40-ft waves). As

Photograph 9. Test section indicating the positioning of the cluster breakage used in the two-dimensional tests.

Photograph 10. Test section with 10-unit clusters broken after testing with an extreme wave condition of 15-sec, 48-ft waves at a swl of +27.4 ft mlw.

Photograph 11. Test section with 5-unit clusters broken after testing with an extreme wave condition of 15-sec, 48-ft waves at a swl of +27.4 ft mlw.

Photograph 12. Test section with 3-unit clusters broken after testing with an extreme wave condition of 15-sec, 48-ft waves at a swl of +27.4 ft mlw.

indicated earlier, it was expected that both the whole dolos test section and the 15 percent broken unit test section would sustain damage for the extreme wave condition (Photographs 13 and 14, respectively). However, the point to be made is that the results show that similar damage occurred for both the broken unit condition and the whole unit condition. This is in agreement with the two-dimensional tests and indicates that if the breakage is uniformly distributed, up to 15 percent of the top layer of dolosse can be broken without having a detrimental stability effect over that obtained using unbroken units under similar conditions.

Conclusions

Based on the findings of this study, it is concluded that:

a. Concentrations of broken dolosse are more detrimental to stability of the breakwater against wave attack than uniform or random breakage.

b. If the uniform or random breakage exceeds 15 percent of the number of dolosse in the top layer and the cluster breakage exceeds 3 dolosse in a cluster, the stability of the breakwater will be less than that exhibited by a breakwater composed of unbroken dolosse.

c. For the type of movement indicated by the no-damage criterion used in this study, the value of using reinforcing steel to reduce potential breakage of armor units is highly questionable.

Acknowledgments

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Photograph 13. Three-dimensional test section of whole units after testing with an extreme wave condition of 15-sec, 48-ft waves at a swl of +27.4 ft mlw.

Photograph 14. Three-dimensional test section with 15 percent of the top layer of dolosse broken and uniformly distributed after testing with an extreme wave condition of 15-sec, 48-ft waves at a swl of +27.4 ft mlw.