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A Semi Empirical Approach to Model the Wave Transmission Characteristics for Submerged Reef Breakwater

SINDHU S, KIRAN G SHIRLAL AND MANU
Department of Applied Mechanics and Hydraulics, National Institute of Technology Karnataka, Surathkal, D.K District – 575 025
***Email:** sindhusanku@gmail.com*

Abstract: Breakwater maintains calm water zone in the harbor area for easy port operations such as loading, unloading of cargo, safe mooring operations, handling of ships and protection for shipping facilities. On the other hand breakwater is an important and unique coastal structure which provides shore line stabilization by controlling "Coastal Erosion". Submerged reef breakwater is an offshore 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. Main purpose of this structure is to attenuate waves and to reduce wave action on the leeside. Submerged reef breakwater is constructed with uniform sized armour units whose weight has been designed in order to be stable and resist wave attack. Modeling of wave transmission coefficient *(K_t)* of such reef is a topic chosen for the present study. Preliminary equation is derived from dimensional analysis which involves different parameters like wave steepness, incident wave height, and free board, nominal diameter of units used for construction of reef, height of structure, time period and depth of water. Simulation of results is continued further with modeling in MATLAB. These results are compared with various experimental results obtained from literature and a suitable semi empirical equation for K_t is evolved which is in good agreement with various experimental works.

Keywords: *Submerged reef breakwater, Wave transmission Characteristics, Dimensional analysis, Modeling-MATLAB, Equation for K_t*

1. Introduction

Most of the breakwaters constructed in harbors function only to provide protection against waves but some of them serve dual purpose by providing berthing facilities alongside for ships.

When it comes to the economical point of view breakwaters requires significant amount of capital investment of the port. Introducing a low crested structure called "Submerged Breakwater" in front of the conventional breakwater induces the wave breaking and reduces the wave action on breakwater and causes turbulence on leeside. [Baba (1986), Cox and Clark (1992), Cornett et al (1993), Shirlal et al (2003, 2007), Manu (2012)]. This would reduce the cost of construction considerably as lighter armor units are sufficient for the conventional breakwater.

1.1. Reef Breakwater

Reef breakwater is a low crested structure constructed by uniform sized armour units whose weight is sufficient to be stable and resist wave attack without core and secondary layer where crest is at or below the sea water level as shown in figure 1.1. This structure helps in controlling coastal erosion. Main purpose of this structure is to attenuate waves and provide shore line stabilization. Establishing the equation for wave transmission co-efficient (K_t) of such a protective reef structure constructed with stones by applying dimensional analysis is the topic chosen for the present study.

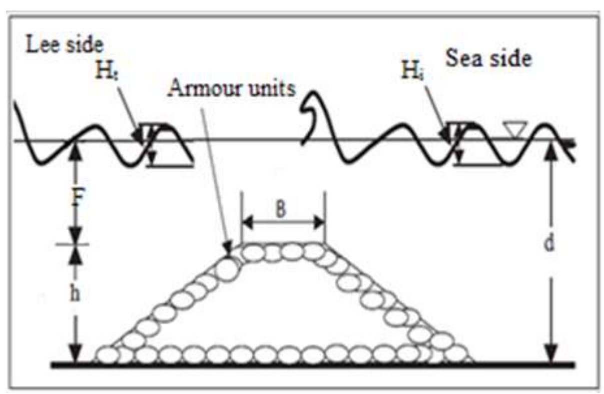

Figure1.1 *Typical cross section of Submerged Reef Breakwater*

2. Literature Review

The reef breakwater is a low crested structure which is little more than a homogeneous pile of stones whose

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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 to 3m 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 Grade 1989). They conducted laboratory studies and achieved K_t of 0.5-0.6 without significant damage to the blocks. Madsen and White (1976) developed an analytical approach to determine the reflection and transmission coefficients and K_t decreasing 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), 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. Many physical model studies have been accomplished by various researchers and scientists to establish various equations for coefficient of wave transmission (K_t), but those are constrained for certain laboratory 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.

2.1. Objective of the study

1) Prediction of wave transmission Co-efficient (K_t) over submerged reef for varying depths and crest widths.
2) Comparison of the results generated by empirical studies with experimental studies.
3) To develop an equation for K_t.

3. Methodology

The present research work is proposed to arrive at the semi empirical equation for coefficient of wave transmission K_t through dimensional analysis by modeling in MATLAB. This is carried out by studying the various parameters on which K_t is dependent from literature. Preliminary equation is derived from dimensional analysis and 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 are selected as the equation for K_t. The details of the methodology are illustrated in figure 3.1.

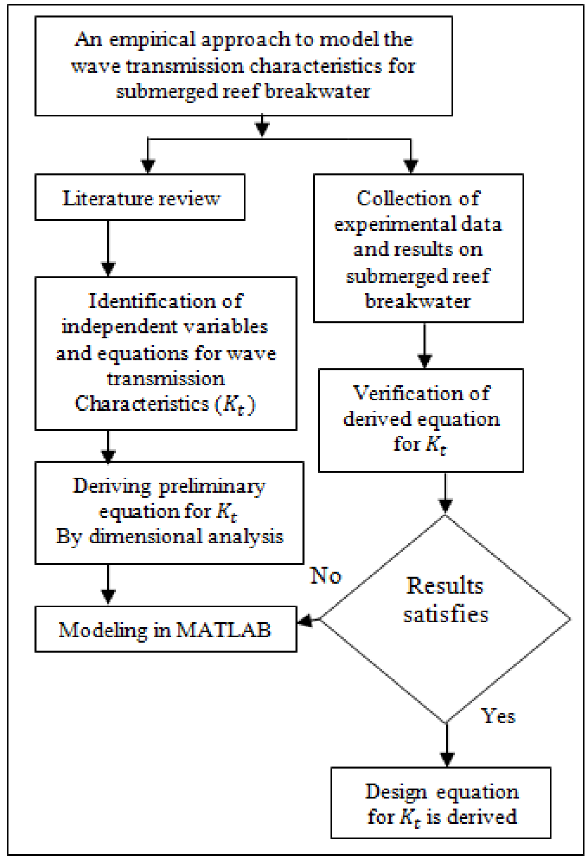

Figure 3.1 *Flowchart of Methodology*

4. Empirical Formulation

4.1. 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 4.1.

Table.4.1 *Identified variables on which K_t is dependent*

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}

$$K_t = \frac{H_t}{H_i} \quad (4.1)$$

$$K_t = f\{H_t, H_i, B, F, d, T, g, D_{n50}\} \quad (4.2)$$

$$\frac{H_t}{H_i} = f\left\{\frac{F}{B}, \frac{d}{D_{n50}}, \frac{2\pi H_i}{gT^2}, \frac{h}{d}\right\} \quad (4.3)$$

Where,

$\frac{F}{H_i}$ = 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

5. 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. The equation is thus obtained is modeled in MATLAB to achieve more accuracy in results. And hence the following equation is obtained.

$$K_t = \left(0.02\frac{F}{B} + 0.035\frac{h}{d}\right) \times \left(\frac{d}{D_{n50}} + \frac{0.25}{\sqrt{S_p}}\right) \quad (4.4)$$

6. Model Study

Above equation is coded in MATLAB and parameters were drawn to the software based on physical model studies on submerged reef breakwater using stones, conducted by Manu et al. (2012) at department of Applied Mechanics and Hydraulics, NITK Surathkal. The structure was a trapezoidal submerged reef model of scale 1:30, slope of 1V:2H, height(h) of 0.25 m and crest width were 0.2 m and 0.4 m are constructed over a flat bed of wave flume with stone as armour of optimum weight. 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 sec to 2.5 sec in a depth of water of varying from 0.3 m to 0.4 m.

As per the study the submerged reef successfully trips the steeper waves and dissipates major portion of the wave energy. The effectiveness of the reef in damping the waves increases in wave steepness. In the present study the waves of 0.1 m to 0.16 m height and wave periods of 1.5 sec to 2.5 sec are generated in water depth of 0.3 m. The waves break over the reef and transmitted wave heights were recorded on the leeside.

7. Results and Discussion

Results obtained by empirical formulation are expressed in non-dimensional quantities. The variation of transmission co-efficient (K_t) with varying wave and reef characteristics like wave steepness $H_0/(gT^2)$, h/d, F/d are compared through graphs which also includes various crest widths and water depths. 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.

7.1. Wave transmission over reef of crest width (B=0.2m) and at varying depth

7.1.1. Influence of deep water wave steepness for depth 0.3 m, 0.35 m and 0.4 m

Co-efficient of wave transmission K_t is determined for submerged reef through empirical analysis where the crest width of reef are 0.2 m and 0.4 m 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.

Figure 7.1 shows the best fit lines for the variation of K_t with deep water wave steepness parameter ($1.45X10^{-3} < H_0/gT^2 < 7.65X10^{-3}$) and for varying relative reef heights (h/d) of 0.625 to 0.833, while crest width is 0.2 m. In the results it is found that K_t decreased with increase in H_0/gT^2 and h/d whereas it increases with F/d K_t decreased from 0.5482 to 0.503 (8.2%), 0.648 to 0.5981(6.5%) and, 0.7585 to 0.7106 (6.3%) at the depth of water 0.3 m, 0.35 m, 0.4 m respectively.

Figure 7.2 shows the best fit lines for the variation of K_t with deep water wave steepness parameter ($1.45X10^{-3} < H_0/gT^2 < 7.65X10^{-3}$) and for varying relative reef heights (h/d) of 0.625 to 0.833 while the crest width is 0.4m. Same as previous results it is found that K_t decreased with increase in H_0/gT^2 and h/d whereas it increases with F/d. K_t decreases from 0.53 to 0.49 (7.5%), 0.55 to 0.51 (7.2%) and, 0.66 to 0.71 (7.04%) to the depth of water 0.3 m, 0.35 m, 0.4 m.

7.2. Comparison of empirical results with experimental results

7.2.1. Wave transmission over reef of crest width 0.2 m and varying depth (d) 0.3 m, 0.35 m, 0.4 m

Figure 7.3, 7.4 and 7.5 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 numerical and experimental results. K_t decreases from 0.58 to 0.4 (31.03%) for experimental and 0.53 to 0.49 (7.5%) for numerical to the depth of water 0.3 m. In the same manner K_t decreases from 0.67 to0.53 (20.8%) for experimental, 0.55 to 0.51 (7.2%) for numerical to the depth of 0.35 m. whereas K_t drops from 0.82 to 0.6 (26.8%) for experimental, 0.66 to 0.71 (7.04%) for numerical to the water depth of 0.4 m.

7.2.2. Wave transmission over reef of crest width 0.4m and varying depth (d) 0.3m, 0.35m, 0.4m

Figure 7.6, 7.7 and 7.8 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 numerical and experimental results. K_t decreases from 0.56 to 0.46 (17.8%) for experimental and 0.53 to 0.49 (7.5%) for numerical to the water depth of 0.3 m. In the same manner from 0.56 to 0.46 (17.8%) for experimental, 0.53 to 0.49 (7.5%) for numerical to the water depth of 0.35 m. whereas 0.76 to 0.62 (18.75%) for experimental and 0.66 to 0.71 (7.04%) for numerical to a water depth of 0.4 m.

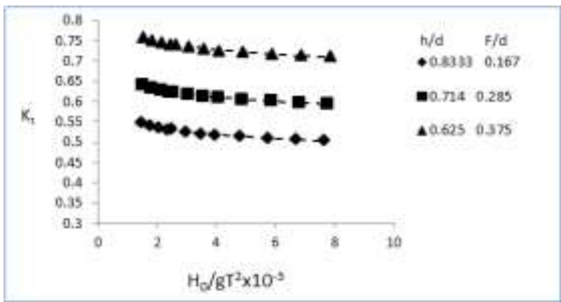

Figure 7.1 *Variation of K_t with H_0/gT^2 (B=0.2 m)*

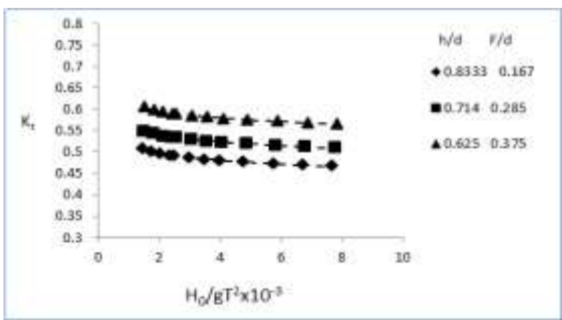

Figure 7.2 *Variation of K_t with H_0/gT^2 (B=0.4 m)*

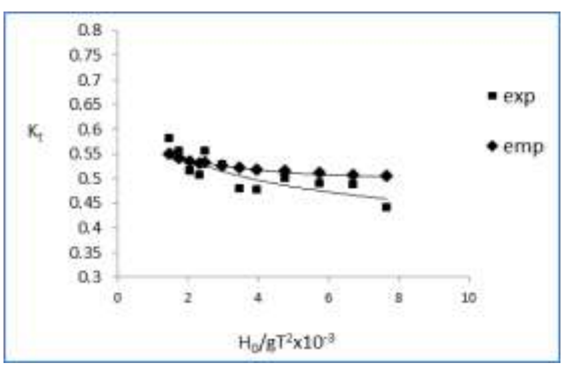

Figure 7.3 *Variation of K_t with H_0/gT^2 (d=0.3 m)*

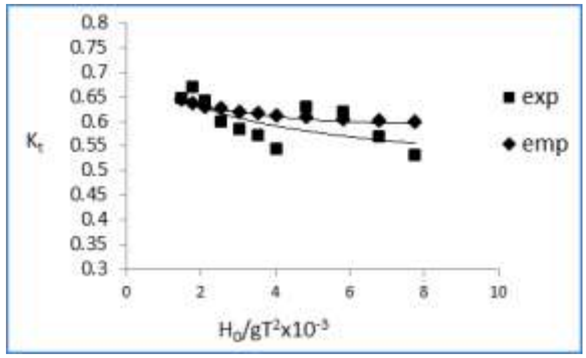

Figure7.4 *Variation of K_t with H_0/gT^2 (d=0.35 m)*

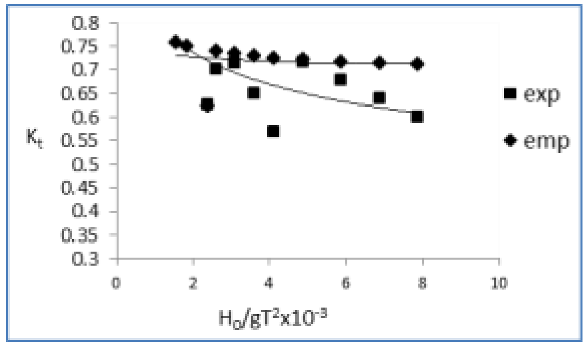

Figure 7.5 *Variation of K_t with H_0/gT^2 (d=0.4 m)*

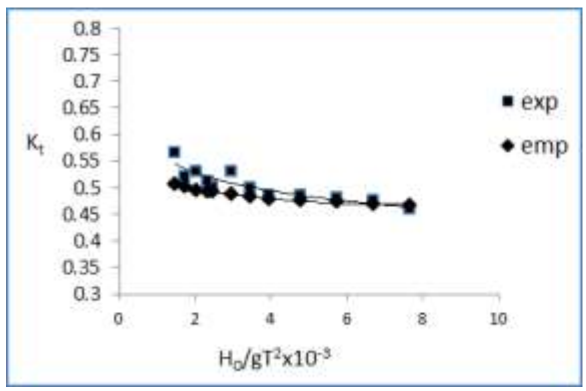

Figure 7.6 *Variation of K_t with H_0/gT^2 (d=0.3 m)*

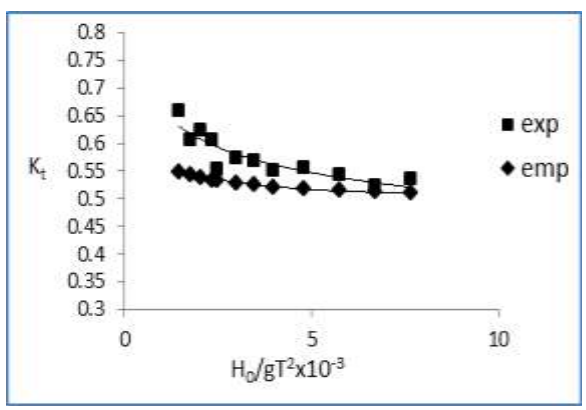

Figure 7.7 *Variation of K_t with H_0/gT^2 (d=0.35m)*

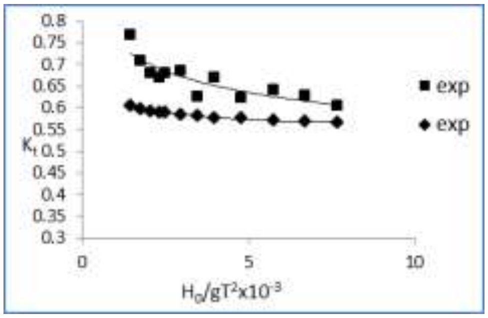

Figure 7.8 *Variation of K_t with H_0/gT^2 (d=4 m)*

8. Conclusions

From the present study the following conclusions are drawn.

1. H_0/gT^2, h/d, F/B are the variables which influences effectively on K_t.
2. As B increases by 200% the value of K_t falls from 0.7583-0.5038 (33.56%) to 0.58-0.44 (24.13%).
3. The final equation for K_t is established as

$$K_t = \left(0.02\frac{F}{B} + 0.035\,\frac{h}{d}\right) \times \left(\frac{d}{D_{n50}} + \frac{0.25}{\sqrt{S_p}}\right)$$

4. Results obtained by empirical formulation are in good agreement with the experimental results.

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