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Prediction of wave transmission characteristics at submerged reef breakwater

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Abstract

Submerged reef breakwater is an off shore breakwater, with its crest at or below the sea water level, used for protection of coastal structures and beaches from the erosion caused by wave action. Reef breakwaters are coast parallel structure built wi th an objective of reducing the wave action on the beach. It is constructed with uniformed size armour whose weight is sufficient to resist wave attack. Modeling of co-efficient of wave transmission (K_t) of such reef is a topic chosen for present study. Preliminary equation is derived from dimensional analysis as semi empirical equation which involves different parameters like wave characteristics, reef dimensions and nominal diameter of armour units. Simulation of results is undertaken with modeling in MATLAB. Results obtained are thus compared with experimental results and existing equations from the literature. Finally semi-empirical equation for K_t is established.

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Keywords: *Submerged reef breakwater, Wave transmission Co-efficient, Dimensional analysis, Modelling-MAT Lab, Semi-empirical equation for K_t.*

1. Introduction

Steep waves in ocean causes damage to life, properties, coastal line and it also disturbs ports and harbors. A structure which is built to absorb such wave energy is called breakwater. Normally breakwater maintains calm water zone on lee side and offers protection to coast. Breakwaters are constructed to provide berthing facilities in harbors and also to give protection over the action of steep waves. Submerged reef breakwater is a type of breakwater whose crest is at or below the sea water level as shown in fig 1.

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It is constructed with desired type of armour units without core or secondary layer. Reef structure helps in premature wave breaking and wave energy dissipation which is necessary for erosion control and shore line stabilization. Waves overtop the reef breakwater and transmit wave energy on the lee side. Reef structure can be designed to have a desired value of co-efficient of wave transmission (K_t) for a given site condition. K_t is defined as the ratio of transmitted wave height to the incident wave height.

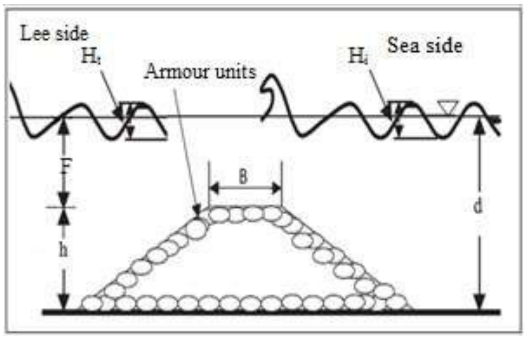

Fig 1. Typical cross section of Submerged Reef Breakwater

2. Literature Review

The reef breakwater is a low crested structure which is little more than a homogeneous pile of stones whose weight is sufficient to resist the wave attack (Ahrens 1989). It is an efficient measure for beach protection without affecting the littoral drift significantly and can be economically constructed to a depth of 2 m to 3 m by using stones of optimum weight, which can be assembled and easily placed with help of boats and 4 to 6 people using locally available materials (Kale and Gadre 1989). They conducted laboratory studies and achieved K_t of 0.5 to 0.6 without significant damage to the armour units. Madsen and White (1976) developed an analytical approach to determine the reflection and transmission coefficients and K_t decreases from 0.35 to 0.15 for H_i/L varying from 2.5×10^{-2} to 3×10^{-2} . Based upon physical model studies an equation for K_t is derived by Van der Meer and d'Angramound (1996), Cox and Clark (1992) and Calabrese et al (2002).

Hanson and Kraus (1991) have presented numerical procedure for computation of wave transmission. Kobayashi and Wurjanto (1989) conducted mathematical model study of transmission over smooth impermeable submerged breakwater and compared with physical model studies. Rambabu and Mani (2005) proposed a Numerical model to predict K_t using Laplace equation for certain boundary condition. Kobayashi et al, (2012) conducted numerical model studies on stability and wave transmission co-efficient on submerged reef breakwater. Physical model studies are conducted by Cox and Clark (1992), Van der Meer (1992), Cornet et al. (1993), d'Angramound et al. (1996), Manu et al.(2012). Many physical model studies have been accomplished by various researchers and scientists to find out wave transmission (K_t) and few numerical studies also found in literature to find out K_t, but those are constrained for certain laboratory conditions and boundary conditions. Hence, there is a need to develop a comprehensive design equation for K_t by the application of dimensional analysis as a semi empirical equation.

3. Objectives of the study

- To develop a semi-empirical equation for Co-efficient of wave transmission (K_t).
- To study the Co-efficient of wave transmission Characteristics K_t of submerged reef breakwater under varying wave characteristics, water depths and crest widths.
- To compare the results obtained by empirical studies with the results of physical model studies.

4. Methodology

The study is to come up with the semi empirical equation for coefficient of wave transmission (K_t) using dimensional analysis through modeling in MATLAB. This is carried out by identifying various parameters on which K_t is dependent from literature. Preliminary equation is derived from dimensional analysis, refined further and compared with various experimental results collected by physical model studies. Any inconsistencies in the equation are removed by continuous modification and refinement through modeling. Lastly the most appropriate and the best fit to the experimental data is selected as the equation for K_t. The details of the methodology are illustrated in figure 2.

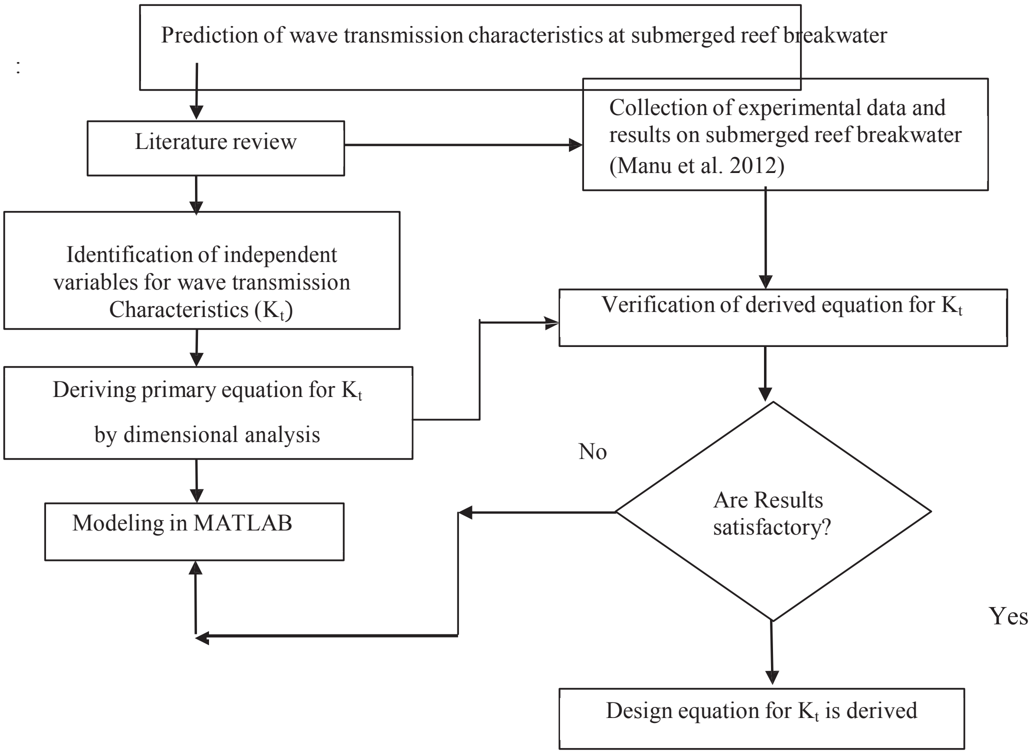

Fig 2. Flowchart of methodology

5. Formulation of Semi-Empirical Formulation

5.1 Dimensional Analysis

Dimensional analysis is a rational procedure for combining physical variables into dimensionless products, thereby reducing the number of variables which need to be considered and physical equation can be formed (Hughes. 1993). The different variables identified and listed in the following table 1.

Table 1. Identified variables on which K_t is dependent and its range.

Sl no	Variables	Dimensions
1	Incident wave height - H_i	L
2	Transmitted wave height-H_t	L
3	Water depth – d	L
4	Wave period-T	T
5	Wave length-L	L
6	Nominal dia- D_{n50}	L
7	Reef submergence (free board) -F	L
8	Crest width – B	L
9	Acceleration due to gravity-g	LT^{-2}
10	Height of the structure	H

5.1 Buckingham π theorem

Steven A. Huges. (1993) stated that, systematic procedure for forming a complete set of dimensionless products from a given set of process variables begins with the determination of how many dimensionless products can be formed.

$$K_t = \frac{H_t}{H_i} \quad (1)$$

$$K_t = f\{H_t, H_i, B, F, d, T, g, D_{n50}\} \quad (2)$$

$$K_t = f\left\{\frac{F}{B}, \frac{d}{D_{n50}}, \frac{2\pi H_i}{gT^2}, \frac{h}{d}\right\} \quad (3)$$

Where,

$\frac{F}{B}$ = Relative reef submergence

$\frac{2\pi H_i}{gT^2}$ = S_p= Wave steepness

$\frac{d}{D_{n50}}$ = Depth parameter

$\frac{h}{d}$ = Relative reef height

Equation for wave transmission co-efficient (K_t)

All parameters formulated are non-dimensional in nature. By understanding the physics involved in obtaining wave transmission co-efficient, these terms are relatively placed in equation by trial and error method based on dimensional analysis as suggested by Hughes (1993). Finally equation is modeled in MATLAB to achieve more accuracy of results. And the following equation is obtained.

$$K_t = \left(0.02\frac{F}{B} + 0.035\frac{h}{d}\right) \times \left(\frac{d}{D_{n50}} + \frac{0.45}{\sqrt{S_p}}\right)$$

6. Results and Discussion

Co-efficient of wave transmission K_t is determined for submerged reef through empirical analysis where the crest width of reef is 0.3m, wave heights (H_i) are 0.1 m, 0.12 m, 0.14 m, 0.16 m similarly for different wave periods (T) are 1.5 sec, 2 sec, 2.5 sec and water depths are 0.3 m, 0.35 m, 0.4 m. These values are incorporated in the empirical model and the model is tested in different runs and corresponding K_t values are obtained. In second part the results shown are both experimental and empirical results where experiment results are taken from experiments conducted by Manu et al (2012) at NITK-Surathkal, India. Then both the experiment results and empirical results are compared. In the third phase empirical results are compared with the various experimental and numerical results of different investigators.

6.1 Influence of deep water wave steepness

Fig 3 shows the best fit lines for the variation of K_t with deep water wave steepness parameter ($1.45X10^{-3}$ $< H_0/gT^2 < 7.65X10^{-3}$) of empirically obtained results. K_t increase with relative reef height (h/d) and decreases with steepness. This is because submerged reef is efficient in breaking steeper waves and efficiency of wave breaking increases with the reef height.Here relative reef heights (h/d) are varied from 0.625 to 0.833 while the crest width is 0.3m. K_t decreased with increase in H_0/gT^2 and h/d. K_t decreases from 0.68 to 0.61(10.29%), 0.61 to 0.54 (11.47%), 0.56 to 0.48 (14.28%) for h/d of 0.625, 0.714, 0.833 respectively.

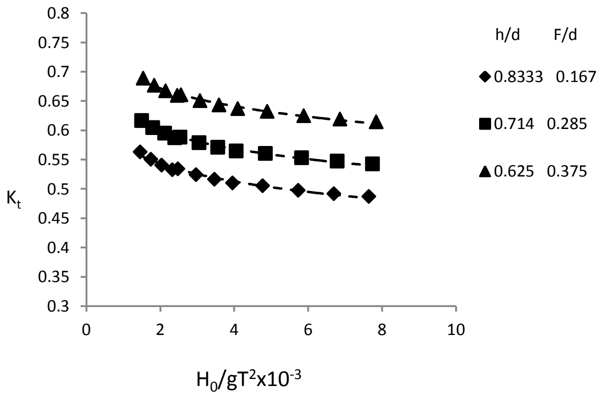

Fig 3. Variation of K_t with H_0/gT^2 (B=0.3 m)

6.2 Wave transmission over reef for depths (d) 0.3m, 0.35m and 0.4m.

Fig 4, 5 and 6 shows the best fit lines for the variation of transmission co-efficient K_t with the deep water wave steepness parameter H_0/gT^2 for both empirical and experimental results. K_t decreases from 0.56 to 0.46 (17.8%) for experimental and 0.56 to 0.48 (14.2%) for empirical to the water depth of 0.3 m. In the same manner from 0.66 to 0.52 (21.21%) for experimental, 0.61 to 0.54 (11.47%) empirical to the water depth of 0.35 m. whereas 0.76 to 0.62 (18.75%) for experimental, 0.68 to 0.61(10.29%).

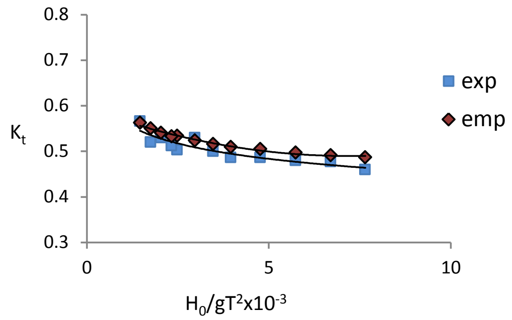

Fig4. Variation of K_t with H_0/gT^2 (d=0.3 m)

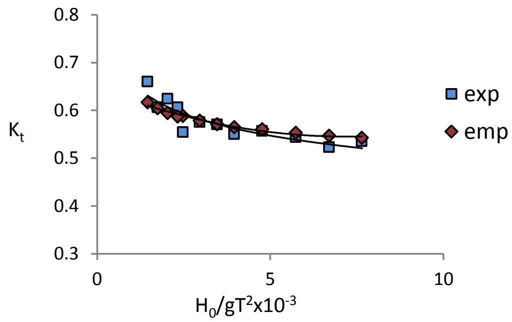

Fig5. Variation of K_t with H_0/gT^2 (d=0.35 m)

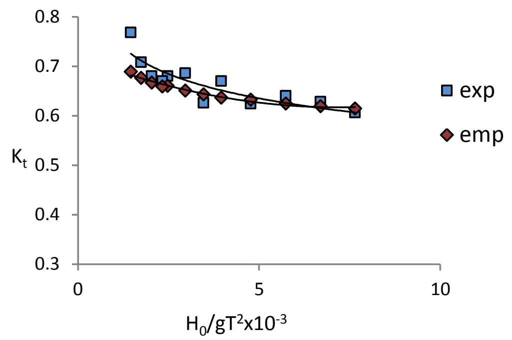

Fig5. Variation of K_t with H_0/gT^2 (d=0.4 m)

6.4 Comparison of Present and Previous studies.

The present study shows transmission co-efficient (K_t) increases with increase in relative reef submergence (F/H_i). The trends are shown in fig 6, 7, 8. Selected results of the present study are compared with those of other investigators.

6.4.1 Crest width 0.2 m

It is observed from Fig 6 that for the period 1.5sec K_t increases from 0.467 to 0.575 (18.78%), Presently obtained values are 42.3%, 32.66%, 20.7%, 12.86% and 3.5% lower than results obtained by Cornet (1993), Cox (1992), Van der Meer (1992), D'Angremond (1996), Manu (2012) respectively.

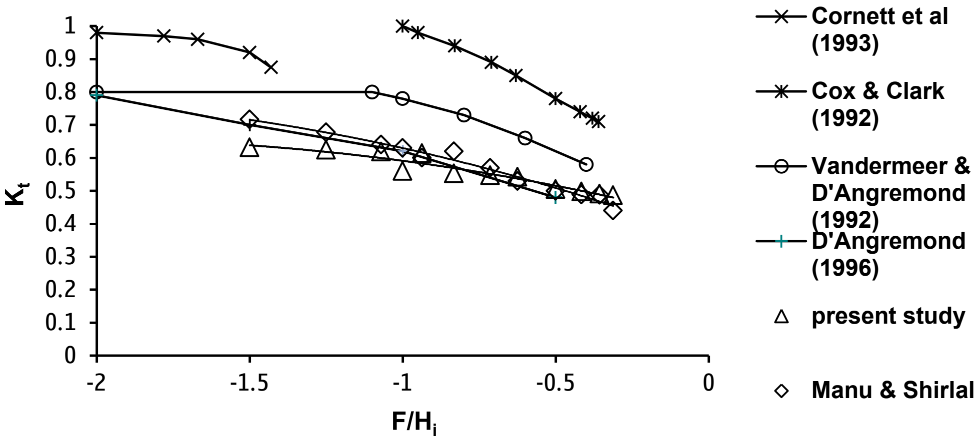

Fig. Variation of K_t with F/H_i for T=1.5sec

7. Conclusions

Following conclusions are drawn from the present study.

- Final semi empirical equation of K_t is established as

$$K_t = \left(0.02\frac{F}{B} + 0.035\ \frac{h}{d}\right) \times \left(\frac{d}{D_{n50}} + \frac{0.45}{\sqrt{S_p}}\right)$$

- Value of K_t decreases from 0.68 – 0.625 (8%) to 0.56 – 0.48 (14.28%) with relative increase of reef height (h/d) 0.625 to 0.833 (33.28%)
- Empirical results obtained matches well with the experimental results of Manu et al (2012).
- Trend line is in the same fashion when compared with other investigators.