STABILITY EFFECTS OF CUBE ARMOR UNIT PLACEMENT CONFIGURATIONS IN THE BERM OF A BREAKWATER

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For the sake of overtopping, stability and economy, rubble mound breakwaters have been built with a berm in the seaward slope. Here, a breakwater model with cube armour units in the lower slope and a horizontal berm, and rock in the upper slope was tested experimentally. The purpose of the study was to investigate the stability of berms for two different configurations of the transition of armor units from the lower slope to the berm. Based on the test results, an effective configuration of cube units at the transition has been obtained.

Keywords: rubble mound breakwater; berm; cube armour unit; breakwater stability; lower slope stability; berm transition

INTRODUCTION

It has been stated that rubble mound breakwaters with a berm are more effective in increasing the stability of the breakwater armor layer, and increasing safety and economy compared to conventional breakwaters. Breakwaters with a berm can significantly reduce overtopping and the required rock size compared to straight slopes without a berm. However, potential damage to the transition from the lower slope to the berm plays a very important role for the stability of this kind of structures.

Berm breakwaters have been introduced in the early 1980s as mass armored reshaping structures, where the wave action causes that the structures reshapes into a more favorable S-shape. Lately, the multi-layered less reshaping structures known as the Icelandic type, have become popular. Berm breakwaters are divided into different categories depending on the reshaping and on the construction method. PIANC (2003) gave a classification only on the reshaping behavior. Van der Meer and Sigurdarson (2017) have introduced a classification of berm breakwaters partly based on their structural behavior, such as hardly reshaping, partly reshaping, and fully reshaping.

In Van Gent (2013), rubble mound structures that consist of a rock armoured slope have been analysed in detail and the design formulas for (non-reshaping or hardly reshaping) mass armour type breakwaters with a berm were given.

If, however, the required armour size is too large to use available rock, concrete armour units in the lower slope may be an option for mass armour type breakwaters with a berm. Various types of concrete armour units may be considered to be used in the lower slope like for instance tetrapodes and cubes, and they are relatively easy to construct. However, cubes in an armour layer of rubble mound breakwaters may be more feasible and potentially economically competitive compared to other types of armour layers.

Another advantage of a berm in the seaward slope is that relatively small material may be used in the upper slope. Moreover, Van Gent (2013) recommended using a combination of concrete units such as cubes in the lower slope and rock in the upper slope to increase the strength and investigate the influence of a berm on the stability of the structure in which rock in the upper slope and concrete armour units in the lower slope and berm (see also Van Gent and Van der Werf, 2017).

Although the cube is one of the oldest armour units among the many other concrete armor units, they are still being used for breakwaters all over the world.

Frens et al. (2008) studied the impact of different placement methods, with different packing densities, on the stability of Antifer-block armour layers for conventional breakwaters. They found that regular placement methods were more stable than irregular placement methods for similar packing densities. They concluded the double pyramid placement method for packing densities around 55% and 60% was the best performing placement method.

In the present study cube armour layers have been tested in the lower slope and the berm but with rock in the upper slope. A double pyramid placement method has been chosen for the cube armour units with a packing density of 57%.

Double pyramid placement method (Frens et al., 2008) has been slightly changed in this study, and the stability has been tested. However, this study focused on the design of a placement configuration in the transition from the lower slope to the berm with open and closed transitions (Figure 1).

EXPERIMENTAL SETUP AND PROCEDURES

An experimental research was carried out in the wave flume of the Coastal and Harbor Engineering laboratory at the Yıldız Technical University. The flume has 26 m in length, 1 m in width and 1 m in

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depth. The channel is equipped with a piston type wave generator that has an active reflection compensation system.

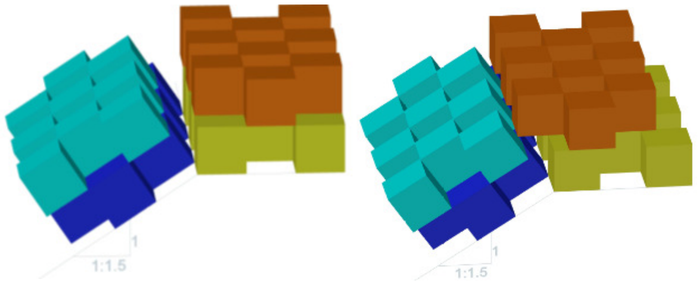


Figure 1. Transition configurations of lower slope and berm. (a) Case 1 Open transition, (b) Case 2 Closed transition.

A cube armor unit breakwater model with a horizontal berm for a trunk section was tested for determination of stability of the berm for two different configurations of the transition from the lower slope to the berm (Figures 2 and 3). The breakwater model was placed on a horizontal foreshore. The nominal diameter of the cubes at the 1:1.5 lower slope and at the berm was 40 mm. For the 1:2 upper slope, the size of the rock in the armour layer was D_{n50}= 32.5 mm. The underlayer consisted of stones with a nominal diameter of 19 mm. The packing density of the blocks was 57% by using the double pyramid placement method. The berm width was $4D_{n.}$ Three different water depths of 0.45, 0.55 and 0.65 m were studied to reflect the effect of position of the berm with respect to still water level.

A total of 11 irregular wave conditions with a JONSWAP spectrum were selected for the tests. Wave conditions were measured at six different locations. One wave probe was placed in front of the structure toe, one was close to the wave board and four were in constant water depth with known spacing to determine reflections.

Before each test series the structure was rebuilt. The blocks and the rocks were placed by hand. Each test run consisted of about 1000 waves. Damage was cumulative for each test series. Damage was determined by using a visualization technique; before and after each run digital photos were taken from a fixed location perpendicular to the slope. Damage was determined by counting the moved armor units and measuring the movement distance.

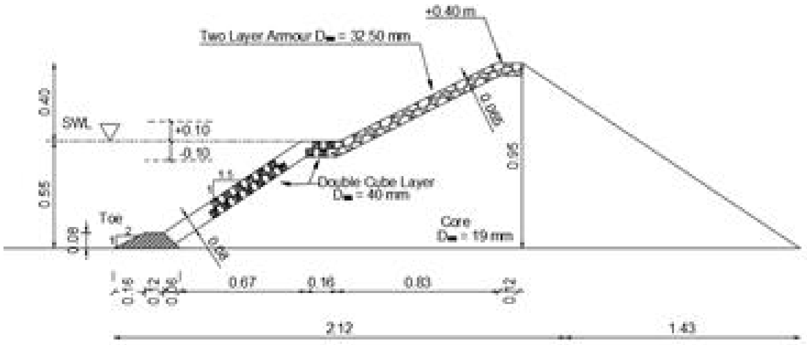


Figure 2. Model set-up

The damage ratio was calculated with the equation given below:

$$\text{Damage Ratio}=\frac{\text{Number of displaced units}}{\text{Total number of units within reference area}} \tag{1}$$

To determine the damage ratio, the reference area should be defined because the displaced units are not uniformly distributed over the slope. In addition to this, a larger reference area results in a lower damage ratio. So, the selection of reference area is a sensitive point for analyzing the stability. The reference area should be defined as the area between two levels. By considering these important issues, for emerged berm tests, the reference area was chosen as the area between $+4D_n$ above the still water level and -6D_n below the still water level by considering the largest wave height used in this study. For submerged berm and the berm at SWL, the reference area was kept constant as -10D_n since the water level is above the berm level for these cases. The damage ratio was classified as D_1, D_2, and D_T which represent displacements between 1 and 2D_n, above 2D_n, and above 1D_n, respectively. Hence, D_T indicates all displaced cubes (total displacement).

Between each sea state damage was not repaired, so the damage ratio after each sea state is the cumulative damage.

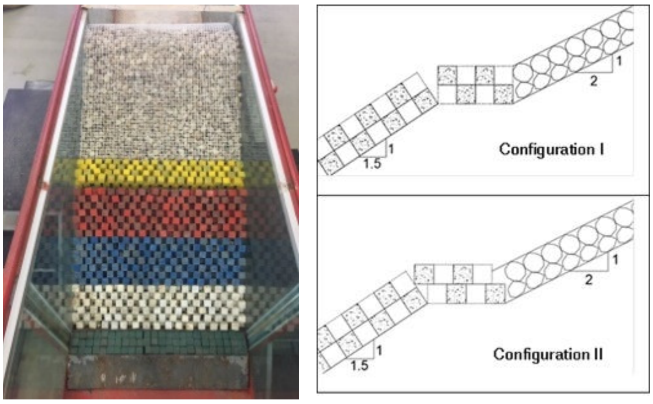
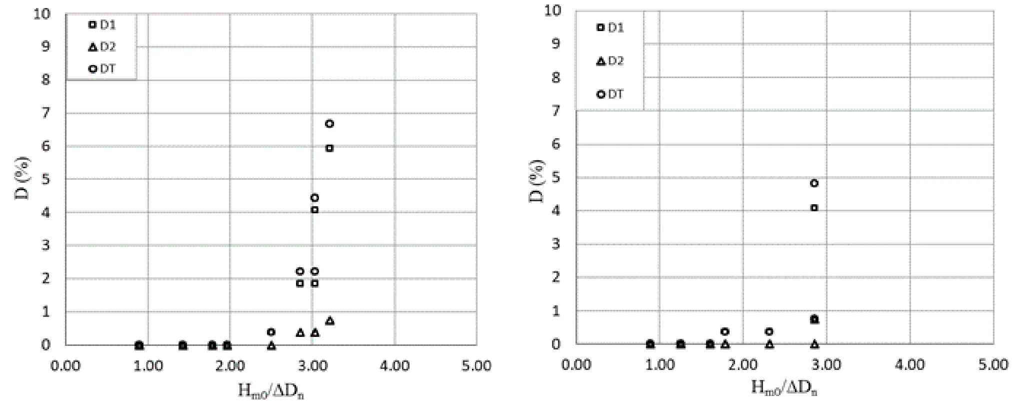


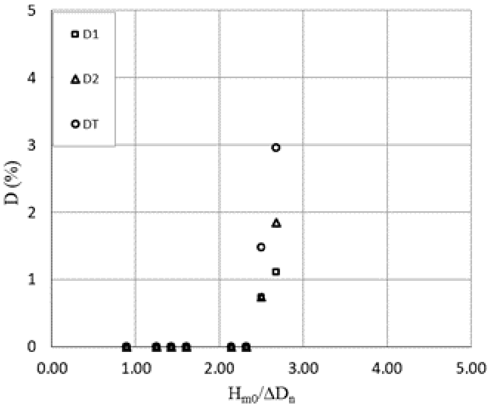
Figure 3. A view from the model and the placement configurations

DISCUSSION of the RESULTS

The variations of damage ratio versus stability parameter for two different cases as open transition and closed transition for a berm width of 4D_n are shown in Figures 4 and 5, respectively.

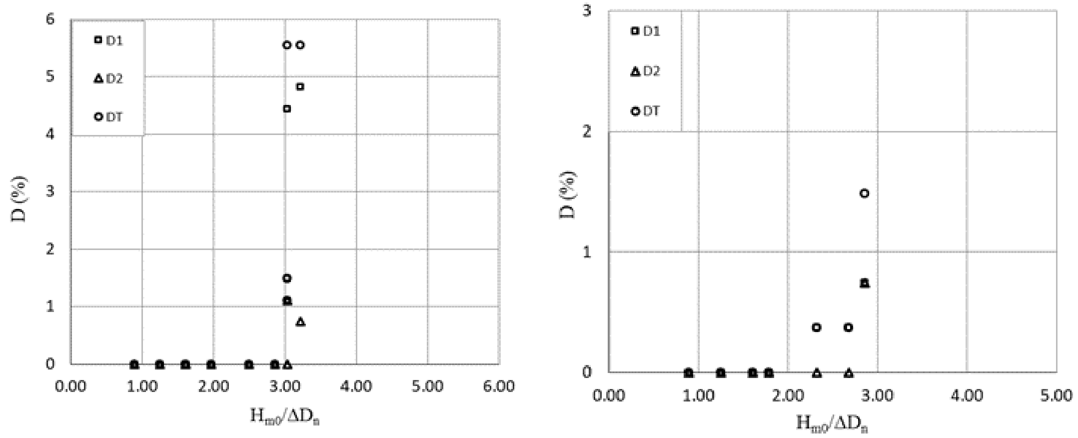


(a) Emerged berm (b) Berm at SWL



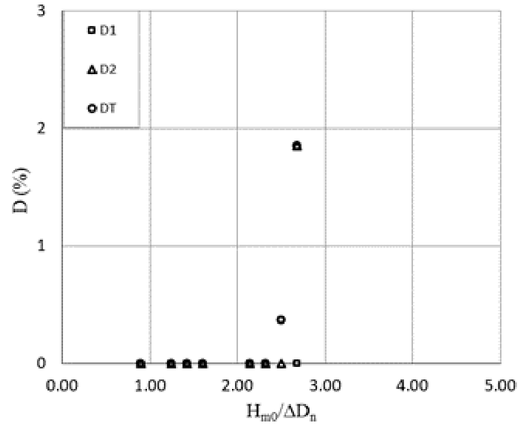
(c) Submerged berm

Figure 4. For Open Transition Case, variation of the damage ratio with stability parameter



(a) Emerged berm

(b) Berm at SWL



(c) Submerged berm

Figure 5. For Closed Transition Case, variation of the damage ratio with stability parameter

Figure 4 and 5 show that for Case 1 (open transition), displacements of more than 1% occur roughly when the stability number, $^{H_{m0}}/_{\Delta D_n}$ exceeds 2, 1.6 and 2.3 for emerged berm, berm at SWL and submerged berm, respectively. For Case 2 (closed transition), more than 1% displacements were roughly at stability numbers larger than 2.8 for emerged berm, larger than 1.8 for berm at SWL, and larger than 2.3 for submerged berm.

Here, displacement is defined as the movement of a block more than the distance D_n. For the movements less than D_n, our observations show that start of movement occur roughly when the stability number exceeds 0.8 and 1 for open and closed transition cases, respectively. For higher values of $^{H_{m0}}/_{\Delta D_n}$, highest movements were observed for the emerged berm, lowest movements were observed for the submerged berm.

These results suggest that, in general, the Case 2 transition is about 10-20% stronger than the Case 1 transition. The transition between lower slope and berm mostly controls the lower slope stability especially for the emerged berm conditions because the incident waves directly interact with the transition region.

The double pyramid placement is a regular placement method, and therefore the displacement of one block causes a chain reaction. However, in our observations, the displaced cubes mostly stayed in the slope and still contributed to the strength. Only a few cubes extracted from the slope during the tests.

CONCLUSION

The presence of a berm increases the stability of the upper slope, but not significantly for the lower slope (Van Gent¸ 2013). In this study, cube armour units with a regular placement (double pyramid) are chosen in the lower slope and the berm to increase the stability. The placement method of cube armor units at the transition from the lower slope to the berm is shown to be very effective for the stability of cube armored breakwaters with a berm. During the experimental tests, damage starts at the transition from the lower slope to berm in the breakwater. Closed lower slope-berm transition placement configurations behave more stable than the open transition in terms of both movement and displacement. The berm location with respect to the still-water level (SWL) was also found to be an important factor in terms of berm and lower slope stability. The most unsuitable condition regarding stability was for configurations with the berm is at SWL. The structure is more stable for the emerged berm than for the submerged berm.

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