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Performance of Perforated Breakwaters Constructed With Geotextile Tubes

A. C. Yalciner†; A. Ergin†; S. Pamukcu† and B. A. Derun†

† Ocean Engineering Research Center, Department
of Civil engineering, Middle East Technical
University, 06531, Ankara Turkey
t.ergin@metu.edu.tr
yalciner@metu.edu.tr

ABSTRACT

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The coastal defense structures are constructed by various types of structural systems varying from traditional rubble mound types and concrete systems to more innovative systems. In recent applications the geotextile is used in some applications of coastal engineering asuch as coastal erosion control or perforated breakwaters. The tubular concrete units can be prepared at site by using geotextile as formwork and construct a perforated structure by placing the tubes in a specified angle and spacing. The performance of this type of perforated structures depends on the wave (height, period, direction) and structure characteristics (i.e. water depth, structure angle, bottom slope, tube spacing). . In this study, a perforated vertical wall structure constructed by placing the geotextile tubes with an angle of 45^0 to the longitudinal axis of the breakwater is tested in hydraulic experiments. The experiments are conducted in a wave flume at a certain water depth and sea bottom slope under regular wave conditions with perpendicular wave approach. The transmission and reflection characteristics of wave heights are investigated. The relation between the reflection/transmission coefficients and the wave/structure characteristics are presented. The performance of this type of perforated structures is discussed.

ADDITIONAL INDEX WORDS: *Reflection, transmission, experiment, model, porosity.*

INTRODUCTION

When constructing the coastal defense structures, one of the most important factors is to find the suitable material for the construction. The rubble mound structures need proper size/weight and amount of natural stones which can not be obtained easily by also satisfying all environmental conditions. The use of various types of artificial units with special shape is becoming popular when they are constructed with new formwork materials such as geotextiles. Thus the economical aspects of the construction and the environmental requirements can be satisfied by using geotextile systems in production of structural elements.

Geotextile systems are composed of high strength synthetic fabrics with the properties of high puncture resistance, large elongation before break and excellent filter characteristics at all strains. They can easily be used as flexible forms for producing special shape of concrete units. These types of applications are becoming an important alternative to conventional type of coastal structures. The main advantages of these systems when compared with traditional methods even using prefabricated concrete units are reduction of work, usage of local material, equipment and low-skilled labor and no need for heavy construction machinery. That can be filled with mortar (concrete) or sand to cast large units whether underwater or on land with minimum work.

There are different types of geotextile systems depending on the project requirements. Some of them are matresses, bags, tubes and containers. Matresses are mainly used for slope and bed protection, PILARCZYK (1995,1998,1999). Although bags are suitable for slope protection, retaining walls or toe protection, they are mainly used for groin and breakwater construction, and perched beach applications. Tubes and containers are similar to bags in which they differ in sizes and application method sometimes.

Various experiments had been carried out by PORRAZ and MEDINA (1977) to determine the hydraulic characteristics of some patented geotextile systems. Results of these test and completed projects around the world indicated that these types of structures can survive even during severe storm conditions with a wave range of 2.5 - 5.0 m.

An innovative approach has been suggested by SILVESTER (1986, 1990) to use large geotextile tubes filled with concrete having a special layout. In this system large tubes which are called "sausages" are laid with an angle of 45^0 to breakwater axis alternatively at each layer forming a cross pattern. Also at the mid-depths spacing between tubes are provided so that wave pressure and reflection can be decreased.. The placing the units at angles permit a surface contact that provides good shear resistance against horizontal wave forces. The water jet which will occur due to spaces provided will attenuate each other quickly as a result of vortices generated. Also uplift forces on tubes will be reduced by this pressure releasing mechanism. The low rate of flow through the structure permits i) low transmission and thus low agitation behind the structure and ii) acceptable level of water inflow and circulation inside the calm area.

Considering the complexity of the hydraulic phenomena of the waves and perforated structures, the formulas describing the transmission and reflection characteristics of the waves with these structures need to be tested and developed by the help of hydraulic experiments.

The experiments are performed by regular waves with perpendicular angle of approach, on 1/50 bottom slope towards the structure which is located at a certain depth. The tubes forming the structure are placed parallel to each other but at 45^o angle with the wave crests and/or the breakwater axis. The tube spacing are selected different in different experimental runs to obtain different porosities. The wave transmission through the structure and reflection from the structure are measured for a range of wave heights and periods in order to obtain good quality and wide range of experimental data for the better detailed presentation and discussion of transmission/reflection coefficients. The transmission characteristics of these structures are given in ERGIN *et al.* (2003). The transmission and reflection characteristics of these structures and their relation with the wave period and tube spacing and the performance of vertical wall perforated structures are discussed in this study.

METHODS

The characteristics of single tube, perforated structure and experimental procedure used in this study are presented in this section.

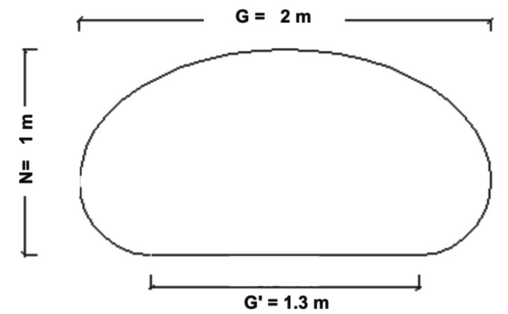

Figure 1 : Cross Section of a Geotextile Tube with Prototype Dimensions used in the Experiments

Geotextile Tubes

While designing a breakwater constructed by using geotextile tubes, one of the most important design stage is the geometry of the tubes. The cross section with prototype dimensions of a single geotextile tube used in the experiments is given in Figure 1, where N is the height, G is the maximum with and G' is the base width of the geotextile tube

In this study the perforated vertical wall breakwater constructed with tubular concrete elements are used in hydraulic experiments.

In the experiments, N / G ratio is selected as 0.5 in order to satisfy the recommendations of the manufacturers and contractors although the theoretical value derived from the dimensionless chart is N / G = 0.61 .(SILVESTER, 1986, 1990).

Vertical Wall Perforated Structure

The vertical wall perforated structure is constructed by placing the single tubes parallel to each other with a specified spacing (d_s) at an angle of 45° with the wave crests and/or the breakwater axis. the spacing between tubes are selected as %10, %15 and %25 of the tube width (G).

According to the recommendations of SILVESTER (1986) three layers from the bottom, one layer above the still water level and two layer at the top of the structure are placed without any gap for stability conditions and better energy reduction purposes. The total number of the layers used in experiments is 13. The length (l) of each tube is 1.41 times the structure width B. By considering the most likely prediction method of wave forces on vertical structures developed by GODA, 1985 and 1995, the final length of the tube is computed as 16 m. (DERUN, 1999, and PAMUKCU, 1999).

Model Set-up and Experiments

The wave channel with dimensions of 28.8m length and 6.2m width and 1.0m. depth in the Coastal and Harbor Engineering Laboratory of Civil Engineering Department at METU is used for the experiments. The channel is equipped with an irregular / regular wave generator, wave synthesizer software, wave gauges, cables, and mobile crane. A glass sided wave flume of width 1.5m. is constructed inside the channel and the perforated structure is located in the flume. Four pairs of wave gauges (WG) were located at various locations in order to measure the progress of wave, wave characteristics in front of the structure and at the harbor side to determine transmission properties. The experimental data of two adjacent wave gauge are analyzed to determine the incoming and reflected wave characteristics. The distances between two adjacent wave gauges are determined according to the method given in GODA and SUZUKI (1976). The model is selected as undistorted with the length scale of 1/20. General layout of the model is given in Figure 2.

The water depth in front of the structure is 7m. in prototype. The results of the experiments with five different wave periods 6,7, 8, 10 and 12 seconds are used. The height of incoming waves in each test are selected starting from 2.0m, increasing with 0.5 intervals up to the upper limit of 4.0, 5.5, 6.5, 7.0 and 7.0m, for the respective wave periods of 6, 7, ,8, 10, and 12sec. During the experiments incoming wave height (H_I) and transmitted wave height (H_T) are measured. The measured transmitted wave heights are corrected for the enlargement of the flume behind the model by considering the conservation of energy.

The transmission (r_t) and reflection coefficients (r_r) are defined as the ratio of transmitted and reflected wave height to incoming wave height just in front of the structure as given in Eq. 1.;

$$r_T = \frac{H_T}{H_I} \quad \text{and} \quad r_R = \frac{H_R}{H_I} \qquad (01)$$

To calculate the porosity of the structure the ratio of unit area to porous area in the cross section is used as given in ERGIN *et. al.*, 2003. The results of experiments for two different relative tube spacing (the ratio of d_s/G) are selected such as 0 (no space), 0.25.(wide space) to show clearly the effect of spacing on the transmission and reflection coefficients of perforated structures. The corresponding porosities of each relative spacing are 0.13, and 0.304 respectively.

RESULTS AND ANALYSIS

The relation between measured transmission and reflection coefficients versus the length ratio (the ratio of tube length to wave length at the structure depth, l/L_7) for the two relative tube spacing of 0.0 and 0.25 are shown in Figures 3-6.

As seen from the figures that the reflection coefficient is maximum (and transmission coefficient is minimum) for the case when the relative length is 0.2 for the tested wave periods and tube spacing.

The experimental results are limited to the data covered within the range of experiment. However, an analytical relation

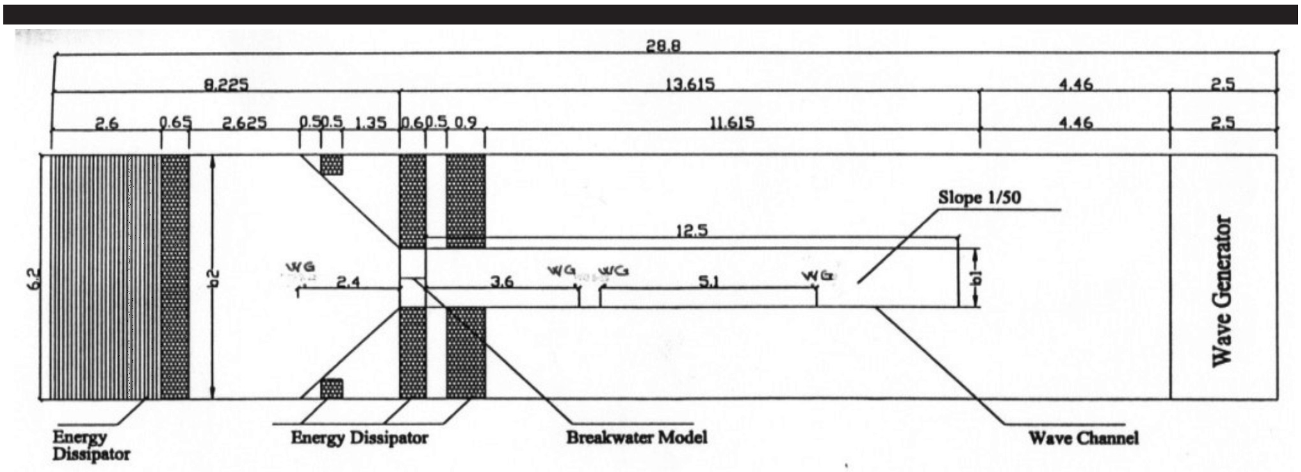

Figure 2. The General Layout of the Model (dimensions are in meters).

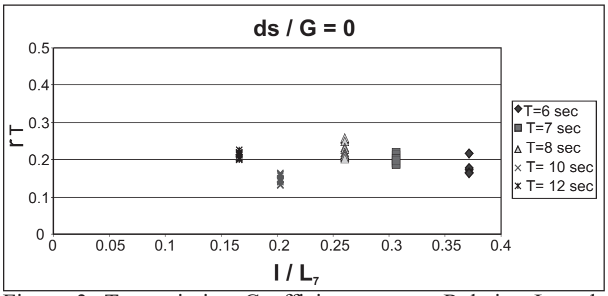

Figure 3. Transmission Coefficients versus Relative Length (l/L_7) for the Relative Tube Spacing ds/G = 0 for all tested periods.

describing wave transmission and reflection as functions of structure and wave parameters may be necessary. HATTORI (1972) studied the problem of the wave transmission through the perforated thin walls in which he derived a relation analytically for wave transmission. In the analytical approach the shallow water wave theory of small amplitude is used and the continuity, Bernoulli and momentum equations in the vicinity of the thin perforated wall are satisfied. The relations developed in HATTORI (1972) for transmission and reflection coefficients have a parameter of discharge coefficient (C) which depends on the porosity of the structure.

The experimental and analytical results are compared in Figures, 7 and 8 for different porosity, wave period and discharge coefficients. It is determined that the discharge coefficient is a porosity and period sensitive parameter

DISCUSSION AND CONCLUSIONS

An experiemental study is performed to measure the transmission and reflection characteristics of perforated structures constructed with geotextile tubes. The experimental results are compared with the analytical approach (HATTORI, 1972). The agreement between epxerimental and analytical results can be obtained with the proper discharge coefficient (KOH and KIMURA, 1972, DERUN, 1999 and PAMUKCU, 1999). According to the experiences gained in the hydraulic experiments and the analysis of the presented experimental results the following concluding remarks can be briefly explained.

- The perforated structures constructed with the tubes can be used as breakwaters for the harbors located in the region where the design wave characteristics are in the acceptable lower limit. Since the transmission of waves is too much period dependent, the wave climate of the project region should be determined carefully before the application. The tube spacing can be selected according to the design wave characteristics. Hovewer the angle 45º between tube axis and breakwater axis clearly provides best alignment of tubes if waves approaches perpendicularly.
- This type of perforated strucutures are preferable since they permit low transmission of waves and satisfy acceptable amount of water input and circulation in the protected water area at harbor side.

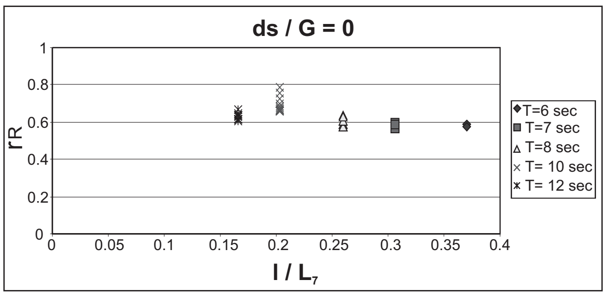

Figure 4. Reflection Coefficients versus Relative Length (l/L_7) for the Relative Tube Spacing ds/G = 0 for all tested periods.

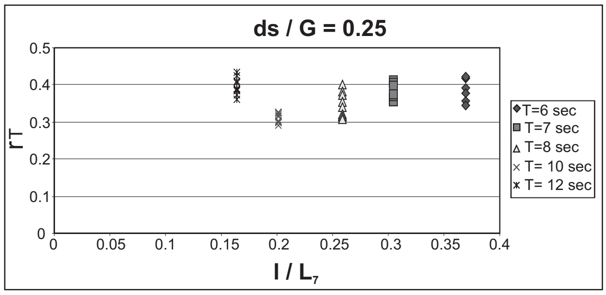

Figure 5. Transmission Coefficients versus Relative Length (l/L_7) for the Relative Tube Spacing ds/G = 0.25 for all tested periods.

- The transmission coefficient increases as the porosity (or tube spacing) increases which also cause decrease in reflection coefficient. As h / H_I increases, transmission coefficients increase and reflection coefficients decrease as also stated by HATTORI (1972) and DERUN (1999). For a certain depth, porosity and wave period as the wave height increases the transmission coefficient decreases but since the incoming wave height is greater, the transmitted wave height is greater when compared with a smaller incoming wave height.
- If discharge coefficient of structure with certain porosity is assumed to be constant for all periods, the numerical model derived by HATTORI (1972) do not fit well with the experimental data for this type of structures. Therefore the derivation to describe the analytical relation for transmission and reflection coefficients with different discharge coefficients according to the wave period, porosity and relative length
- Transmission coefficient minimum and reflection coefficient is maximum when l / L_7 is around 0.2 (Figure 3-6), which is in agreement with the experiments carried out for perforated breakwaters by KOH (1972).
- Transmission and reflection coefficients remain almost constant with changing depth to incident wave height ratio in front of the structure when tube spacing is 0 (Figure 7).
- Transmission coefficient becomes heigher and reflection coefficient becomes lower when wave amplitudes get smaller (Figures 7, 8) This result is also in agreement with HATTORI (1972).

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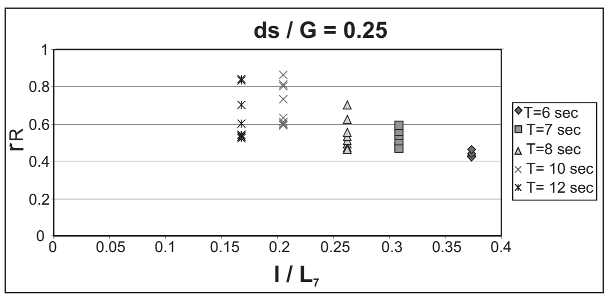

Figure 6. Reflection Coefficients versus Relative Length (l/L_7) for the Relative Tube Spacing ds/G = 0.25 for all tested periods.

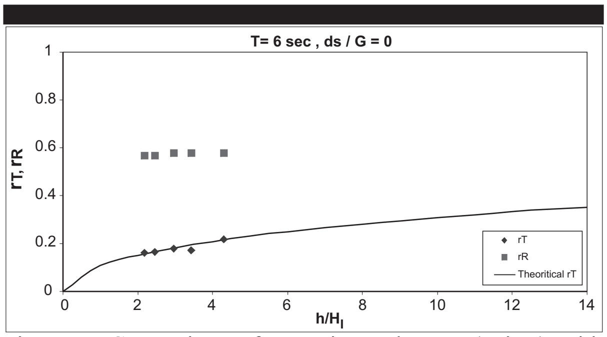

Figure 7. Comparison of Experimental Data (points) with Analytical Results (curve) as the Function of Structure Depth to Incoming Wave Height for the Discharge Coefficient C=0.18 , ds/G=0, porosity=0.13, wave period 6 sec.

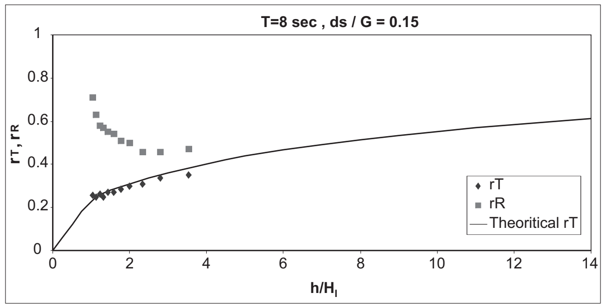

Figure 8. Comparison of Experimental Data (points) with Analytical Results (curve) as the Function of Structure Depth to Incoming Wave Height for the Discharge Coefficient C=0.32 , ds/G=0.15, porosity=0.2435, wave period 8 sec.

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