An Investigation on the Stability of Rubble Mound Breakwaters with Armour Layers of Antifer Cubes

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Abstract

This paper presents the results of hydraulic model tests on the stability of rubble mound breakwaters with armour layers of antifer cubes. The tests were performed using irregular waves. The effect of wave parameters and the structure slope on the stability of these artificial armour units has been investigated and the stability formulae have been derived. Finally a comparison between these formulae and the stability relationships derived by van der Meer (1988) for cubes has been made.
Keywords: Rubble Mound Breakwaters, Stability, Antifer Cubes, Physical Modelling

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Introduction

A rubble mound breakwater is composed of several layers of random shaped and random-placed stones, protected with a cover layer of selected armour units of either quarry stone or specially shaped concrete units. The relationship between wave parameters and the weight of armour units in rubble mound breakwaters has been the subject of a large number of experimental studies over many years.

Edge et al (1993) reviewed the evolution of breakwater design. According to Edge et al, the major breakthrough for design of rubble mound breakwaters occurred during the period called the Iribarren and Hudson Era. In this era, a direct relationship was developed to link the weight or size of the armour unit to the incident wave characteristics and specifications of the

Iribarren (1938) presented the following formula for the weight of the armour stone:

$$W = \frac{N S_r H_D^3}{(\tan\theta\cos\alpha - \sin\alpha)^3 (S_r - 1)^3} \qquad (1)$$

where:

$N =$ stability coefficient
$H_D =$ design wave height
$S_r =$ specific gravity of stone (in metric tons per cubic meter)
$\alpha =$ angle of the front face of the structure with the horizontal
$\theta =$ angle of repose of the stones

Following Iribarren, comprehensive investigations were made by Hudson and a formula was developed to determine the weight of armour units (U. S. Army Corps of Engineers, 1958):

$$W = \frac{\rho_r H_D^3}{K_D \Delta^3 \cot\alpha} \qquad (2)$$

where:

$K_D =$ stability coefficient

$\Delta =$ relative buoyant density of armour unit $(\Delta = \rho_r / \rho_w - 1)$

$\rho_r =$ mass density of armour unit (saturated surface dry density)

$\rho_w =$ mass density of water

Hudson's formula has some limitations. For example the effects of wave period and storm duration have not been considered in this formula.

Van der Meer (1994) carried out an extensive research program on the stability of rubble mound structures and derived the following formulae:

i) for plunging waves:

$$\frac{H_s}{\Delta D_{n50}} = 6.2 P^{0.18} \left(\frac{S}{\sqrt{N}}\right)^{0.2} \xi_m^{-0.5} \qquad (3)$$

ii) for surging waves:

$$\frac{H_s}{\Delta D_{n50}} = 1.0 P^{-0.13} \left(\frac{S}{\sqrt{N}}\right)^{0.2} \sqrt{\cot\alpha}\ \xi_m^{P} \qquad (4)$$

The transition from plunging to surging waves can be calculated using a critical value of ξ_{mc}:

$$\xi_{mc} = \left(6.2 P^{0.31} \sqrt{\tan\alpha}\right)^{\frac{1}{P+0.5}} \qquad (5)$$

where:

$D_{n50} =$ nominal diameter of armour stone $(D_{n50} = M_{50} / \rho_r)^{1/3}$

$M_{50} =$ mass of unit given by 50% on mass distribution curve

$H_s =$ significant wave height

$P =$ notional permeability factor, defined by Van der Meer

$S =$ dimensionless damage ($S = A_e / D_{n50}^2$)

$A_e =$ erosion area on profile of the structure around still water level

$N =$ number of waves in a storm

Van der Meer (1988) has also carried out a series of hydraulic model tests to derive the stability formulae for rock, cubes, tetrapods and accropodes. His research, however, was limited to only one cross-section (i.e. one slope and permeability) for each armour unit. Thus the effect of the surf similarity parameter (ξ_m) was not included in the design formulae.

Van der Meer (1988) described the damage to concrete units by the N_{od} and N_{omov} parameters. N_{od} is the actual number of displaced units related to a width (along the longitudinal axis of the breakwater) of one nominal diameter, D_n (Van der Meer, 1994). N_{omov} is the number of moving units.

The formulae for cubes are given by:

$$\frac{H_s}{\Delta D_n} = \left(6.7 \frac{N_{od}^{0.4}}{N^{0.3}} + 1.0\right) s_{om}^{-0.1} \qquad (6)$$

$$\frac{H_s}{\Delta D_n} = \left(6.7 \frac{N_{omov}^{0.4}}{N^{0.3}} + 1.0\right) s_{om}^{-0.1} - 0.5 \qquad (7)$$

where:

$s_{om} =$ wave steepness for mean period ($s_{om} = 2\pi H_s / g T_m^2$)

$g =$ gravitational acceleration

$T_m =$ mean wave period

Antifer cubes have been used as armour layer of rubble mound breakwaters in I R of Iran and other countries. For example, the breakwaters of Chabahar and Southern Pars Petrochemical and Service Ports have been covered by these cubes.

Günbak (1999) presented a summary of the antifer cube applications around the world in a comparison bases with respect to design stability number (K_D) used in the Hudson's formula. However, as mentioned before, this formula has some limitations. Moreover, the stability formula for antifer cubes is not included

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in the set of relationships derived by Van der Meer (1988) for concrete armour units.

In this paper, the effects of wave characteristics (i.e. wave height, wave period, and storm duration) and the slope of the structure on the stability of rubble mound breakwaters with armour layers of antifer cubes against random waves are considered and a new set of formulae is presented to calculate the weight of antifers. It should be mentioned that the effects of wave period and storm duration have not be considered in the previous studies on the stability of antifer cubes.

Set-up of Experiment

The laboratory tests were performed in the 33 m length, 5.5 m width and the 1.5 m height of the wave flume of Shore Protection Section of Soil Conservation & Watershed Management Research Institute (SCWMRI), the Ministry of Jihad-e-Agriculture, I R of Iran. The wave flume is equipped with a piston type wave maker capable of operating in a regular and irregular mode. The flume is divided into three parts (figure 1). The tests were carried out in the middle part of the wave flume, using irregular waves. The cross sections of the wave flume and the structure are shown in figures (2) and (3), respectively.

The wave profiles were measured by using four wave height meters installed in situations shown in figure (1). Goda's technique was used to calculate the wave reflection coefficients. Shingle slopes were employed to dissipate the incident wave energy at the end of the wave flume. The slope of these absorbers is 1:8.

The significant wave height ranged from 4.5 to 15 cm and the periods applied were: T_m = 1.4, 1.75, 2.11 and of wave heights and periods, it may be concluded that a wide range of wave steepness in nature has been covered. Each complete tests consisted of a pre-test sounding, a test of 1000 waves, the second sounding, a test of 2000 waves, the third sounding, a test of 3000 waves, a final sounding.

The slope of the structure were 1:1.5 and 1:2. The second slope was selected to investigate the effect of the surf similarity parameter (ξ_m) on the stability of antifers.

The water depth in front of the wave paddle and the structure were 40 and 24.6 cm, respectively. A JONSWAP type spectrum was used to generate the random waves. Totally 129 tests were performed.

Experimental Results and Discussions

The results of the experimental tests for the structures built with slopes of 1:1.5 and 1:2 are depicted in figures (4) and (5) respectively. These figures show the variations of N_{od} and N_{omov} versus the stability number. This number is defined as follows:

$$N_s = \frac{H_s}{\Delta D_{n50}} \tag{8}$$

N_{od} and N_{omov} were determined using Van der Meer 's definitions discussed in introduction section, and the photos were taken and video camera films were recorded during the laboratory tests.

Considering the number of waves (storm duration), the experimental results showed that the influence of storm duration is negligible for the no-damage criterion. However, when some damaged is considered, the damage becomes a function of the storm duration.

Figure (6) depicts variations of the stability number against the wave steepness for mean wave period. This figure was plotted using Excell software. Due to the large number of data, these data have not been shown on the figure. This figure shows a slight effect of the wave period on the stability of antifer cubes, so that, by increasing the wave period, the stability is increased. The same result was obtained by Van der Meer (1988) on rock slopes and cubes.

The experimental tests showed that the stability number of antifer blocks can be determined from the following formulae:

i) cot α = 1.5

$$\frac{H_s}{\Delta D_n} = (6.951\frac{N_{od}^{0.443}}{N^{0.291}} + 1.082)\, s_{om}^{-0.082} \quad (9)$$

$$\frac{H_s}{\Delta D_n} = (6.951\frac{N_{omov}^{0.443}}{N^{0.291}} + 1.082)\, s_{om}^{-0.082} - 0.5 \quad (10)$$

$$R^2 = 0.994$$

ii) cot α = 2

$$\frac{H_s}{\Delta D_n} = (6.138\frac{N_{od}^{0.443}}{N^{0.276}} + 1.164)\, s_{om}^{-0.07} \quad (11)$$

$$\frac{H_s}{\Delta D_n} = (6.138\frac{N_{omov}^{0.443}}{N^{0.276}} + 1.164)\, s_{om}^{-0.07} - 0.5 \quad (12)$$

$$R^2 = 0.992$$

Considering the surf similarity parameter (ξ_m), the stability formulas for both slopes can be given by:

$$\frac{H_s}{\Delta D_n} = (5.886\frac{N_{od}^{0.502}}{N^{0.268}} + 1.449)\, \xi_m^{0.065} \quad (13)$$

$$\frac{H_s}{\Delta D_n} = (5.886\frac{N_{omov}^{0.502}}{N^{0.268}} + 1.449)\, \xi_m^{0.065} - 0.5 \quad (14)$$

$$R^2 = 0.984$$

Formulae (9) to (14) were derived using SYSTAT software. The square of correlation coefficient obtained from each nonlinear regression has been written after each set of equations. These coefficients show that the presented formulae are quite reliable.

Figure (7) compare the results of the present study and the stability formula derived by Van der Meer (1988). This figure shows that the antifer cubes are more stable than the ordinary cubes. The increasing of the stability is due the specific geometry of this kind of cube, which provides a more porous media for dissipation of wave energy in comparison with the ordinary cube.

Conclusion

A series of laboratory tests were performed to study the stability of rubble mound breakwaters with layers of antifer cubes. The effects of wave period, wave height, storm duration, density of armour unit, and the structure slope on the stability of these units were examined.

The results of tests showed that the storm duration and the wave period affect the stability of antifer cubes. Therefore, the weight of this kind of armour units against random wave attack can be calculated using the new set of equations presented in the previous section.

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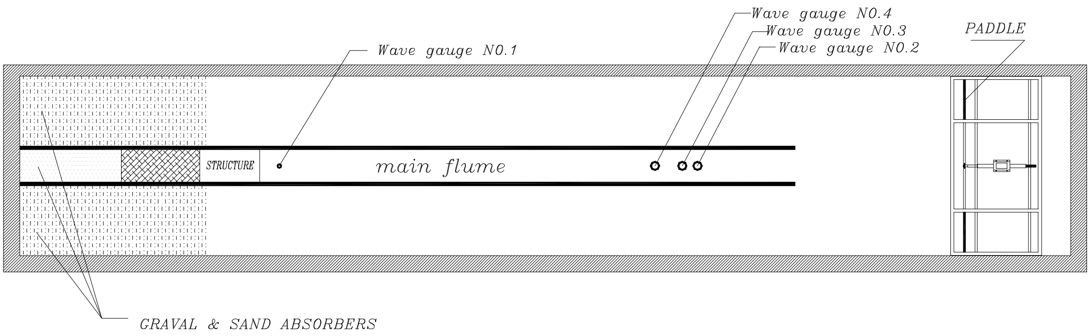

Fig. 1 - Plan view of wave flume and setup of wave height meters

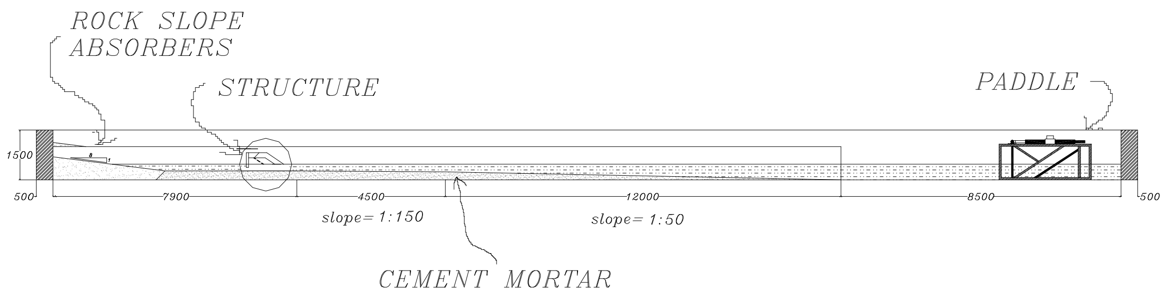

Fig. 2 - Cross section of wave flume

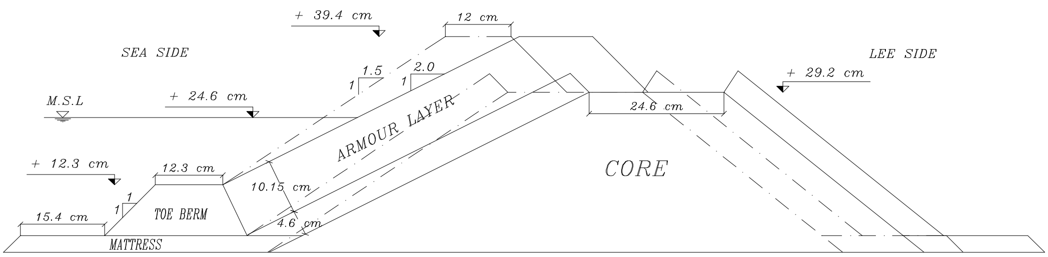

Fig. 3 - Tested Cross sections (slope = 1:1.5 & 1:2)

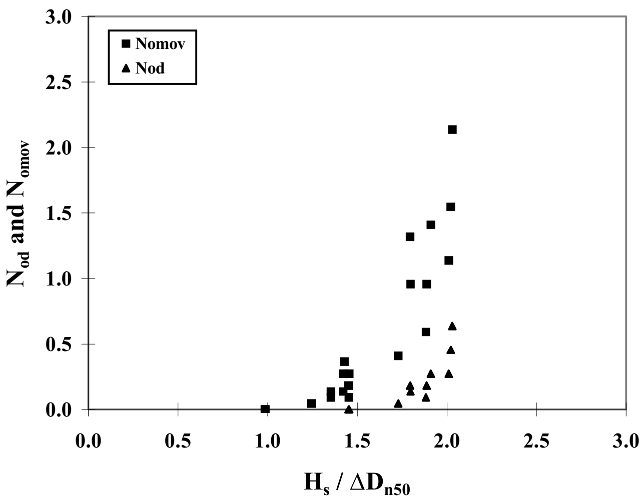

Fig. 4 - ***N_{od}*** **and** ***N_{omov}*** **versus the stability number (cotα = 1.5)**

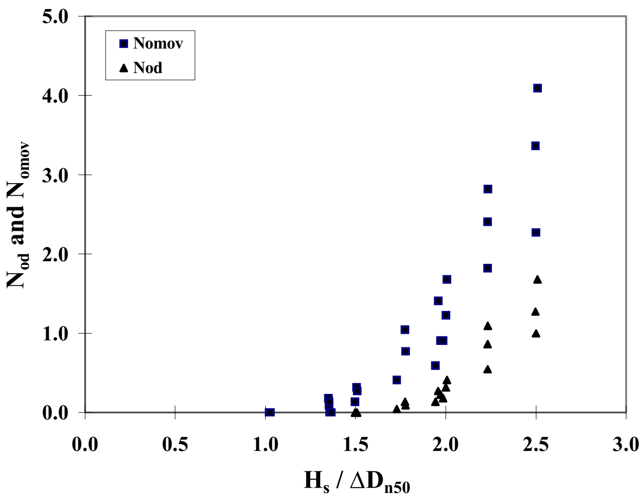

Fig. 5 - ***N_{od}*** **and** ***N_{omov}*** **versus the stability number (cotα = 2.0)**

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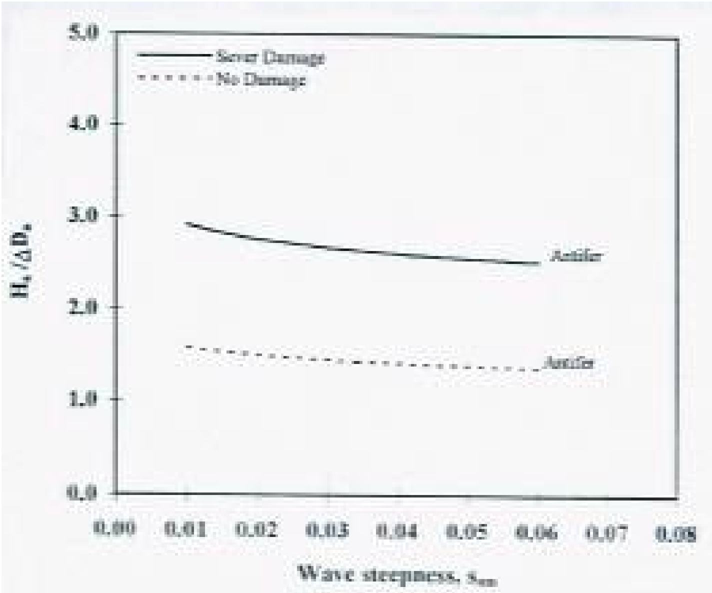

Fig 6- The stability number versus the wave steepness for mean period

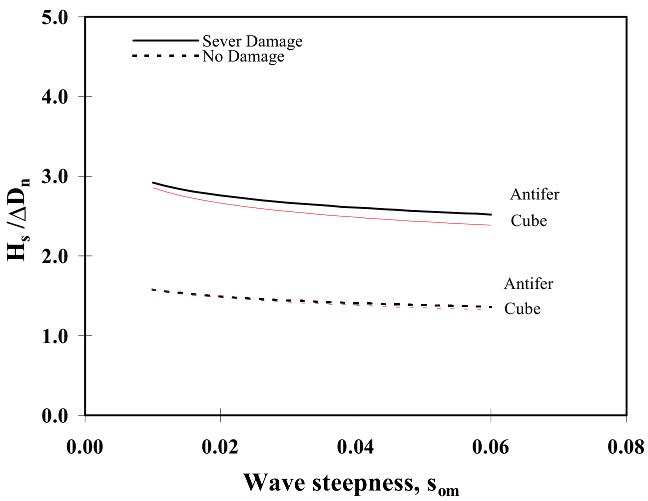

Fig. 7 - Comparison of the stability of antifers (present study) and cubes (Van der Meer, 1988)

References

1-Edge, B. L.; Magoo, O. T. And Baird, W. F.: "The Evolution Of Breakwater Design", Proc. Waves'93, 1993, Pp 1024-1039.

2-Gunbak, A. R.: “Antifer Cubes On Rubble Mound Breakwaters”, Proc. Fifth Conf. On Coastal And Port Eng. Conf. In Developing Countries (COPEDEC V), Cape Town, South Africa, April 1999, Pp. 1450-1455.

3-Iribarren, C. R.: "Una Formula Para El Calculo De Los DiquesDe Escollera", Revista De Obras Publicas, Madrid, Spain, 1938 (Translated By D. Heinrick, Univ. Of California, Dept. Of Civil Eng., TR-HE-116-295, Berkely, CA, 1948).

4- U. S. Army Corps Of Engineers: "Design Of Quarry- Stone Cover Layers For Rubble-Mound Breakwaters", Research Report No. 2-2, WES, Vicksburg, 1958.

5- Van Der Meer, J. W.: “Conceptual Design Of Rubble Mound Breakwaters”, Jan. 1994, 74 Pages.

6-Van Der Meer, J. W.: “Stability Of Cubes, Tetrapods And Accropodes”, Proc. Breakwaters ’88, Eastbourne, Thomas Telford, 1988.

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