HYDRAULIC PERFORMANCE OF RUBBLE MOUND BREAKWATERS

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Abstract: Breakwaters are widely used to mitigate the adverse impacts of ocean wave action. Breakwater failures that occurred during late seventies and early eighties, have highlighted the need for further investigations on breakwaters in terms of their hydraulic performance.

This paper presents the hydraulic performance of conventional rubble mound rock armoured breakwaters and concrete armoured rubble mound breakwaters, statically stable berm breakwaters and reshaping berm breakwaters based on the re-analysis of large scale model tests.

Keywords: Breakwaters, Rubble mound, Rock armoured, Concrete armoured, Berm

1. Introduction

Coastal Structures are used to protect the shoreline from wave actions and coastal erosion. Breakwaters provide protection and calm waters for vessels to manoeuvre, load and unload in sheltered areas. They are widely used to form convenient environments in harbour basins by creating calm areas at their lee.

1.1. Energy dissipation through the breakwaters

Based on the mechanism used to obtain a calm area at the lee, breakwaters can be divided into two categories, as vertical breakwaters (both porous and non porous) and rubble mound sloping breakwaters which are porous. Vertical breakwaters reflect a large proportion of the wave energy while rubble mound sloping breakwaters facilitate energy dissipation through the pores. Even though rubble mound breakwaters are designed to facilitate energy dissipation, reflection and transmission also occur, sometimes in appreciable magnitudes. From the conservation of energy,

$$E_i = E_r + E_t + E_d \quad (1)$$

Therefore, the relationship between C_r, C_t and C_d can be obtained.

$$1 = C_r^2 + C_t^2 + C_d^2 \quad (2)$$

1.2. Breakwater failures and causes

Major breakwater failures in late seventies and early eighties made the coastal engineers to be more concerned regarding the breakwater design methods. According to Hettiarachchi (2011) the reasons for the failures can be summarized as:

1. Underestimation of the design wave climate
2. Limitations of adopting standard hydraulic model investigations for the total design

3. Inadequate understanding of the hydro geotechnical aspects of wave action and flow through porous structures
4. Poor assessment of wave induced loads and resulting force domain
5. Limited relative strength of large unreinforced interlocking types of armour units
6. Instability of armoured units in steep slopes
7. Poor durability of concrete in the marine environment
8. Inadequate understanding of the inter-relationship among different failure modes (i.e. understanding of the fault tree)
9. Improper construction practice and management
10. Absence of Design Code of Practice for the design of maritime structures (which was rectified only in 1991)

2. Objective of the Paper

This paper presents re-analysed results on hydraulic performance used on physical model studies of rubble mound structures, referring to four structural configurations. These studies were carried out by Hettiarachchi and Mirihagalle (1998, 1999, 2000).
The outputs obtained are presented in graphical format to facilitate proper understanding regarding the hydraulic performance of the rubble mound structures considered. The main three areas in breakwater design are geotechnical performance, hydraulic performance and structural performance. When considering about hydraulic performance, (energy dissipation, wave transmission, wave reflection and etc.) these results can be effectively used for the preparation of design guidelines for rubble mound breakwaters because a broader design wave climate has been achieved by having a variety in incident waves with respect to wave period, steepness etc.

3. Experimental programme

Large scale models of the structures had been tested in a wave flume to assess the hydraulic performance. The structures on which the experiments were carried out are classified as follows. (The scales of the model investigation are stated in brackets.)

1. Rubble mound trapezoidal layered breakwater armoured with hollow block concrete units of cubic form and having a crest wall (1:20)
2. Rubble mound trapezoidal layered breakwater armoured with rock (1:20)
3. Statically stable rubble mound trapezoidal layered breakwater with a berm (1:20)
4. Reshaping rubble mound trapezoidal layered breakwater with a berm (1:36)

The structures had been tested for both regular and random wave conditions for different water depths near the structure. Wave probes had been used to measure the wave heights at the desired locations, both within and outside the structures. A random wave generator which is also capable of generating regular waves had been used for wave generation. Since the incident wave and reflected wave together create a standing wave, a special arrangement had been used for the reflection analysis.

4. Analysis and Results

4.1 Presentation and discussion of results

This paper presents selected important results from the re-analysis conducted. The results obtained from the experimental model investigations are presented in graphical format. The results illustrate hydraulic performance for a range of incident waves for three different structures.

Since the graphs obtained for different water depths near the structure show similar behavior patterns for both regular and random waves, only the graphs obtained for regular waves, for a 8m water depth at the structure are included. (In all the graphs presented, the wave period is stated in seconds)

4.1.1 Variation of C_r , C_d and C_t with the wave steepness

Figures 1, 2, 3 and 4 present the variation of C_r , C_d and C_t vs wave steepness, for Rubble mound concrete armoured breakwater, Rubble mound rock armoured breakwater, statically stable breakwater with berm and the Reshaping breakwater with berm. These figures show the behavior of C_r , C_d and C_{te} with the steepness. According to these figures, it can be noted that C_r decreases when the wave steepness increases and when the wave period increases. This behavior is common for all structures considered. It can also be noted that C_d increases with the wave steepness.

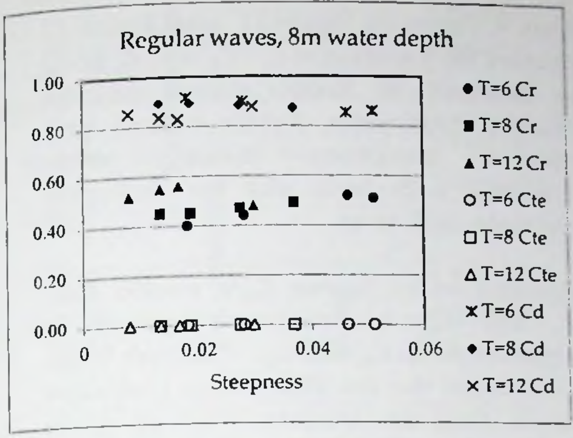

Figure 1: C_r , C_d and C_{te} vs wave steepness, for Rubble mound concrete armoured breakwater

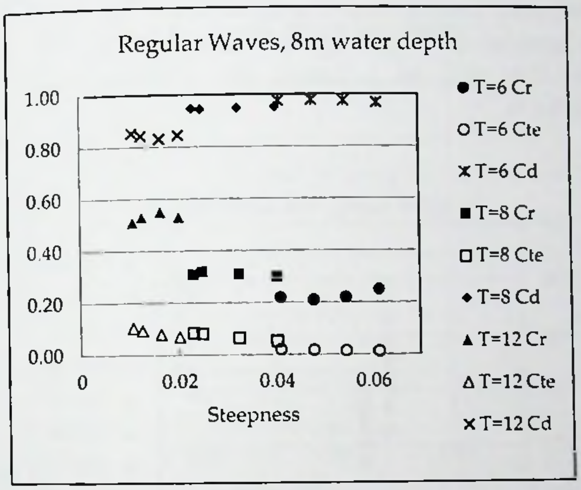

Figure 2: C_r , C_d and C_{te} vs wave steepness, for Rubble mound rock armoured breakwater

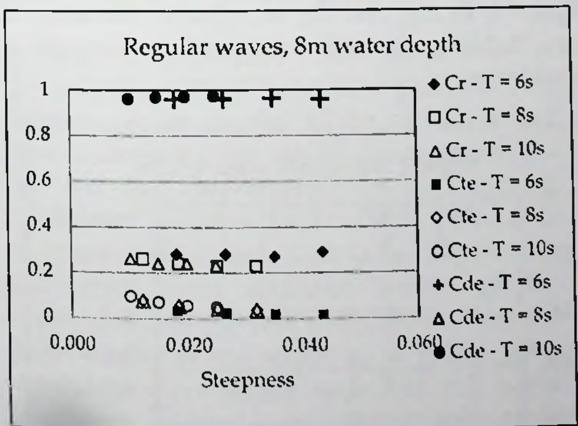

Figure 3: C_r , C_d and C_{te} vs wave steepness, for Statically stable breakwater with berm

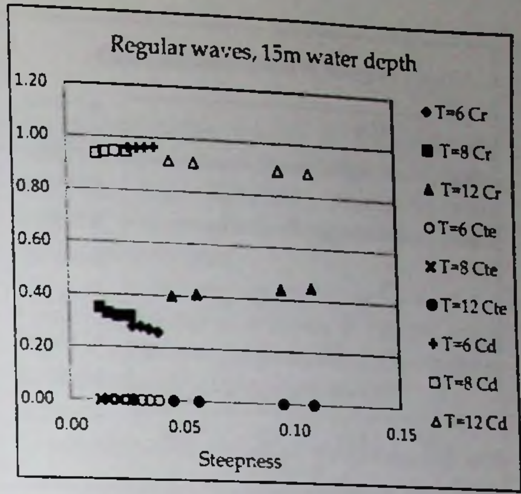

Figure 4: C_r , C_d and C_t Vs wave steepness, for Reshaping breakwater with berm

4.1.2 Variation of C_{t1} , C_{t2} and C_{te} with the wave steepness

Figure 5, Figure 6, Figure 7 and Figure 8 represent the variation of C_{t1}, C_{t2} and C_{te} Vs wave steepness, for Rubble mound concrete armoured breakwater, Rubble mound rock armoured breakwater, statically stable breakwater with berm and the Reshaping breakwater with berm. According to the figures, it can be noted that the transmission coefficients increase with the increase of wave period for all the considered structures. Both C_{t1} and C_{t2} decrease with the increase of wave steepness.

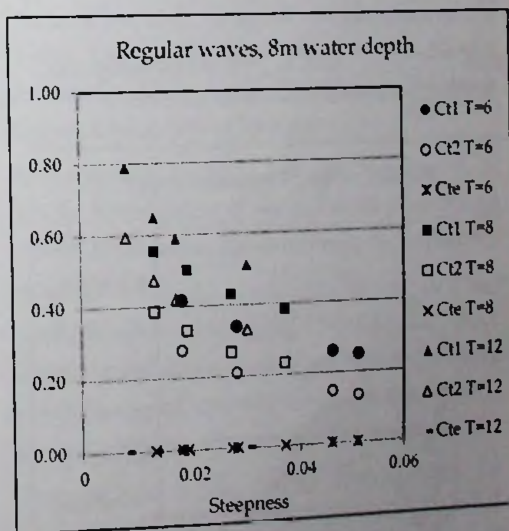

Figure 5: C_{t1}, C_{t2} and C_{te} Vs wave steepness, for Rubble mound concrete armoured breakwater

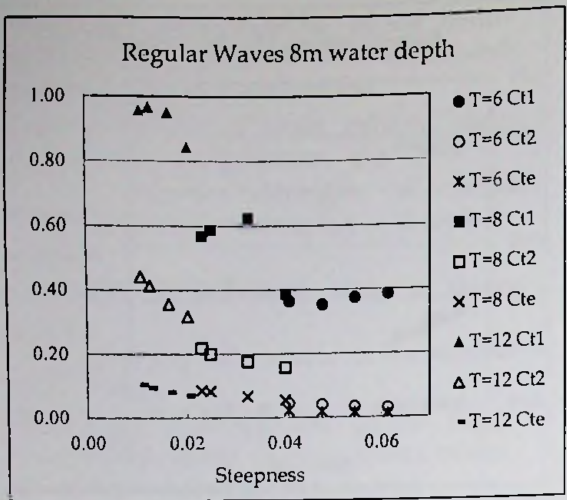

Figure 6: C_{t1}, C_{t2} and C_{te} Vs wave steepness, for Rubble mound rock armoured breakwater

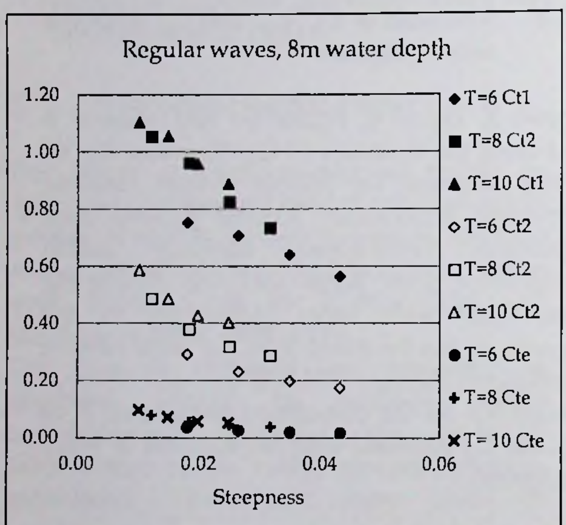

Figure 7: C_{t1}, C_{t2} and C_{te} Vs wave steepness, for Statically stable breakwater with berm

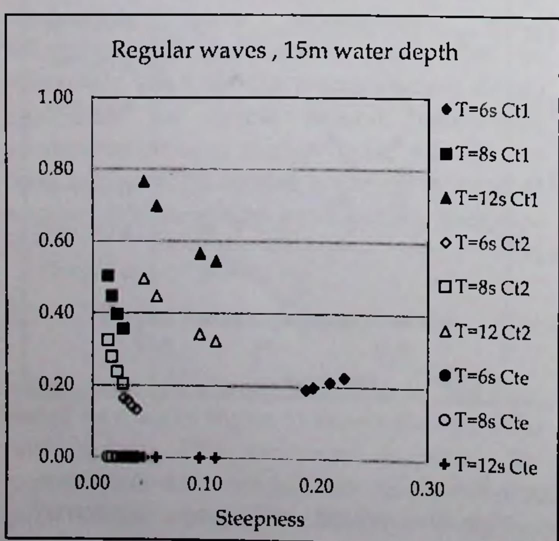

Figure 8: C_{t1}, C_{t2} and C_{te} Vs wave steepness, for Reshaping breakwater with berm

4.1.3 Variation of C_r , C_d and C_t along the structure

Figure 9, Figure 10, Figure 11 and Figure 12 represent the Variation of C_r , C_d and C_t along the structure, for Rubble mound concrete armoured breakwater, Rubble mound rock armoured breakwater, statically stable breakwater with berm and the Reshaping breakwater with berm.

According to the figures, C_{t2} is smaller than C_{t1}, and C_{te} is considerably small in comparison with C_{t1} and C_{t2}. Therefore it can be concluded that the transmission coefficient reduces along the structure. 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.

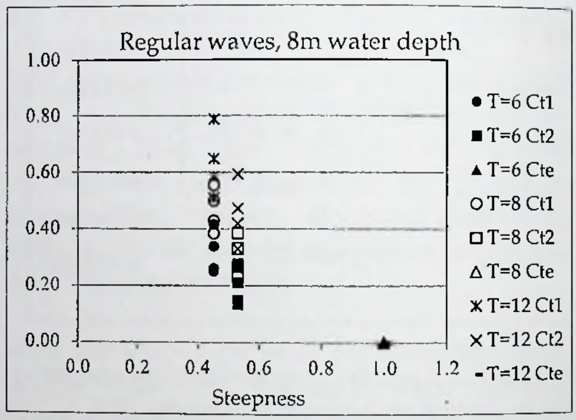

Figure 9: C_{t1},C_{t2} and C_{te} Vs relative distance, for Rubble mound concrete armoured breakwater

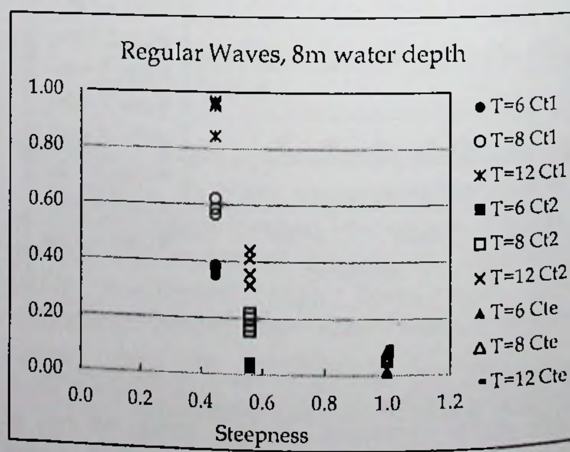

Figure 10: C_{t1}, C_{t2} and C_{te} Vs relative distance, for Rubble mound rock armoured breakwater

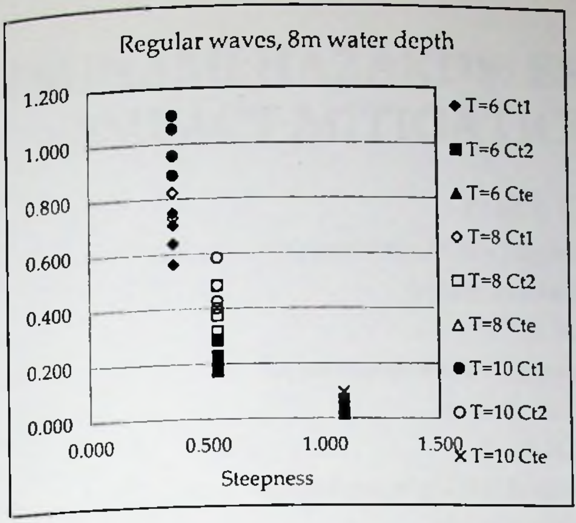

Figure 11: C_{t1}, C_{t2} and C_{te} Vs relative distance, for for Statically stable breakwater with berm

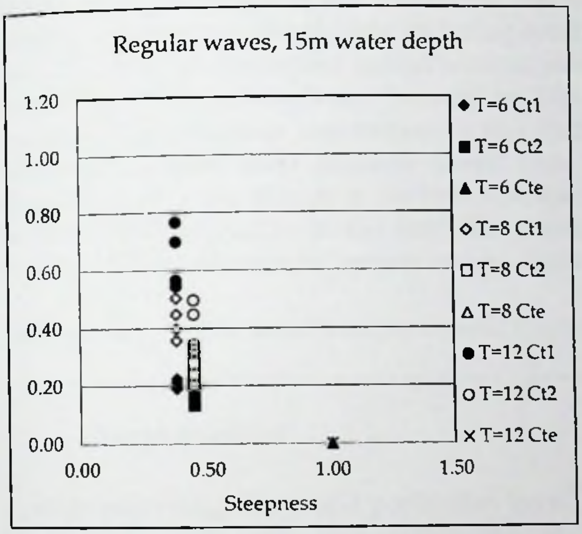

Figure 12: C_{t1}, C_{t2} and C_{te} Vs relative distance, for Reshaping breakwater with berm

It was noted that the variations of C_r, C_d and C_{te} have similar patterns for different water depths at the structure. But when comparing the results for water depths 7m and 8m respectively, the transmission coefficients are lower for 7m depth for all four structures considered. This is mainly due to the larger cross sectional length of the structure along the still water level when the water depth at the structure is small. 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 length of the structure along the still water level contributes to greater energy dissipation and lower transmission.

5. Conclusions

The characteristics related to the hydraulic performance obtained from large scale model tests for four different structures were 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, and with wave period for all the considered structures. Further it can be noted that C_d increases with the wave steepness.

The transmission coefficients increase with the increase of wave period for all the considered structures. Both C_{t1} and C_{t2} decrease with the increase of wave steepness. The transmission coefficient reduces along the structure.

C_r, C_d and C_{te} have similar behavior patterns for different water depths at the structure. But when comparing the results obtained for different water depths, the transmission coefficients are lower for smaller water depth at the structure, for all four structures considered.

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Notations

T	Wave period (seconds)
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	Total dissipated energy
E_r	Total reflected energy
E_{te}	Total transmitted energy throughout the full length of the structure
E_i	Total energy in the incident wave