Performance of Submerged Reef of Concrete Cubes

Manu, Kiran Gangadhar. Shirlal, and Subba. Rao

***Abstract*—** Ocean waves can be destructive as steeper waves, due to their high energy, erode the sandy beaches. If these waves are made to break prematurely and away from the beach and attenuate them, then, beach erosion could be reduced. This can be economically accomplished by a submerged reef suitably designed and constructed at some offshore distance. Meanwhile, due to the non availability of the stones nearby quarries, the most logical solution is use of concrete cubes. This paper experimentally investigates the armour cube stability of the submerged reef and influence of its varying distance from shore on wave transmission. A stability equation for a submerged reef has been obtained. It is found that a 0.25 m high reef with 1:1.75 slope, having a crest width of 0.1 m and of constructed with an optimum armour cube of weight of 40 g in a water depth of 0.3 m is stable. These structures achieve a wave transmission of nearly 51% for the test wave conditions while the wave reflection is about 4% to 11%.

***Keywords*—**Armour Cube Stability, Submerged Reef, Wave Breaking and Wave Transmission, Wave Reflection.

I. Introduction

IN places where tidal variations are moderate and only partial protection from waves is required like harbour entrance, beach protection, small craft harbours etc. Wave damping or wave height attenuation can be effectively and economically realized using a submerged breakwater [1], [2]. Current and turbulence together on lee side of submerged breakwater have a strong power of erosion on a sandy bottom and can thus prevent siltation. These structures offer resistance through friction and turbulence by their interference in the wave field causing wave damping, energy dissipation, smaller wave transmission, minimum wave reflection and bottom scour and maximum sand trapping efficiency. Hence, they can be used for coastal protection.

Reef is a kind of offshore structure with its crest at or below the SWL. They are a homogeneous pile of armour units, with individual armour weight sufficient to resist the wave attack. They break the incoming waves and dissipate the wave energy due to turbulence and offer low transmission coefficient. These are used basically to protect a beach or to reduce the beach erosion. These types of structures are constructed where only partial attenuation of the waves on the lee side of the structure is required or where the overtopping is allowed.

The review of literature revealed that the influence of geometry, slope, relative crest width (B/d) and relative crest elevation (h/d) on wave transmission have been considered as important parameters and are studied by various researchers [1], [3]-[5] where 'B', 'h' and 'd' are crest width, crest elevation and water depth respectively. Most of the researchers opine that the submerged structure is constructed in a water depth of 1.5 m to 5 m with a slope of 1:2 to 1:3 and a height exceeding 0.7 times the depth of water. Various investigators have presented equations and graphs to compute the armour weight of submerged reef breakwater [6]-[10]. However, there is a dilemma regarding the criteria of armour stability to be adopted for the submerged reef as different design formulae suggest a wide range of armour weights.

In the early days when reef breakwaters were built in relatively shallow waters, the use of natural stones as armour units posed no problem since stones of required size/weight were easily obtained from quarries nearby. Presently the stones may not available in the quarries nearby. With the development of concrete technology, the most logical solution is the use of concrete cubes instead of natural stones. Hence, the present experimental investigation is undertaken to arrive at a stable armour cube weight and estimate the wave transmission (K_t) and reflection (K_r) coefficients.

II. Objective of the Study

The objectives of the present experimental investigation, under selected test conditions are to:

1. study the armour cube stability of the reef and arrive at optimum armour cube weight,
2. obtain a design equation for submerged reef,
3. study the wave transmission,
4. study the wave reflection.

III. Experimental Details

A. Wave Flume

The physical model is tested for regular waves in a two dimensional wave flume of Marine Structures laboratory of Department of Applied Mechanics and Hydraulics, National Institute of Technology Karnataka, Surathkal, India. Gradual transition is provided between normal bed level and that of generating chamber by ramp. The wave filter consists of a

Manu is with National Institute of Technology Karnataka, Surathkal, PO-Srinivasnagar, 575025, Mangalore, INDIA (Phone:+91 9844087664; fax:+91 824 2474039; e-mail: manunitk77@gmail.com).

Kiran Gangadhar. Shirlal is with National Institute of Technology Karnataka, Surathkal, PO-Srinivasnagar, 575025, Mangalore, INDIA (e-mail: kshirlal@gmail.com).

Subba. Rao is with National Institute of Technology Karnataka, Surathkal, PO-Srinivasnagar,575025, Mangalore, INDIA (e-mail: surakrec@gmail.com).

series of vertical asbestos cement sheets spaced at about 0.1 m centre to centre parallel to length of the flume. Fig. 1 gives a schematic diagram of experimental setup. The changing of frequency through inverter, one can generate the desired wave period. A fly-wheel and bar-chain link the motor with flap. By changing the eccentricity of bar chain on the fly-wheel the wave height can be varied for a particular wave period. The wave flume is 50 m long, 0.71 m wide and 1.1 m deep. It has a 41.5 m long smooth concrete bed.

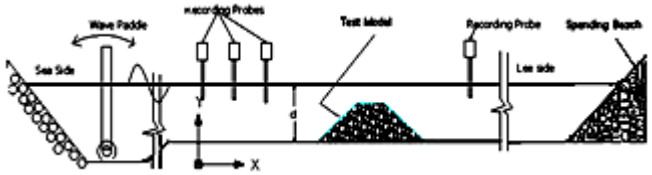

Fig. 1 Details of experimental setup

About 15 m length of the flume is provided with glass panels on one side. It has a 6.3 m long, 1.5 m wide and 1.4 m deep chamber at one end where the bottom hinged flap generate waves. The flap is controlled by an induction motor of 11 Kw power at 1450 rpm. This motor is regulated by an inventor drive (0 – 50 Hz) rotating in a speed range of 0–155 rpm. Regular waves of 0.08 m to 0.24 m heights and of periods 0.8 s to 4.0 s in a maximum water depth of 0.6 m can be generated with this facility.

B. Instrumentation

The capacitance type wave probes along with amplification units are used for data acquisition. Four such probes are used during the experimental work, three for acquiring incident and reflected wave heights (H_i and H_r) and one for transmitted wave heights (H_t) as shown in Fig. 1. The spacing between probes is adjusted approximately to one third of the wave length to ensure accuracy as suggested by Isaacson [11]. During the experimentation, the signals from wave probes are verified online and recorded by the computer through the data acquisition system. These are then processed for separating the incident and reflected components using software based on the Isaacson's method.

C. Test Model

A 1:30 scale model of trapezoidal submerged reef of slope 1V:1.75H, height (h) of 0.25 m and crest width (B) of 0.1 m is constructed, with concrete cube armour of varying weight, on the flume bed at 28 m away from the generator flap. Five such reef models are designed with concrete armour cube weighing 30 g, 35 g, 40 g, 45 g, and 50 g considering various design criteria [6] – [9]. This test section is subjected to normal wave attack of 3000 regular waves of height ranging from 0.1 m to 0.16 m, of periods varying from 1.5 s to 2.5 s in a depth of water (d) of 0.3 m as the reef stability is critical at the lowest water level [12]. The damage to the structure is recorded in the form of reduction in crest height (h_c). From the test model an optimum armour cube weight for stable submerged reef is derived. Fig. 2 shows the cross section of submerged reef.

Further, wave transmission over the submerged reef is studied. The incident waves are recorded at 1 m seaward of the reef. The transmitted wave height (H_t) on the leeside is recorded at 1 m on the lea side. Wave reflection at the reef structure is also studied using the method proposed by Isaacson [11].

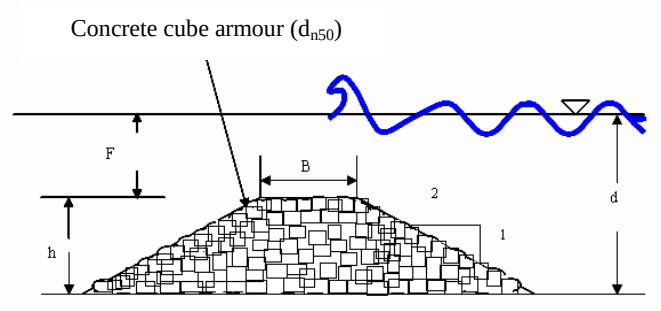

Fig. 2 Cross section of test model

D. Test Conditions

The present experimental investigation is carried out with the following test conditions:

- The sea bed is rigid and horizontal and it is assumed that the sediment movement does not interfere with the wave motion and do not affect the model performance.
- The waves are periodic and monochromatic.
- Waves are generated in short burst of five waves.
- Between wave bursts there are brief intervals to allow wave energy to dampen out.
- Secondary waves generated during the test are not considered.
- The density difference between freshwater and seawater is not considered.
- Piling up of water behind the reef is neglected.

IV. Results and Discussion

The data collected in the present experimental work are expressed as non-dimensional quantities. The variation of damage level (h_c/h) with spectral stability number (N_S^*) for different armour weight and transmission coefficient (K_t) with deep water wave steepness parameter (H_o/gT^2) for relative shoreward distance (X/d) are studied through graphs.

A. Study of Reef Armour Stability

The graph of dimensionless damage (h_c/h) versus spectral stability number (N_S^*) is shown in Fig. 3. The graph shows increasing damage with an increase in stability number for armour cubes of mean weight 30 g and 35 g. The armour cubes of 50 g are completely stable however, it is seen that, the armour cubes of 45 g and 40 g are relatively safer in spite of minor readjustment of armour where $h_c/h \leq 5\%$. Therefore, it is concluded that, armour cubes of mean weight 40 g (i.e. armour cube size (d_{n50}) of 0.0244 m) is an optimum and safe for the stable submerged reef under the test conditions.

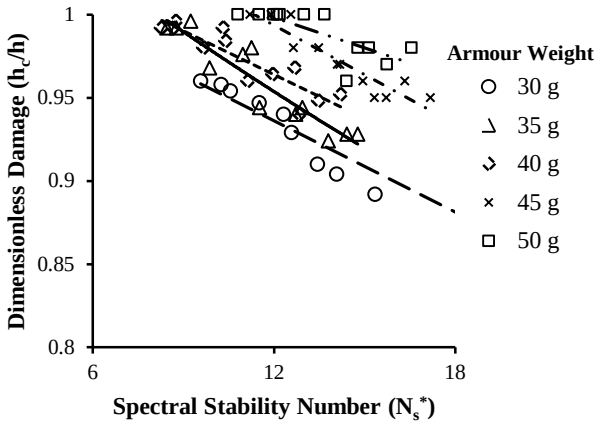

Fig. 3 Variation of damage with spectral stability number

B. Stability Equation

All the above test data are plotted in Fig. 4 and an exponential curve is fitted to the data points using M.S. Excel sheet for which the trendline has a correlation coefficient of 0.8745. The 95% confidence and prediction bands are drawn for the curve.

The stability equation of the submerged reef under test condition is derived as

$$\left[\frac{h_c}{h}\right]\left[\frac{d_{n50}}{gT^2}\right]10^{-3} = 2.756e^{-0.147\,N_S^*} \qquad (1)$$

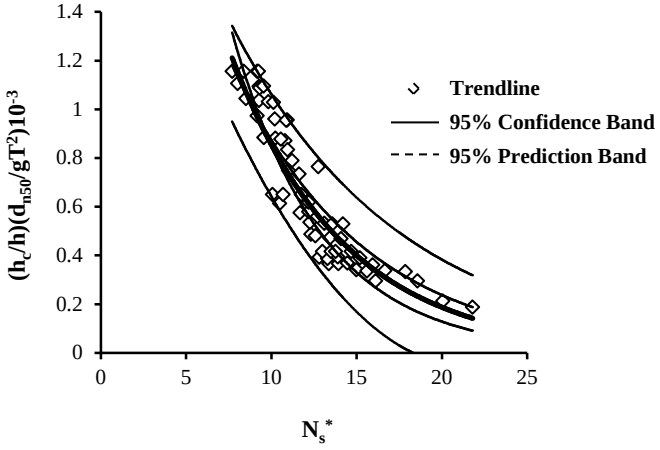

Fig. 4 Stability equation for submerged reef

Where,

(h_c/h) is the dimensionless damage, (gT^2/d_{n50}) is the dimensionless wave period and N_S^* is the spectral stability number which is given by

$$N_S^* = N_S S_P^{-1/3} \; and \; N_S = \frac{H}{\Delta d_{n50}} \qquad (2)$$

N_S is Hudson's stability number, H is the wave height, • is the relative mass density, d_{n50} is the nominal size of armour cube and S_p is the local wave steepness.

C. Study of Wave Transmission

Fig. 5 shows the best fit lines for the variation of wave transmission coefficient (K_t) with the deep water wave steepness parameter (H_o/gT^2) for the shoreward distance of 1 m and optimum armour cube weight of 40 g. The transmission coefficient decreases with an increase in wave steepness as submerged reef is efficient in breaking the steeper waves. It ranges from 0.73 to 0.88 for the test conditions.

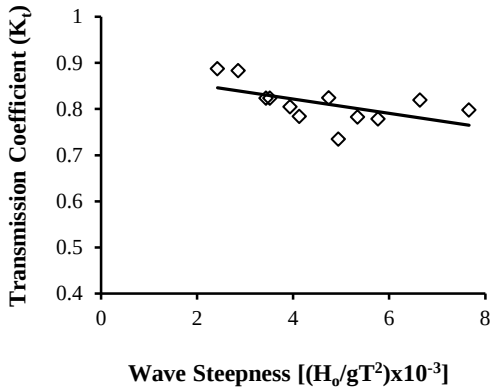

Fig. 5 Variation of transmission coefficient with wave steepness

D. Study of Wave Reflection

The typical variation of reflection coefficient (K_r) with the deep water wave steepness parameter (H_o/gT^2) for an optimum armour cube weight (40 g) is shown in Fig. 6. It is observed from the figure that the reflection coefficient decreases with an increase in wave steepness parameter in a given water depth of 0.3 m. The reflection coefficient varies in the range of 0.04 to 0.11.

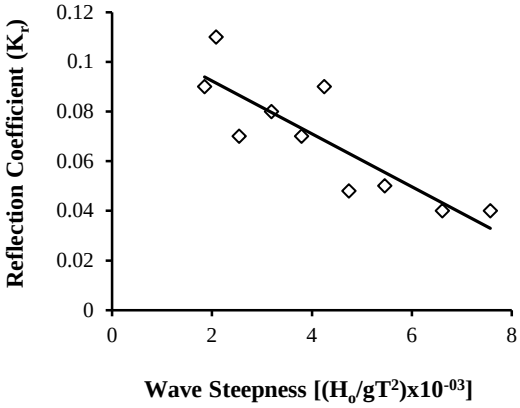

Fig. 6 Variation of reflection coefficient with wave steepness

V. CONCLUSIONS

Following are the conclusions drawn from the present study:

1. An optimum concrete armour cube weight for a stable submerged reef is 40 g.
2. The stability equation for the submerged reef is derived as:

$$\left[\frac{h_c}{h}\right]\left[\frac{d_{n50}}{gT^2}\right]10^{-3} = 2.756e^{-0.147\,N_S^*}$$

3. Wave transmission coefficient varies from 0.73 to 0.88.

4. Reflection coefficient varies in the range of 0.04 to 0.11 for test parameters considered.

ACKNOWLEDGMENT

The authors are thankful to the Director of National Institute of Technology Karnataka, Surathkal, and Head of the Department of Applied Mechanics and Hydraulics for the facilities provided for the investigation and permission granted to publish the results.

REFERENCES

[1] J. W. Johnson, R. A. Fuchs, and J. R. Morison,. "The damage action of submerged breakwater," Transaction, American Geophysical Union 2 (5), 1951, pp. 704 – 718.

[2] M. Baba, "Design of submerged breakwater for coastal protection and estimation of wave transmission coefficient," 1st National Conf. on Dock and Harbour Engg., I.I.T. Bombay, 1985, pp. B 13 - B 26.

[3] J. Dattatri, H. Raman, and N. Jothi Shankar, "Performance characteristics of submerged breakwater," Proc. of 16th Coastal Engineering Conf., Hamburg, 1978, pp. 2153 – 2171.

[4] M. H. Khader Abdul, and S. P. Rai, "A study of submerged breakwaters," J. of Hydraulic Research, 28, (2), 1980, pp. 113 - 121.

[5] K. G. Shirlal, "Studies on the stability of conventional rubble mound breakwater defenced by a submerged reef," PhD Thesis, N. I. T. K., Surathka, India, 2005.

[6] J. P. Ahrens, "Stability of reef breakwater," J. of Waterway, Port, Coastal and Ocean Engg., ASCE, 115(2), 1989, pp. 221 – 234.

[7] M. R. Gadre, I. Z. Poonawala, and M. D. Kudale, "Stability of rock armour protection for submarine pipeline," Proc. of 8th Congress of the Asian and Pacific Regional Division of the International Association for Hydraulics Research, CWPRS, Pune, India, October 1992, pp. D-149 – D-160.

[8] Nizam, and N. Yuwono, "Artificial reef as an alternative beach protection," Proc. of 10th Congress of Asian and Pacific Division of International Association for Hydraulic Research, Malaysia, 2, August 1996, pp. 422 – 430.

[9] K. W. Pilarczyk, and R. B. Zeidler, Offshore breakwater and shore evolution control, A. A. Balkema Rotterdam, Netherlands, 1996.

[10] K. G. Shirlal, S. Rao, and Manu. 2008. "Performance of a Submerged Reef – A Physical Model Study," International J. of Ecology and Development, Vol. 11, No. F08, 2008, pp. 90 - 98.

[11] M. Isaacson, "Measurement of regular wave reflection," J. of Waterways, Port, Coastal and Ocean Engg., (117) 1991, pp. 553 – 569.

[12] D. A. Y. Smith, R. M. Warner Sorensen, and Atherley, "Submerged crest breakwater design," Advances in Coastal Structures and Breakwaters, Thomas Telford, London, 1996, pp. 208 - 219.