INVESTIGATION OF HYDRAULIC PERFORMANCE OF GABION STRUCTURES

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Abstract: This paper presents selected results of a detail study of the transmission and reflection performance of gabion structures used in harbour and costal engineering applications. The performance of the structures is discussed and the results of experimental investigations relating wave reflection and transmission are reviewed and presented in a user friendly format. The paper also provided important observations on the response of the design parameters to varying incident wave conditions.

Keywords: wave reflection, wave transmission, energy dissipation

1. Introduction

1.1. Wave Energy Dissipation

Coastal structures are used to dissipate and/or reflect wave energy to protect land or water behind them from the effect of waves. Although tide or surge - induced water movements may influence the water levels at the structure giving rise to local currents, it is the section of wind waves and swell which constitute the principal forces acting on the structure. These structures may be broadly classified into two main categories.

1. Vertical Structures
2. Sloping Structures

Further classification can be made depending on geometric characteristics and internal composition.

Each of these structure types will dissipate some portion of the incident wave energy and will generally reflect the greatest part of the remainder. In the extremes the reflection performance of such structures may be compared either with that of solid vertical wall for which the proportion reflection approaches unity, or with a gently sloping yet porous beach for which the energy reflected approaches zero. Wave action on a costal structure results in a number of processes of interest to the designer. Wave energy arriving at a structure will experience three main transformations.

1. Dissipation,
2. Transmission by overtopping and due to the permeability of the structure, where applicable
3. Reflection.

The conservation of energy will be satisfied by an energy sum;

$$E_i=E_r+E_d+E_t \text{..............} (1)$$

The wave reflection coefficient (C_r), the transmission coefficient (C_t) and the dissipation coefficient (C_d) are correlated by the relationship.

$$1=C^2_r+C^2_t+C^2_d \text{..............} (2)$$

Wave reflections from costal structures are of considerable importance both in relation to costal harbours and the open coast. The wave reflection coefficient is a measureable parameter in both random waves and regular waves. The interaction of incident and reflected waves will often lead to a confused sea state in front of the structure, giving rise to occasional steep and unstable waves of considerable hazard to small boats. Reflected waves can propagate into areas of a harbour previously sheltered from wave action.

Wave transmission can cause erosion within structures leading to failure. Transmitted waves can cause increased wave activity in the harbour basin.

Owing to the complex nature of the processes involved, quantitative design information on wave reflection, transmission, run-up, and overtopping are developed primarily from physical experiments, mostly at reduced scale in wave flumes and basins.

1.2 Gabion Structures

Gabion structures are used for protection of river and estuary banks, for coast protection and as temporary structures for loading in fishery harbours. An assembly of gabions structures with a concrete slabs at the top have been used successfully as quays for loading and unloading in fishery harbours in Sri Lanka. These structures though temporary have performed well for more than a decade. These include near-shore waves, estuarial waves, waves within harbours and waves arising from vessels.

2. Objective of the Paper

This paper presents re-analysed results of a study on the hydraulic performance of vertical gabion structures. The experimental was carried out by Hettiarachchi et al (2007). The paper refers to three structural configurations which are investigated in detail for their hydraulic performance. The results of the physical model investigations using mainly random waves cover a wide domain with respect to geometry and incident wave conditions.

3. Experimental Programme

The three structures which were tested can be classified as

1. Open gabion structure
2. Gabion structure with impervious rear wall
3. Open gabion structure with berm

The configurations are presented in Figures 1, 2 and 3.

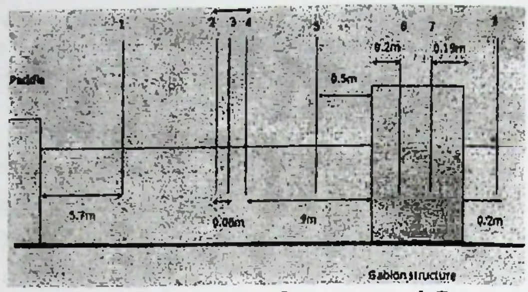

Figure 1 - Open Gabion Structure and Gauge Positions

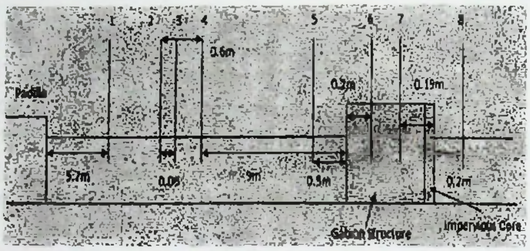

Figure 2 - Gabion Structure with Impervious Rear Wall and Gauge Positions

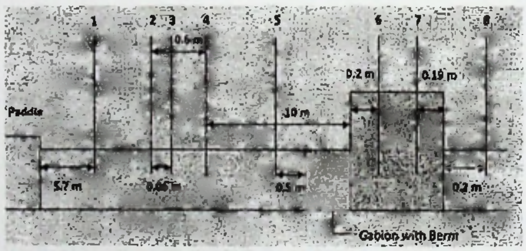

Figure 3 - Open Gabion Structure with Berm and Gauge Positions

Some of the relevant details of the experimental programme which was done on a large scale are described below.

Model Scale	: 1:5
Types of waves	: Random
Depth at paddle	: 0.545m
Number of wave gauges	: 8
(Numbered from 1-8 in Figure1, 2 and 3)	
Paddle to gauge 1 distance	: 5.7m
Depth near structure	: 0.4m
Total test duration	: 8.5 min

All three structures were tested under similar condition to compare the results.
Prototype block simulated in the experiment is 1m × 1m ×1m in dimensions and use 50 mm × 50 mm mesh.
The wave heights for the three structures were measured over the same frequency range and no overtopping was permitted.

3.3. Observed Graphs

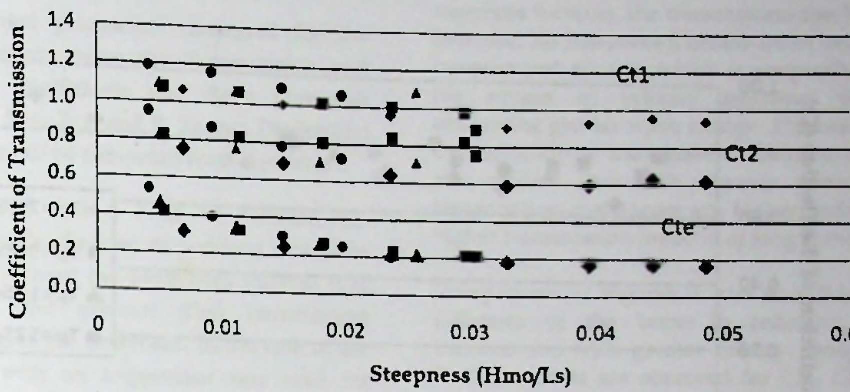

Figure 4 - Coefficient of Transmissions Reflection Coefficient vs. Steepness

Pervious Core

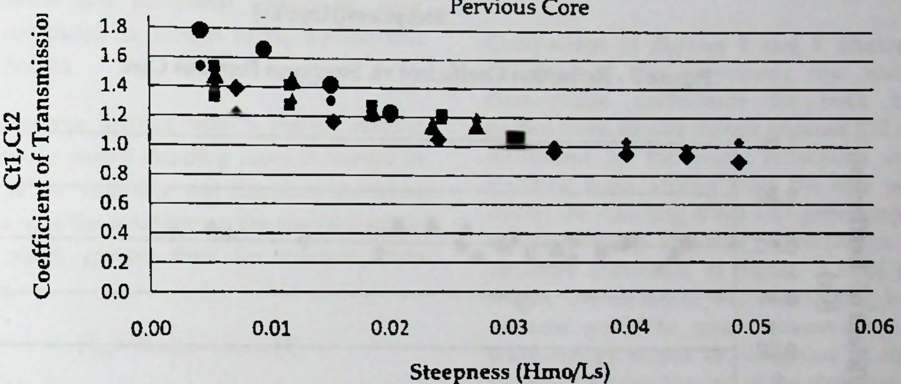

Figure 5 - Coefficient of Transmissions Reflection Coefficient vs. Steepness

Impervious core

(A smaller marker represents Ct1 values and a large marker represents Ct2 values.)

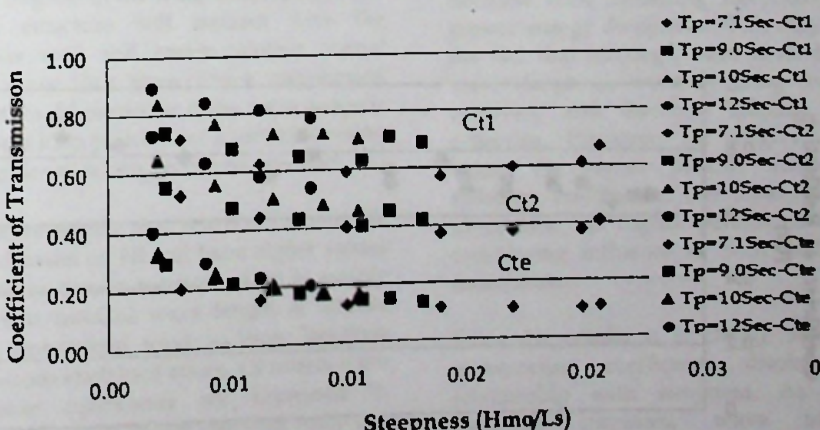

Figure 6 - Coefficient of Transmissions Reflection Coefficient vs. Steepness

Pervious Core with a Berm

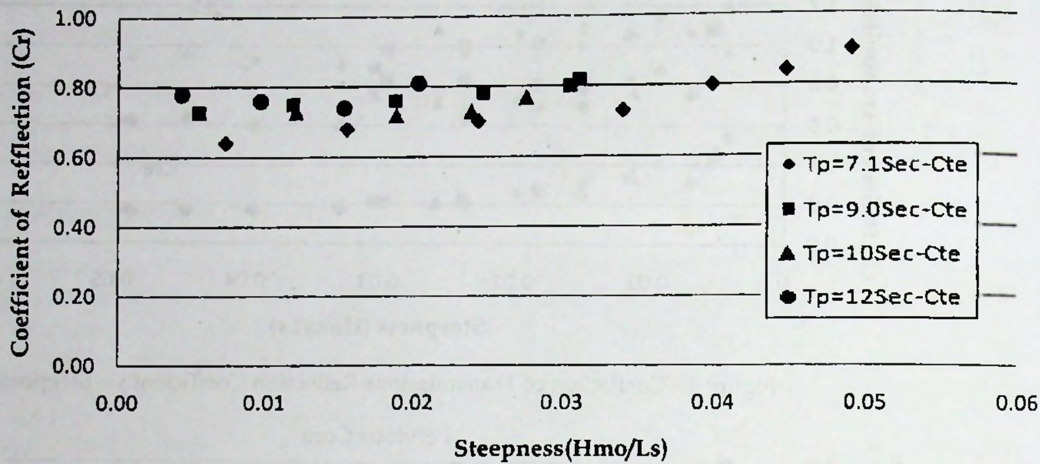

Figure 7 - Reflection Coefficient vs. Steepness Pervious Core

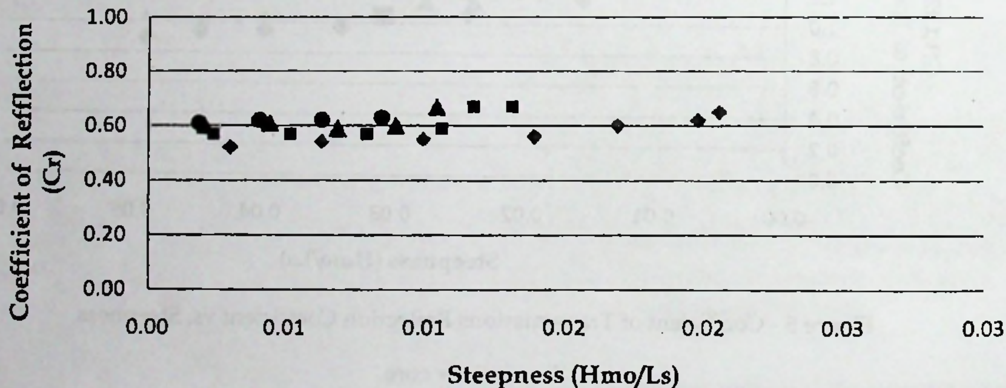

Figure 8 - Reflection Coefficient vs. Steepness Impervious core

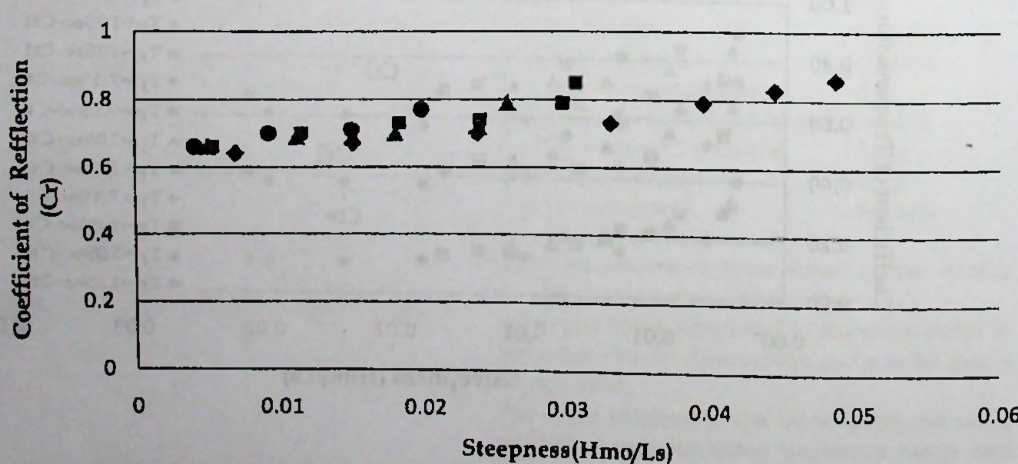

Figure 9 - Reflection Coefficient vs. Steepness Pervious Core with a Berm

3.4. Discussion of results

The principal parameters measured for the three structures were the Transmission and Reflection Coefficients and these presented Figures 4, 5, 6, 7, 8 and 9. Energy Dissipation coefficients can be computed from Equation 2.

Figures 4, 5 and 6 refer to Transmission Coefficients. In the case of pervious structures with and without the berm both internal (Ct1 and Ct2) and external (Cte) transmission characteristics are presented. In the case of the structure with an impervious rear wall the external transmission coefficient (Cte) is not applicable. For all structures the transmission coefficients and reflections coefficients have been computed in relation to Hi, the incident wave height.

When waves interact with a porous vertical structure a partial standing wave is formed in front of the structure and therefore the wave height near the structure on the seaward size is very much greater than the incident wave height.

$$H_{ns} > H_i \ldots\ldots\ldots\ldots\ldots (3)$$

From continuity therefore the wave height just inside the structure is also fairly high and will reduce as it progresses along the structure.

In the case of a structure having an impervious rear wall (Figure 2), the wave which progresses into the structure will interact with the impervious wall and create another partial standing wave thus generating a complicated wave pattern. In particular if the wave gauge is located near loop positions of a partial standing wave, higher wave heights can be expected.

It is therefore evident that values of Ct1 and Ct2 computed based on Hi will have higher values than unity at certain locations. That is mainly because that incident wave height is smaller than the transmitted wave at those locations due to reasons explained above. Of course if the transmission coefficients are expressed in relation to Hns then values less than unity can be expected.

The above arguments explain the reasons for the presence of transmission coefficients greater than unity in Figures 4 and 5.

From Figures 4, 5, 6 it is evident that as wave steepness increase, the transmission coefficients decrease. As steepness increase wave velocities increase and friction which is proportional to the square of velocity increases thereby dissipating greater wave energy. This results in the reduction of transmission coefficients. It is also evident that with increase period, the transmission coefficients are higher, indicating higher transmission capacity of long waves.

Comparison of Figures 4 and 6 indicate the influence of the berm in reducing wave transmission with greater energy dissipation. Distinct curves are observed for Ct1, Ct2 and Cte for both structures and values for transmission coefficients are less for the structure with a berm.

Comparison of Figures 4 and 5 illustrate the influence of the impervious rear wall. The transmission coefficients for both internal probes have similar values because Ct2 is now influenced by the wave reflections and the standing wave arising from the rear wall. Of course the standing wave will generate vertical motion leading to energy dissipation. If the structure illustrated in Figure 5 is of greater length, the influence of the standing wave at the rear would be small because most of the wave energy would be dissipated by the time the wave reaches the end of the structure.

Figures 7, 8, and 9 illustrate the variation of reflection coefficients with steepness. A slight increase in reflection is observed with increasing steepness. One would expect a slight decrease with increasing steepness assuming greater energy dissipation. This may be due to the fact that although there is an increase in wave steepness, wave breaking may not be occurring and therefore leading to higher reflection. However, for a given steepness value, the higher periods display higher reflection coefficients. This means that energy dissipation for higher periods is low when considering influence of both reflection and transmission.

From the results it is clearly observed that transmission coefficients display a clear relationship with steepness. As the wave steepness increases, wave transmission decreases. Low steepness waves penetrate porous structures effectively. The variation of reflection should be examined in greater details to develop a definite relationship.

4. Conclusions

The paper has identified wave structure interaction in relation to wave disturbance in basins. The relevance of selecting the appropriate type of structural configuration to overcome undesirable impacts of wave reflection is high lightened. Attention is focus into on the need to have maximum energy dissipation characteristics while reducing the influence of wave reflection.

The performance of gabion structures under extreme conditions is very low. The wave energy dissipation from a berm breakwater is very high and also the contribution to toe erosion also very low. In order to achieve the lowest possible wave disturbance inside the harbour can be obtained from the berm breakwater structure. A gabion structures can effectively use in internal harbour structures and cannot be use as external structure due week performance under extreme wave conditions.

The investigations have also provided important observations on the response of the design parameters to varying incident wave conditions. As an example, the observations on influence of energy dissipation through Gabion structures, provides the wave energy dissipation across the structure as a basis for improved design by economising on the geometry.

Notations

C_d = Dissipation Coefficient
C_r = Reflection Coefficient
C_t = Transmission Coefficient
C_{t1} = Transmission Coefficient at wave probe 6
C_{t2} = Transmission Coefficient at wave probe 7
C_{te} = Transmission Coefficient at wave probe 8
E_d = Energy Dissipated
E_i = Total incident Wave Energy
E_r = Energy Reflected
Et = Energy Transmitted
H_i = Incident wave height
H_{mo} = Wave height given by the wave spectrum
H_{ns} = Wave height near the structure
Ls = Wave Length near structure
T = Wave period

References

Hettiarachchi S.S.L., Amaraweera R. and Fernando.M. (2007) "Data on Wave Structure Interaction with Gabion Structures", Internal Report Department of Civil Engineering, University of Moratuwa 2007.