# Hydraulic Performance of 'HOBO' units

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***Abstract*—The paper presents the results of a detailed two dimensional model investigation of a rubble mound breakwater armoured with Hollow Block (HOBO) concrete armour units, with respect to the hydraulic performance. The results of the model investigations are analysed to obtain graphical and numerical relationships between the energy dissipation, wave reflection, energy transmission, wave steepness, wave period, Iribarren number and the section properties of the breakwater.**

***Keywords—Concrete Armour Blocks, Rubble Mound Breakwaters, Hollow Block Armour Units***

## I. Introduction

When waves interact with a porous sloping breakwater armoured with concrete armour units, most of the wave energy is dissipated the rest of the wave energy is reflected or transmitted, the magnitude of which will depend on the porosity and geometry of the structure. Achieving minimum energy transmission through the breakwater is preferred for the stability of the structure. From the energy conservation law, where $E_i$ is the energy of the incident wave, $E_r$ is the reflected energy, $E_t$ is the transmitted energy through the structure and $E_d$ is the dissipated wave energy; the relationship between $E_i$, $E_r$, $E_t$ and $E_d$ is given by (1).

$$E_i = E_r + E_t + E_d \tag{1}$$

Therefore, the relationship between $C_r$, $C_{te}$ and $C_d$ can be obtained as in (2), where $C_r$ is the Coefficient of Reflection, $C_{te}$ is the External Transmission Coefficient and $C_d$ is the Coefficient of Dissipation.

$$1 = C_r^2 + C_{te}^2 + C_d^2 \tag{2}$$

Hettiarachchi and Holmes (1988) have developed two formats to express the relationship between $C_r$ and $I_r$, where $I_r$ is the surf similarity parameter (Iribarren number), defined as $I_r = \tan\alpha/\sqrt{(H_i/L_o)}$ for regular waves, and the modified surf similarity parameter defined as $I_r' = \tan\alpha/\sqrt{(H_s/L_p)}$ for random waves. For regular waves, $H_i$ is the incident wave height, $L_o$ is the deep water wave length and α is the armour slope. For random waves, $I_r'$ is expressed using significant wave height ($H_s$) and Wave length of peak period ($L_p$). Of course there are other variations using, for example median period etc.

Hettiarachchi and Holmes (1988) proposes to express the relationship between $C_r$ and $I_r$ either as $C_r = a.I_r^2/(I_r^2+b)$ or $C_r = a\,(1 - \exp(-I_r.b))$ where a and b are constants. When $C_r = a.I_r^2/(I_r^2+b)$ is considered, it can be shown that the graph of $1/C_r$ vs $1/I_r^2$ will be in the form of $1/C_r = m.(1/I_r^2)+c$, where m is the gradient of the graph and c is the intercept.

Dunster et al. (1988) quotes Allsop and Hettiarachchi having developed the relationship between $C_r$ and $I_r$ for COB and SHED armour units, both belonging to the single layer hollow block variety. For COBs when regular waves are present, $C_r$ varies with $I_r$ as in (3), while for SHEDs when random waves are present, $C_r$ varies with $I_r'^2$ as in (4).

$$C_r = 0.5\, I_r^2/(I_r^2 + 6.54) \tag{3}$$

$$C_r = 0.49\, I_r'^2/(I_r'^2 + 7.94) \tag{4}$$

## II. Objective Of The Paper

This paper presents re-analysed results of a two dimensional physical model investigation conducted on a trapezoidal rubble mound breakwater section armoured with Concrete Hollow block armour units also referred to as HOBO Units. These model investigations were carried out on designs developed by Hettiarachchi and Mirihagalle (1998, 1999, and 2000).

The outputs obtained are presented in graphical format for convenience. The results can be effectively used for the preparation of design guidelines for rubble mound breakwaters armoured with HOBO units; because a broader design wave climate has been achieved by having a variety in incident waves with respect to wave period, steepness etc.

## III. Experimental Programme

### A. Details of HOBO Unit

Details of the HOBO Unit area given below in Table 1 and Fig 1.

TABLE I. DETAILS OF HOBO UNIT

| Property | Description |
|---|---|
| Prototype dimensions | 1.3 m sides, and 0.7m diameter hole perpendicular to the breakwater slope<br>Void ratio of units = 22.7% |
| Model dimensions | 6.5 cm sides, and 3.5cm diameter hole perpendicular to the breakwater slope |
| Classification | Single layer hollow block armour unit without lateral porosity |

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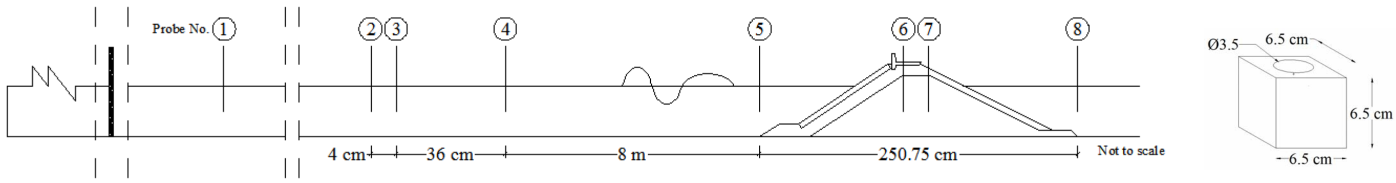


Fig. 1. Experimental Setup, probe arrangement and armour unit (model) dimensions

## B. *Preparation of Armour Units*

Large scale model of the breakwater structure had been tested in a wave flume to assess the hydraulic performance. The details of the structure are as follows.

TABLE II. PREPARATION OF ARMOUR UNIT

| Property | Description |
|---|---|
| Scale | 1:20<br>(Since the scale is high, the test is representing prototype conditions) |
| Structure | Trapezoidal layered breakwater with a crest wall |
| Armour type | Main armour hollow block units of the cubic form |
| Laying of armour units | Single layered, predetermined pattern; on beside the other in rows<br>Laid in rows, well defined and uniform voids matrix |
| Mix design for the models | 1:3 cement sand mortar<br>Cured for 28 days |

The design of cubes for the model test had been carried out in accordance to the design of COB and SHED armour units. The decision making regarding thickness of the armour layer, thickness of under layers, characteristic dimensions of the armour unit and materials used for the under layer was also done in relation to the breakwaters armoured with COB and SHED armour units. Core material was selected complying with the prototype gradation curve.

## C. *Physical Modelling*

TABLE III. EXPERIMENTAL SETUP

| Element | Considerations |
|---|---|
| Wave generator | Random wave generator which is also able to generate regular waves |
| Flume dimensions | Length 30 m, Width 0.8 m, Height 1 m |
| Seabed profile | Sand compacted to the required levels and applying a thin cement mortar screed on top of it |
| Special considerations | Sufficient length has been provided between the paddle and the deepest point of the seabed to facilitate fully development of waves<br>Simultaneous wave records have been taken from three different points in the wave flume to facilitate reflection analysis<br>wave records have been taken at the middle of the structure to measure the transmission through the structure |
| Regular waves | Water depth near structure 7m and 8m<br>Wave Periods 6s, 8s and 12s |
| Random waves | Water depth near structure 7m and 8m<br>Wave Periods 4s, 6s, 8s and 10s |

## D. *Instrumentation and Data Acquisition*

Both regular and random waves were used for the tests which were carried out for two still water depths. Probes had been used to measure the wave heights which facilitate the calculation of wave energy. They had been placed at pre-determined locations in the wave flume as shown in Figure1. External and internal transmission through the structure was measured. The experiment design permitted internal wave heights to be measured whereby it was possible to compute wave energy dissipation at selected locations within the structure.

## E. *Reflection Analysis*

Since waves reflect after interacting with the breakwater, an arrangement is used to separate measurements of the incident and reflected waves. Simultaneous wave recordings have been taken at three different locations in the wave flume for the reflection analysis. Spacing between these probes was designed in accordance with the incident wave climate and the software for flume instrumentation control. Even though reflection analysis has been a focus of attraction of researchers, the evaluation of wave reflection still remains a reliable estimate.

# IV. ANALYSIS AND RESULTS

## A. *Variation of $C_r$, $C_d$ and $C_{te}$ with wave steepness*

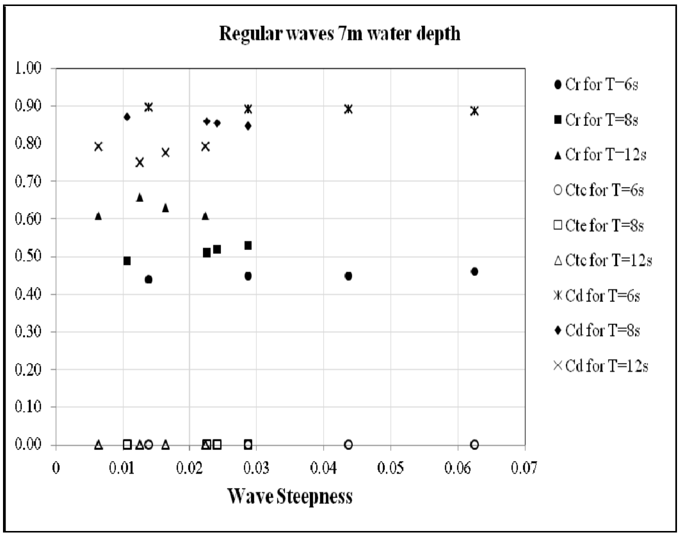


Fig. 2. $C_r$, $C_d$ and $C_{te}$ vs wave steepness for 7 m water depth – Regular waves

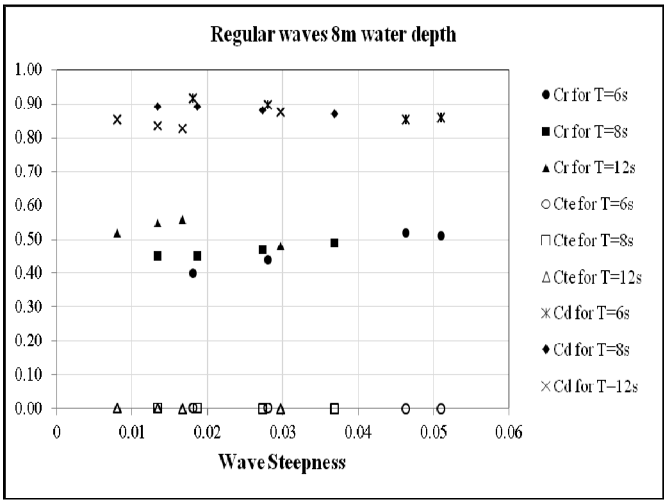


Fig. 3. $C_r$, $C_d$ and $C_{te}$ vs wave steepness for 8 m water depth – Regular waves

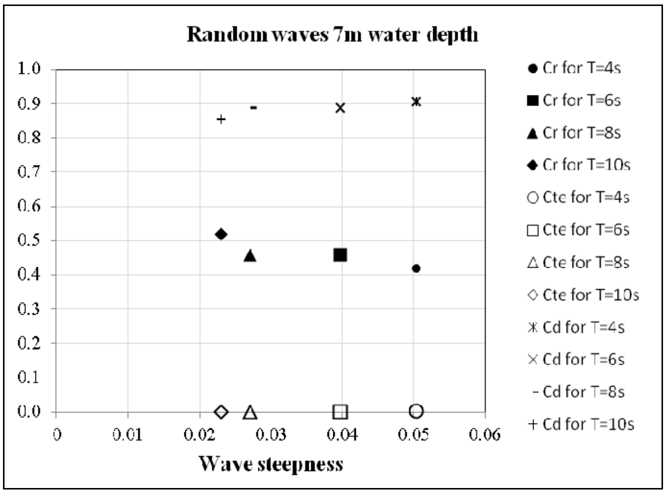


Fig. 4. $C_r$, $C_d$ and $C_{te}$ vs wave steepness for 7 m water depth – Random waves

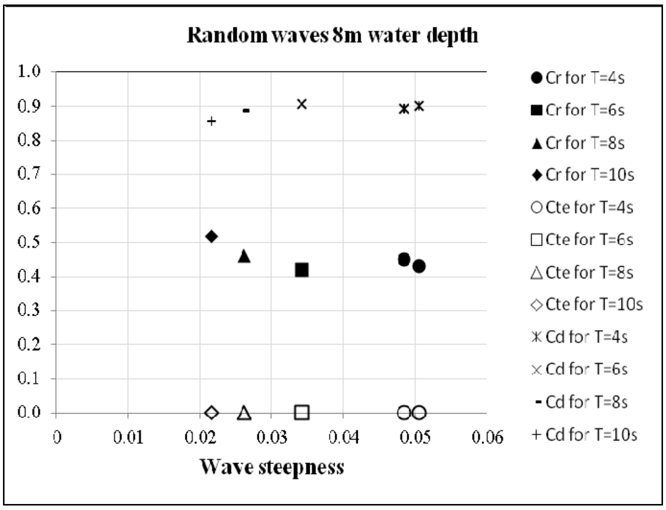


Fig. 5. $C_r$, $C_d$ and $C_{te}$ vs wave steepness for 8 m water depth – Random waves

Figure 2 and Figure 3 present the variation of $C_r$, $C_d$ and $C_{te}$ vs wave steepness for regular waves. According to these figures, it can be noted that $C_r$ increases with wave period. It can also be noted that $C_d$ increases with the wave steepness.

Figure 4 and Figure 5 present the variation of $C_r$, $C_d$ and $C_{te}$ vs wave steepness for random waves. According to these figures, it can be noted that $C_r$ increases with wave period and $C_d$ increases with the wave steepness.

Therefore it can be observed that the same behavior pattern as for regular waves prevails for random waves as well.

*B. Variation of $C_{t1}$, $C_{t2}$ and $C_{te}$ with wave steepness for regular waves*

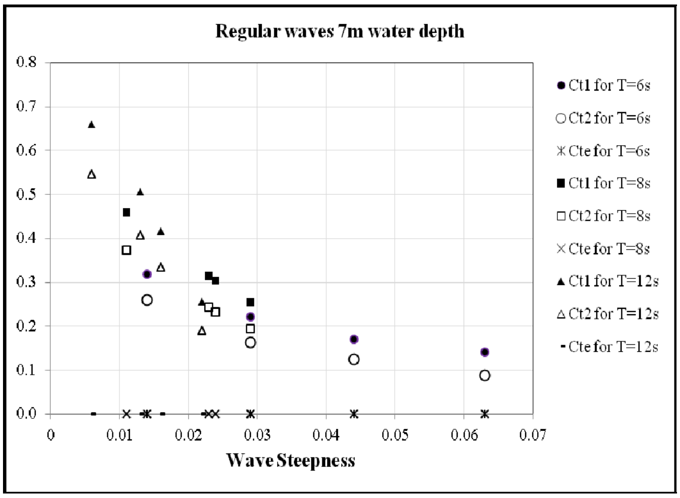


Fig. 6. $C_{t1}$, $C_{t2}$ and $C_{te}$ vs wave steepness for 7 m water depth

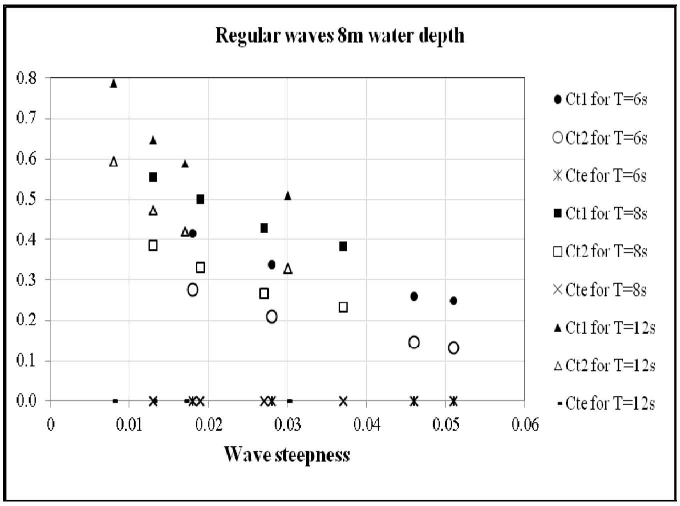


Fig. 7. $C_{t1}$, $C_{t2}$ and $C_{te}$ vs wave steepness for 8 m water depth

Figure 6 and Figure 7 represent the variation of $C_{t1}$, $C_{t2}$ and $C_{te}$ vs wave steepness thereby understanding the behavior of internal transmission coefficients as well as external transmission coefficients; because $C_{t1}$ is the coefficient of transmission until the location of 1st probe inside the structure and $C_{t2}$ is the coefficient of transmission until the location of 2nd probe inside the structure. According to the figures, it can be noted that the transmission coefficients increase with the increase of wave period. Both $C_{t1}$ and $C_{t2}$ decrease with the increase of wave steepness. Further it can be noticed that $C_{t1}$ and $C_{t2}$ increases with the increase of water depth at the structure. This is mainly due to the reduction of the length of the structure at mean water depth level where considerable wave energy dissipation takes place.

### *C. Variation of $C_{t1}$, $C_{t2}$ and $C_{te}$ along the structure for regular waves*

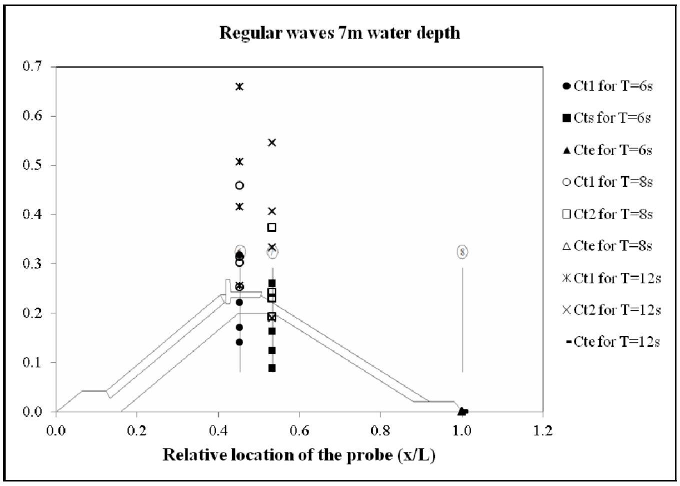


Fig. 8. $C_{t1}$, $C_{t2}$ and $C_{te}$ vs the probe location – Regular waves, 7 m water depth

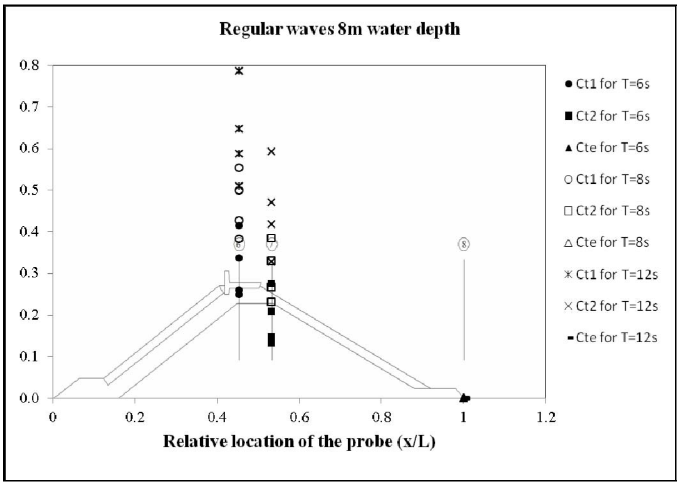


Fig. 9. $C_{t1}$, $C_{t2}$ and $C_{te}$ vs the probe location – Regular waves, 8 m water depth

Figure 8 and 9 represent the Variation of $C_r$, $C_d$ and $C_{te}$ along the length of the structure. The length of the structure is expressed as a non dimensional parameter called x/L, where x is the length to the probe location from the seaside end of the breakwater base and L is the total length of breakwater.

According to the figures, transmission coefficient reduces along the structure. All transmission coefficients ($C_{t1}$, $C_{t2}$ and $C_{te}$) are high when the water depth is higher at the structure. This can be due to the smaller cross sectional area along the structure at the still water level; when the water depth is increased at the structure. Since significant wave action occurs at still water level and thereby energy dissipation takes place in the vicinity of the mean water level, the increase in the structure along the still water level contributes to greater energy dissipation and hence to lower energy transmission. When the wave transmits through the pores of the structure, velocity increases as a result of the smaller cross sectional area. Due to the velocity increase, the frictional forces increase. Further, a resistance occurs by the presence of air bubbles and as a result, the transmission reduces along the structure.

### *D. Variation of $1/C_r$ with $1/I_r^2$*

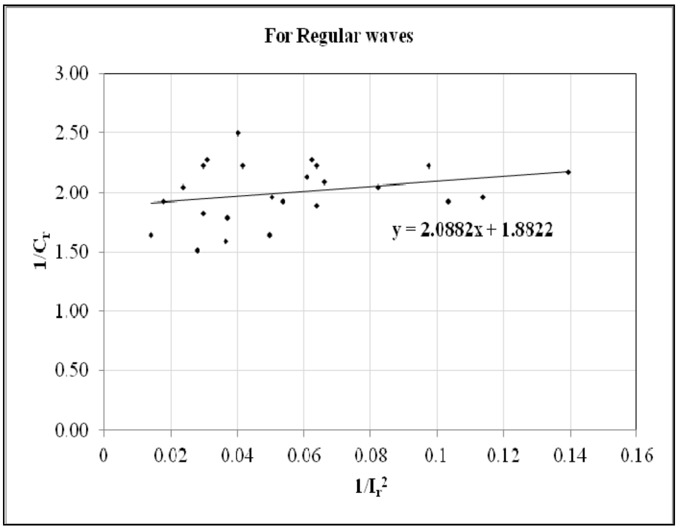


Fig. 10. $1/C_r$ vs $1/I_r^2$ for Regular waves

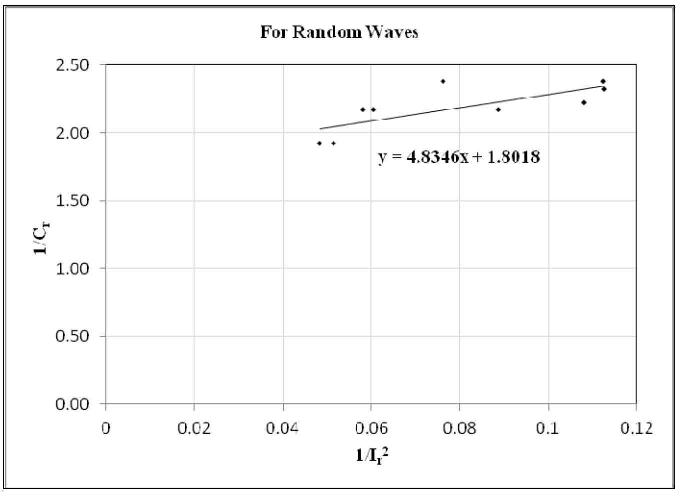


Fig. 11. $1/C_r$ vs $1/I_r'^2$ for Random waves

By considering the above variation and using liner regression analysis, it is possible to develop expressions for wave reflection.

According to the graphical analysis in Figure 10, $C_r$ is related to the Surf similarity parameter as $C_r = 0.52\, I_r^2/(I_r^2+1.11)$ for HOBO units, regular waves.

According to the graphical analysis in Figure 11, $C_r$ is related to the Surf similarity parameter as $C_r = 0.56\, I_r'^2/(I_r'^2+2.68)$ for HOBO units, random waves.

## V. Conclusions

The characteristics related to the hydraulic performance obtained from large scale model tests for a rubble mound concrete armoured breakwater armoured with hollow block units was analysed and graphical representation of the results are presented.

According to the re-analysis it can be noted that the structures behave in a similar manner for both regular and random waves.

$C_r$ increases with the wave steepness for a constant wave period. Further it can be noted that $C_d$ increases with the wave steepness.

The transmission coefficients increase with the increase of wave period. Both $C_{t1}$ and $C_{t2}$ decrease with the increase of wave steepness. The transmission coefficient reduces along the structure indicating energy dissipation.

The transmission coefficients are lower for smaller water depth at the structure in view of increase length of structure at mean water level.

$C_r$ is related to the Surf similarity parameter as $C_r = 0.52\, I_r^2/(I_r^2+1.11)$ for regular waves and as $C_r = 0.56\, I_r'^2/(I_r'^2+2.68)$ for random waves, when the breakwaters are armoured with HOBO units

## VI. Notations and Abbreviations

$C_d$ Coefficient of dissipation

$C_r$ Coefficient of reflection

$C_{t1}$ Coefficient of transmission until the location of 1st probe inside the structure

$C_{t2}$ Coefficient of transmission until the location of 2nd probe inside the structure

$C_{te}$ Coefficient of transmission until the harbor side end of the structure

$E_d$ Dissipated wave energy

$E_i$ Energy of the incident wave

$E_r$ Reflected energy

$E_t$ Transmitted energy through the structure

H Wave height

$H_i$ Incident wave height

$H_s$ Significant wave height

$I_r$ Iribarren Number (Surf similarity parameter)

$I_r'$ Modified Iribarren Number (Modified Surf similarity parameter)

L Total length of the breakwater

$L_o$ Deep water wave length of the wave

$L_p$ Wave length of peak period

T Wave period in seconds

x The length to the probe location inside the breakwater measured from the seaside end of the breakwater base

α Armour slope of the seaside of breakwater

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