SECM/15/124

Experimental Investigation of Performance of Reef Breakwaters

R.M.D.B. Rathnayaka[1*], R.M.J.R. Rathnayaka[1] and K.P.P. Pathirana[1]

[1]University of Peradeniya, Peradeniya, Sri Lanka
*E-Mail: dilanrathnayaka1127@gmail.com, TP: +94713481207

Abstract: Reef breakwater is a low crested, rubble mound breakwater without a conventional multilayered cross section. It has been identified that transmission coefficient is one of the main parameters to quantify the performance of reef breakwaters and several parameters that influence transmission coefficient was identified. Accordingly, a comprehensive laboratory investigation was carried out and transmission of different reef breakwaters was studied by varying different influence parameters. It was observed that wave steepness, crest width and depth of crest submergence are the most influential parameters on transmission coefficient. Comparison between existing equations to calculate transmission coefficient was done using data from the present study. When using existing equations for the same input parameters, it can be seen that estimated transmission coefficient values differ from each other suggesting that their applicability to a real life problem is questionable. Therefore a new improved formula to estimate transmission coefficient was derived using dimensional analysis incorporating more influence parameters than existing equations. This formulation proved to be better than the previous equations.

Keywords: Physical model tests, Reef breakwaters, Transmission coefficient.

1. Introduction

Reef type breakwaters refer to a law crested rubble mound breakwater without the traditional multilayered cross section (see figure 1). These types of breakwaters are little more than a homogenous pile of stones with individual stone weight sufficient to resist wave attack. Because of the low crest height and using one armour layer these kinds of structures are relatively cheaper compared to conventional rubble mound structures.

These kinds of structures are mainly used at places where partial attenuation of the waves on the lee side of the structure is needed. Other purposes of reef breakwaters are,

- Protecting a beach or reduce the cost of beach maintenance
- Protecting the water intake for power plants
- Providing an alternative to revetments for stabilizing an eroding sea line

Reef breakwaters can be either submerged or partially submerged.

The idea of reef breakwaters first came up around the year 1976. Since then a number of reef breakwaters have been constructed. Reef breakwaters can be seen in places like, the lower central east coast of Florida, New Jersey coast, offshore of Grand Cayman Island etc... (Donald, et.al. 2003).

However, the amount of research done on reef breakwaters, specially submerged breakwaters is limited. Also the design criteria available for reef breakwaters are not well defined. Therefore, further researching is required to specify design parameters for reef breakwaters.

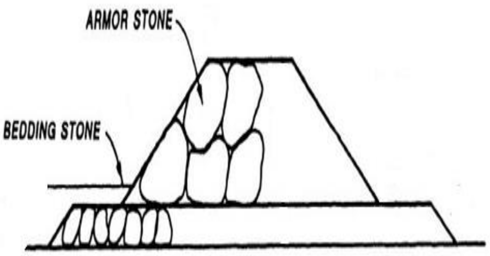

Figure 1: Typical cross section of a reef breakwater

Performance of reef breakwaters can be quantified using transmission coefficient ($K_t = H_t/H_i$), Reflection coefficient ($K_r = H_r/H_i$), Loss coefficient ($K_l = H_l/H_i$) and the stability of the breakwater where H_i is incident wave height H_t is transmitted wave height, H_r is reflected wave height and H_l is equivalent wave height corresponding to energy loss of the wave.

Among these parameters transmission coefficient was studied in this study. Figure 2 shows the most influential parameters on transmission coefficient.

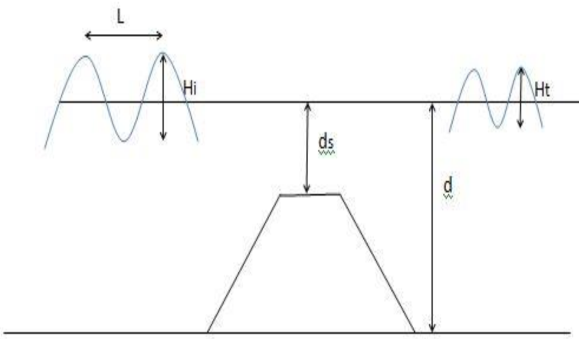

Figure 2: Influence parameters

where, d = water depth, d_s = depth of crest submergence, H_i = incident wave height and L = incident wave length.

2. Previous studies on transmission coefficient of reef breakwaters

Several research studies have been conducted and several formulae and methods to estimate transmission coefficient of reef breakwaters have been introduced in those studies. Most of these studies are based on physical model tests conducted under different conditions and others are from numerical model analysis. In this study, transmission coefficient was estimated using existing equations with present model parameters and those results were compared with model test results. These equations are from Coastal Engineering Manual (CEM) (2001) and from research studies done by Ahrens, et al. (1987), Van der Meer, et al. (2003), D'Agremond, et al. (1996).

The equation given in CEM (2001) for the calculation of transmission coefficient of reef breakwaters is a result of various model test results for rock armed law crested, submerged and reef breakwaters.

$$C_t = \left(0.031 * \frac{H_s}{D_{50}} - 0.24\right) * \frac{R_c}{D_{50}} + b \tag{1}$$

For submerged breakwaters,

$$b = -2.6\, S_{op} - 0.05 \frac{H_s}{D_{50}} + 0.85 \tag{2}$$

where, C_t = Transmission coefficient, H_s = Significant wave height of incident waves, D_{50} = Median of nominal diameter of rocks, R_c = Free board (negative for submerged breakwaters) B = Width of the crest, S_{op} = Deep water steepness corresponding to peak period.

For reef type breakwaters transmission coefficient has been limited to maximum of 0.6 and minimum of 0.15. As mentioned earlier the equation is based on test data from several researchers under following test ranges.

$$1 < \frac{H_s}{D_{50}} < 6 \qquad 0.01 < S_{op} < 0.05 \qquad -2 < \frac{R_c}{D_{50}} < 6$$

It can be seen that influence of breakwater crest width has not been included in this equation.

The equation given by the Ahrens, et al. (1987) is given in equation 3. This equation has been given for breakwaters with relative free board $\left(\frac{F}{H_{mo}}\right)$ less than 1. The cross section area of the breakwater has been incorporated in this equation.

$$K_t = \frac{1}{1+\left(\frac{h_c}{d_s}\right)^{C_1}+\left(\frac{A_t}{d_s L_p}\right)^{C_2} .exp\left[C_3\left(\frac{F}{H_{mo}}\right)+C_4\left(\frac{A_t}{d_{50}^2} * \frac{1}{L_p}\right)\right]} \tag{3}$$

where, C_1= 1.188, C_2= 0.261, C_3= 0.529, C_4= 0.00551, F = free board, h_c = water depth, L_p = incident wave length, H_{om} = zeroth moment incident wave height, A_t = cross section area of the reef and d_s = water depth.

Van der Meer, et al. (2003) proposed the following equation for the calculation of transition coefficient with a minimum of 0.075 and maximum of 0.8.

$$K_t = \left(-0.3\,\frac{R_c}{H_{om}} + 0.75\left[1 - \exp(-0.5\varepsilon_{op})\right]\right) \tag{4}$$

Seaward slope of the breakwater has been included in this equation with the introduction of surf similarity parameter. But the formula does not include the crest width and the armor gradation. R_c is the depth of crest submergence and this equation is valid under the range of $-1.66 < \frac{R_c}{H_{om}} < 1.66$.

D' Agremond, et al (1996) has proposed an empirical equation to calculate transmission coefficient from the experimental results using irregular wave conditions.

$$K_t = -0.4\frac{R_c}{H_{mo}} + \left(\frac{B}{H_{mo}}\right)^{-0.31}\left[1 - \exp(-0.5\epsilon_{op}\right] * C \tag{5}$$

In this equation the influence of the crest width (B) and the permeability have been incorporated with a constant C (0.64 for permeable structures and 0.84 for impermeable structures).

When using the above equations for the same input parameters, it can be seen that estimated transmission coefficient values differ from each other suggesting that their applicability to a real life problem is questionable. In addition, each of these equations to calculate transmission coefficient has limitations, constraining their applicability in problems which exceed those limitations. Therefore, to get a better understanding of wave transmission phenomena over reef breakwaters a series of physical model test runs were carried out.

3. Experimental procedure

3.1 Experimental set-up

The experiments were carried out in the wave channel in the Hydraulics Laboratory in Faculty of Engineering, University of Peradeniya, Sri Lanka. The wave channel was 12.75 m long, 0.52 m wide and 0.71 m deep. The side panels of the channel consisted of sixteen 12 mm thick Perspex sheets, which enabled visual observation such as the wave breaking and interactions of waves with models constructed in the channel.

The breakwater models were constructed using uniformly graded aggregates. Two uniform sizes of aggregates were used for the construction (D_{50}=41.5 mm and D_{50}=26 mm). For each stone class, three breakwaters were constructed with different crest width values (B) of 20 cm, 40 cm and 50 cm. Trapezoidal cross sections were used to construct the breakwater models. Each breakwater was constructed with a constant height of 25 cm and the seaward and the leeward slopes of the each and every breakwater model was maintained at a constant value of 1:1.5.

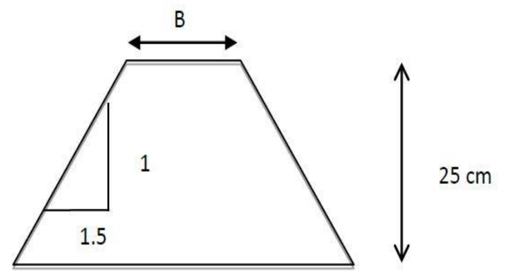

Figure 3: Cross section of a model breakwater

Figure 4: Breakwater model for 40 cm crest width using 26 mm armor units

One Armfield H40, resistant type, twin-wire wave probe was used to measure the wave parameters. Analogue to Digital converter with 16 analogue input channels was used to convert the analogue signals from the wave probes to digital signals. LAB VIEW data acquisition software was used to acquire the data from wave probes. A MATLAB program was used to obtain the required wave parameters. Figure 5 shows the experimental set-up used in this study.

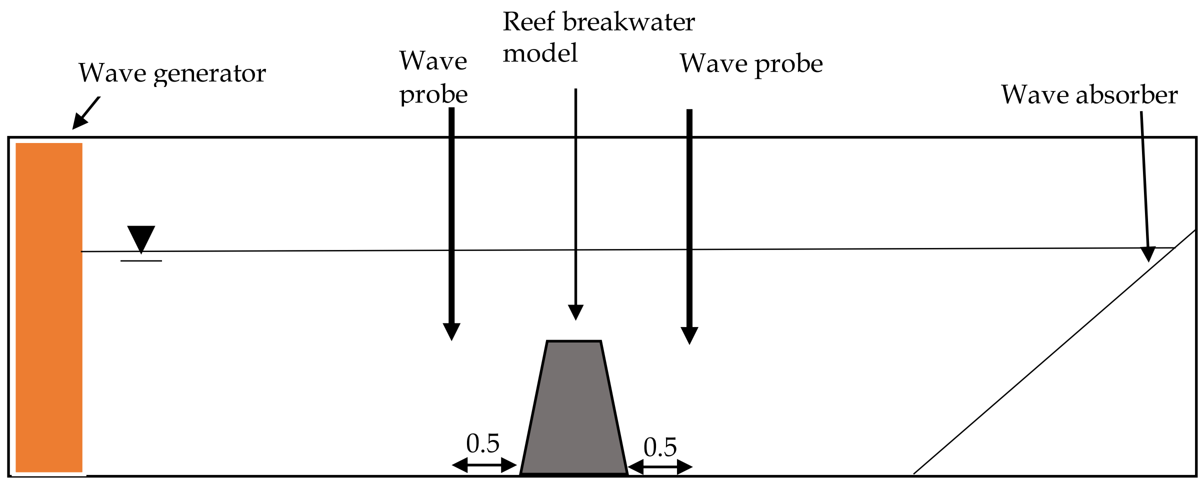

Figure 5: Experimental set-up

3.2 Model runs

Details of the experimental runs that were carried out for the varying parameters are shown in Table 1. Though 192 experimental runs were conducted, transmission wave height of some of the test runs could not be measured because wave energy transmitted was very low and transmitted wave was small. Rest of the experimental results were used in data analysis.

Table 1: Different sets of experimental runs

Variable	Values
Wave height (cm)	2 - 17
Crest width (cm)	20, 40, 50
Water depth (cm)	25, 30, 35, 40
Armour size (mm)	26, 41.5
Total no. of test runs 196	

4. Data analysis

4.1 Estimation of wave transmission coefficient using existing methods

Each of the existing formulae discussed in section 2 were used to calculate transmission coefficient inputting the data from this study and calculated transmission and measured transmission coefficients were compared. Figure 6 shows the variation of calculated and measured transmission coefficients.

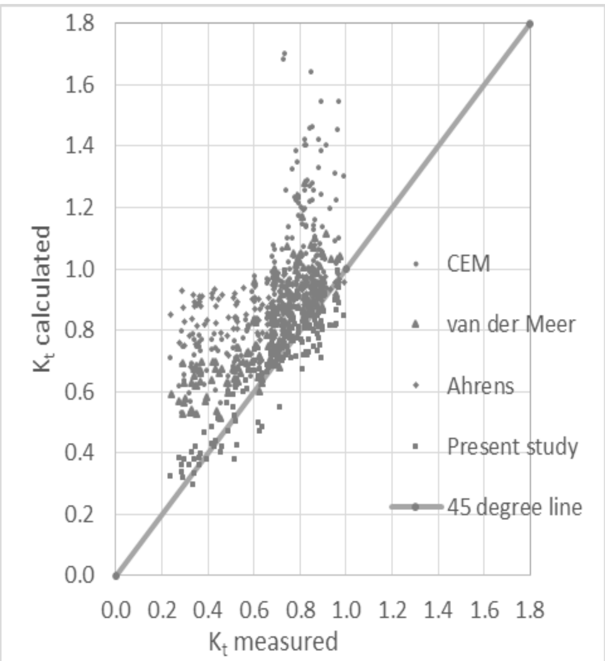

Figure 6: Comparison with previous studies

From the analysis it can be seen that data points are highly scattered. In addition there are some cases where estimated transmission coefficient is greater than one which is not acceptable. This seems there are major drawbacks and limitation in existing equations. Therefore a new formula was derived using an empirical method.

4.2 Development of a new formula to predict transmission coefficient

Dimensional analysis was carried out to formulate the dimensionless parameters which influence the transmission coefficient. Selection of the parameters affecting the transmission coefficient was done with the help of coastal engineering concepts and past studies. Following parameters were selected as the governing influence parameters associated with the performance of reef breakwaters considering the transmission of waves.

$$K_t = f(H_s, d_s, d, B, D_{50}, T, tan\alpha, g)$$

Where, d_s is the depth of crest submergence and *tan α* is the seaward slope of the breakwater. In the present study seaward slope was kept constant for every model test as 1:1.5. Therefore dimensionless parameter representing the seaward slope was neglected.

Using the dimensional analysis, following relationship was derived.

$$K_t = f\left(\frac{H_s}{d}, \frac{H_s}{d_s}, \frac{H_s}{B}, \frac{H_s}{D_{50}}, \frac{gT^2}{H_s}, tan\alpha\right)$$

Multi variable regression analysis was carried out to obtain the relationship between these dimensionless groups and the transmission coefficient. The derived formula is shown in equation 6 below.

$$K_t = 0.613 - 1.83\left(\frac{H_i}{d}\right)^2 + 0.02\left(\frac{H_i}{B}\right)^{-1} + 0.317\left(\frac{d_s}{H_s}\right)^{0.35} + 0.002\left(\frac{H_i}{D_{50}}\right)^2 + 5.32 * 10^{-7} * \left(\frac{gT^2}{H_i}\right)^2 \quad (6)$$

After obtaining the formula, K_t values calculated using it were plotted against the K_t values obtained from the experimental runs. Figure 7 shows those results. Compared to results from the existing equations, number of scattered data points are less and mean relative error between calculated transmission coefficient and measured transmission coefficient is less than 10%.

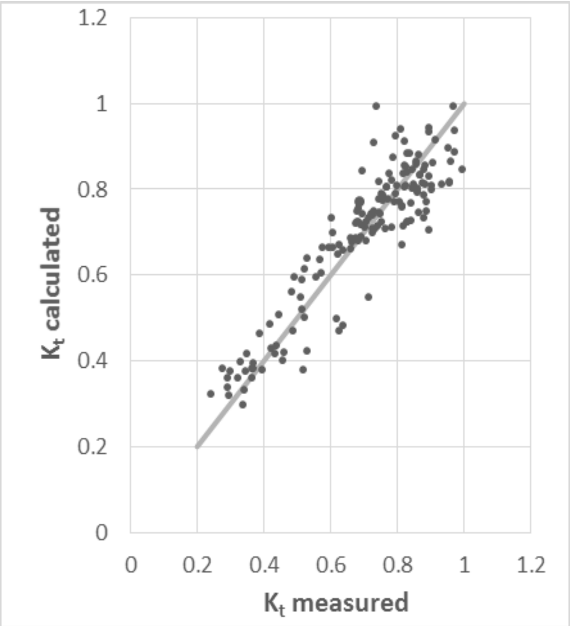

Figure 7: K_t measured Vs K_t calculated

5. Conclusion

The present formula derived for estimation of transmission coefficient contains more variables than the existing formulas. Existing equations are poor in estimating transmission coefficient when the depth of crest submergence is zero. But with equation derived from this study above shortcoming was eliminated.

Although the present study has arrived at the above conclusions, following limitations could be pointed out.

- Present study was done using regular wave conditions.
- Seaward slope of the model breakwaters was maintained at a constant value of 1:1.5 in the present study. Therefore validation of the obtained formula should be done if it is to be used for other seaward slope values.
- Wave periods used for the tests vary from 0.7 to 1.25 seconds. For higher wave periods, the present equation should be validated.
- Only two armor sizes were used for the construction of the breakwaters.

References

[1]. Ahrens, J.P., Cox, J., 1990. ‘Design and Performance of Reef Breakwaters’, Journal of Coastal Research, no.7,pp. 61-75.

[2]. Coastal Engineering Manual, 1110-2-1100 U.S. Army Corps of Engineers, 2001.

[3]. Dattari, J., Raman, H., Shankar, N.J., 1978. ‘Performance characteristics of submerged breakwaters’, Coastal Engineering Journal, ASCE, New York, pp. 2152-2171.

[4]. Donald, K.S., Jeffery, R. T., 2003. ‘The use of submerged narrow-crested breakwaters for shoreline erosion control’, *Journal of Coastal Research*, Vol. 3, pp.684-722.

[5]. Van derMeer, J.,Wang, B.,Wolters, A., Zanuttigh, B., Kramer,M., 2003. Obliquewave transmission over low-crested structures. ASCE, Proc. Coastal Structures, Portland, Oregon.

[6]. Van der Meer, J.W. and d’Angremond, K., 1991. Wave transmission at low-crested structures, ICE,Thomas Telford. In: Coastal structures and breakwaters. London, United Kingdom, p. 25 – 4