EXPERIMENTAL ANALYSIS OF THE PERFORMANCE OF A MODULAR FLOATING BREAKWATER STRUCTURE

Abstract In this experimental study, a modular floating breakwater consisting of "Wave Breaker" modules produced by PMS Inc. has been tested in order to assess its wave attenuation performance. Carried out as two-dimensional in a wave flume with 24 m x 0.98 m x 1.00 m dimensions and with a model scale of 1:10, 35 regular wave series have been used in order to evaluate the performance of the structure. Transmission coefficients have been calculated and their variation with governing parameters has been presented as charts. With respect to relative width parameter, it has been found out that the structure is an effective wave attenuator for relative width values higher than 0.5 whereas for values higher than 0.7 attenuation performance is exceeding 70%.

Keywords: Floating breakwater, modular floating breakwater, coastal protection structures

INTRODUCTION

Floating breakwaters are particularly suitable for coastal areas exposed to mild to moderate wave climates. While they are applicable in areas where site characteristics, such as low-bearing soils and large water depths, make the construction of conventional breakwaters difficult, their permeability and relatively small size make them a preferred choice for situations requiring the installation of demountable or reconfigurable harbor and breakwater systems, and for situations requiring minimal environmental impact in terms of water quality and aesthetics.

While the first floating breakwater proposals are known to have emerged at the end of the 19th century (Shields, 1910), studies on these structures continued, particularly after World War II, both by military units and by the port industry serving small boats. A comprehensive literature review of the many floating breakwater designs proposed during this period was compiled by Hales (1981). However, many of the floating breakwater models examined were unable to compete with simpler designs in terms of manufacturing, resistance to marine effects, and maintenance costs. McCartney (1985) classified the most commonly used floating breakwater types as box and catamaran types, consisting of prismatic elements, and wicker-type floating breakwaters, which are constructed as a flexible layer on the surface, and provided basic design criteria. Oliver et al. (2004) stated that the operating principles of floating breakwaters are reflection in rigid systems such as boxes and catamarans, and turbulence and friction damping in wicker-type systems.

Mesh-type breakwaters have attracted the attention of many investors due to their lower anchoring forces compared to rigid systems and their modular manufacturing capabilities. The first examples of mesh-type floating breakwaters were systems created using patented arrangements of scrap vehicle tires. The first patented design, named Wave-maze, was developed by Stitt and Noble (1963) to utilize the large quantities of scrap vehicle tires generated by intensive land transportation, particularly in the United States (Noble, 1969). Good-Year also developed another patented arrangement

(Giles and Sorensen, 1978; Harms and Bender, 1978) and conducted laboratory tests to evaluate its performance and anchoring forces.

Another system, called Wave-Guard, consisting of tubes and scrap tires, was developed by Harms and Bender. The authors (Harms and Bender, 1978) stated that this system provided higher damping compared to the other two systems due to its greater rigidity. Kowalski (1974) conducted physical model studies on simpler vehicle tires arranged in three rows of mats. These types of structures became obsolete in the 1990s due to the problems of tires breaking away from the system, causing environmental pollution, internal contamination, and high density.

There are also models constructed with elastic material in the form of a flexible water-filled body or thin membrane. Williams (1991) investigated the effect of an elastic curtain stretched between the bottom and a circular buoy on wave transmission and reflection using physical and numerical modeling. Kim and Kee (1996) numerically investigated the effect of a taut, flexible, vertical barrier on wave transmission. Williams (1996) investigated the effect of a membrane stretched between a buoy on the water surface and a ballast at its lower end on wave transmission. Kee and Kim (1997) investigated the effect of a prestressed membrane, extending between the bottom and the calm water level and anchored by buoys on the surface, on wave transmission. Lo (1998) investigated the effect of a system consisting of two vertical membranes on wave transmission, and Williams (2003) investigated the effect of a permeable membrane tensioned between the bottom and the surface using a buoy, both experimentally and numerically.

While similar designs exist, their application is rare due to their low resistance to the marine environment.

The floating breakwater design has also attracted interest from the plastic manufacturing industry, and various plastic floating breakwater designs have been considered in different countries for different purposes. These designs generally consist of modular plastic elements elastically connected to each other. This facilitates easy maintenance and disassembly when not in use, allowing for easy storage on land. Various models of modular plastic floating breakwaters have been developed by various companies, and are generally suitable for use in milder wave conditions. In addition to single-row arrangements, which are primarily used to protect against small boat waves, they can also be designed to withstand larger waves by using various combinations of multiple-row arrangements.

Plastic floating breakwaters, developed by some companies specifically for small-scale applications, have become increasingly common in recent years.

In this study, the performance of a floating breakwater unit, designed by PMS Polyethylene Products Industry and Trade Inc. and composed of modular plastic floating breakwater units, named "Wave Breaker," was investigated in a laboratory environment. The study was conducted using two-dimensional physical model experiments, and the primary objective was to evaluate the structure's performance in terms of wave transmission.

EXPERIMENTAL STUDY

Test Channel

Experiments were conducted in the irregular wave channel located in the Hydraulics Laboratory of the ITU Faculty of Civil Engineering. The channel is 22 meters long, 0.98 meters wide, and 1.00 meters deep. The channel is equipped with a flap-type wave paddle driven by a hydraulic piston, which can generate regular and irregular wave series under computer control. A composite slope with a 1:7 slope was constructed at the downstream end of the channel to prevent reflection (Figure 1).

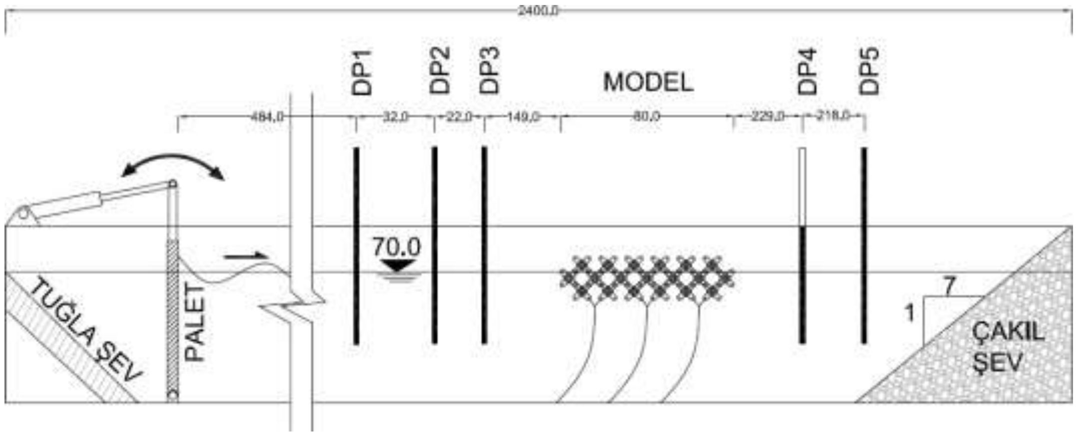

Figure 1. Schematic profile view of the wave channel (all dimensions in cm).

The 1:10 scale model was constructed using general floating structure physical modeling procedures and prior experience with floating breakwater structures. The water depth was maintained at 70 cm during the experiments.

Breakwater Model

The breakwater model was constructed using plastic modules designed and supplied by PMS Inc. The individual modules, whose foundation dimensions are given in Table 1, were connected to each other in a staggered arrangement as shown in Figure 2, creating primary blocks consisting of seven modules. Three of these blocks were constructed to form the breakwater model with a total width of 80 cm. The blocks were ballasted with water and adjusted to a draft of 15 cm.

Figure 2. (a) Cross-section, (b) plan view of the single module.

A relatively practical mooring system was used to connect the floating breakwater to the ground, with each block anchored to the ground with two steel cables.

Measurement Equipment

Wave measurements were performed during the experiments using five resistance-type wave probes (Figure 1). Three of the probes were placed on the offshore side of the structure to determine incoming wave characteristics, and two were placed downstream to measure passing wave characteristics (Figure 1).

The sampling frequency was selected as 40 Hz, and data readings were performed synchronously from all probes.

Test Matrix

After determining the 1:10 test scale and the wave period range within which the breakwater is expected to be effective, as described above, a test matrix was prepared to include four different wave heights. Additionally, three more wave series were added to the experiments to examine the passage of lower-height but longer-period swell-type waves through the structure. A total of 30 tests were conducted, and details are provided in Table 1.

Table 1. Characteristics of the waves used in the experiments.

Test No	H_{rms} [cm]	T_m [s]	Test No	H_{rms} [cm]	T_m [s]	Test No	H_{rms} [cm]	T_m [s]
1	3.253	0.7	11	7.353	0.66	21	0.95	1.14
2	4.591	1.15	12	6.655	0.66	22	1.2	0.8
3	5.161	0.71	13	7.041	0.75	23	3.237	0.82
4	6.008	0.61	14	7.43	0.81	24	5	0.86
5	5.869	0.62	15	7.729	0.88	25	1.2	0.9
6	6.439	0.65	16	2.664	0.91	26	1	1.1
7	5.749	0.66	17	0.753	0.97	27	0.798	1.14
8	6.202	0.71	18	1	1.04	28	1.091	1.01
9	5.293	1.05	19	0.6	1.1	29	1.8	1.1
10	5.781	1.13	20	0.806	1.1	30	3.5	1.19

The wave characteristics used in the experiments allow waves to be classified into four different groups based on their height. Taking the outer-to-outer diagonal length D = 120 mm as the characteristic dimension of a single module, these groups can be nondimensionalized as H/D = 0.50, H/D = 0.625, H/D = 0.75, and H/D = 0.92. The test ranges, taking into account a model width of B = 80 cm, can be given as follows:

$0.50 \leq H/D \leq 0.92$

$0.36 \leq B/L \leq 1.37$

EVALUATION OF EXPERIMENT RESULTS

Evaluation of Wave Data

In the evaluation of wave data, the height and period of each wave were obtained from the water level time series using the zero-cutoff method. Wave statistics were then calculated from individual waves. An important parameter to consider during this process is the reliable recording duration. Since there is no active fin in the channel, waves reflecting off the wave fin and downstream slope and reaching the measurement probes and structure will negatively affect wave measurements and performance evaluations. Therefore, valid recording durations were calculated using wave group velocities, taking into account the distances between the fin, breakwater model, wave probes, and obstacles. Records unaffected by reflections were included in the analyses. A significant problem encountered in this way is that the recording durations obtained are very short, especially for long-period waves, and in some cases, they may only contain one wave.

Structure Performance Analysis

The wave attenuation performance of floating breakwaters is expressed by the parameter known as the transmission coefficient (C_T). The transmission coefficient is defined as the ratio of the wave height (H_T) passing downstream of the structure to the wave height (H_I) in front of the structure (Min. 1):

$$C_T = \frac{H_T}{H_I} \tag{1}$$

Another parameter used for floating breakwater performance is relative width (b_{rel}). Relative width is defined as the ratio of the structure's width to the wavelength incident on it:

$$b_{rel} = \frac{B}{L} \tag{2}$$

In this study, transmission coefficients were calculated using the DP1 and DP4 probes shown in Figure 1. The H_{rms} wave height parameters of individual waves extracted using the zero-cutoff method were used in the calculations. Relative width and wave steepness parameters were calculated based on offshore wavelengths using T_m mean wave period data.

Variation of Transfer Coefficients with Dominant Parameters

The wave series used in the experiments were selected to represent four fundamental wave amplitudes. These wave heights were nondimensionalized using the module diagonal length D to represent a characteristic dimension of the structure and were grouped into four different groups: H/D=0.50, H/D=0.625, H/D=0.75, and H/D=0.92, respectively.

The variation of the transmission coefficients with relative width is shown in Figure 3. As can be seen from Figure 3, the structure acts as an effective wave absorber when the relative width is 0.7 and above, and its damping performance reaches 80% of the wave height. For relative width values between 0.5 and 0.7, damping is in the range of 40% and 80%, while for smaller relative width values, the structure is ineffective. Although the experimental data are classified according to the relative wave height H/D ratio in Figure 3, it can be seen that wave transmission depends on wavelength rather than wave height. The effect of wave period on wave transmission, taken from screenshots taken during the experiments, is shown in Figure 4.

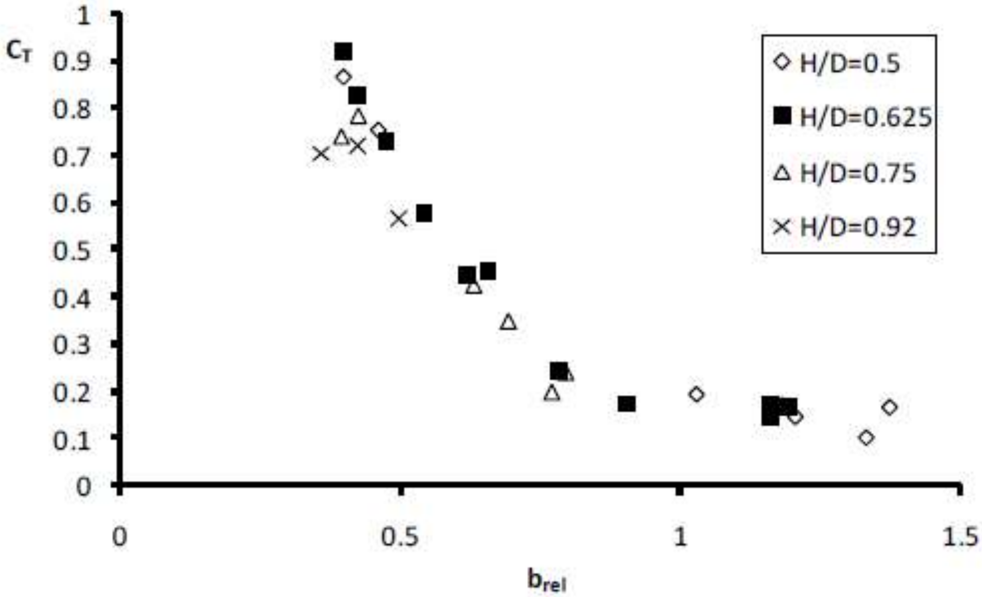

Figure 3. Change of transmission coefficients with respect to relative width.

The changes in the transmission coefficients depending on the offshore wave steepness are shown in Figure 4. As can be clearly seen from Figure 4, as the wave steepness parameter increases, the wave damping capacity of the structure also increases. However, compared to Figure 3, the effect of wave height on wave transmission is more clearly seen in Figure 4. It is observed that the transmission coefficients are greater for waves with higher wave heights than for waves of the same steepness.

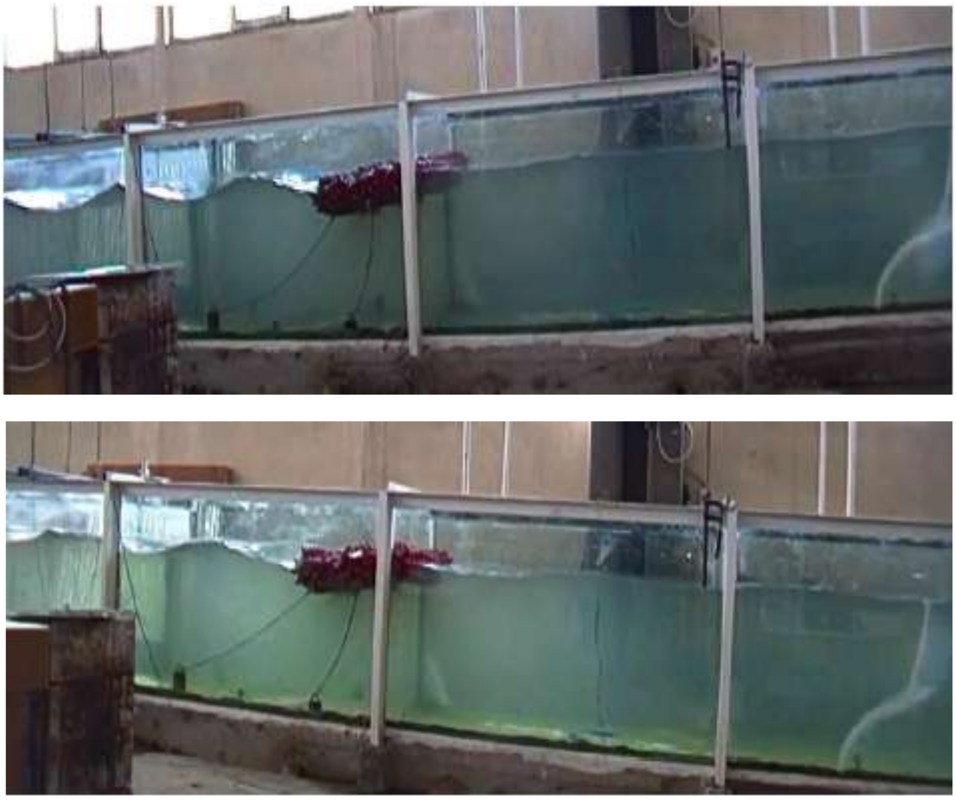

Figure 4. Illustration of the effect of wave period on the transition using experimental videos: (a) T_o = 0.7s (b) T_o = 0.85s (c) T_o = 1.1s

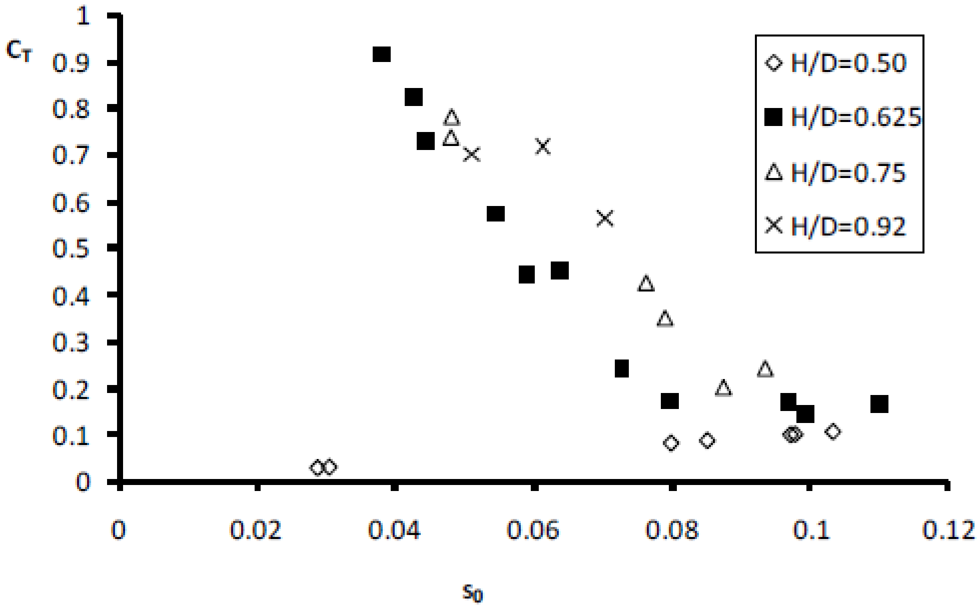

Figure 4. Variation of transmission coefficients with offshore wave steepness.

The graphs of the variation of transmission coefficients with the dominant parameters, given in Figures 3 and 4, demonstrate characteristics consistent with the general behavior and performance curves of floating breakwaters.

Comparison of Performance with a Box-Type Structure

To compare the structure's performance, wave transmission through a fixed rectangular obstacle was calculated using the Macagno (1953) equation and compared with the results of the tested breakwater model. The Macagno equation is expressed as follows:

$$C_T = \left(\sqrt{1 + \left[\left(\frac{\pi B}{L}\right)\left(1 + \frac{d}{h-d}\right)\right]^2}\right)^{-1} \quad (3)$$

In applying Min. (3) to the existing structure, the external width of the structure was taken as the B value, and the depth of the structure, 15 cm, was used for draft. A comparison of the empirical transfer coefficients obtained with Min. (3) with the transfer coefficients obtained from model experiments, depending on the wave steepness parameter, is shown in Figure 5. As clearly seen in Figure 5, at low wave steepness, the empirical correlation predicts transfer coefficients at much lower levels, while at high wave steepness, it yields transfer coefficients slightly higher than the experimental results. The absence of the wave height parameter in Min. (3) is believed to be a contributing factor in this.

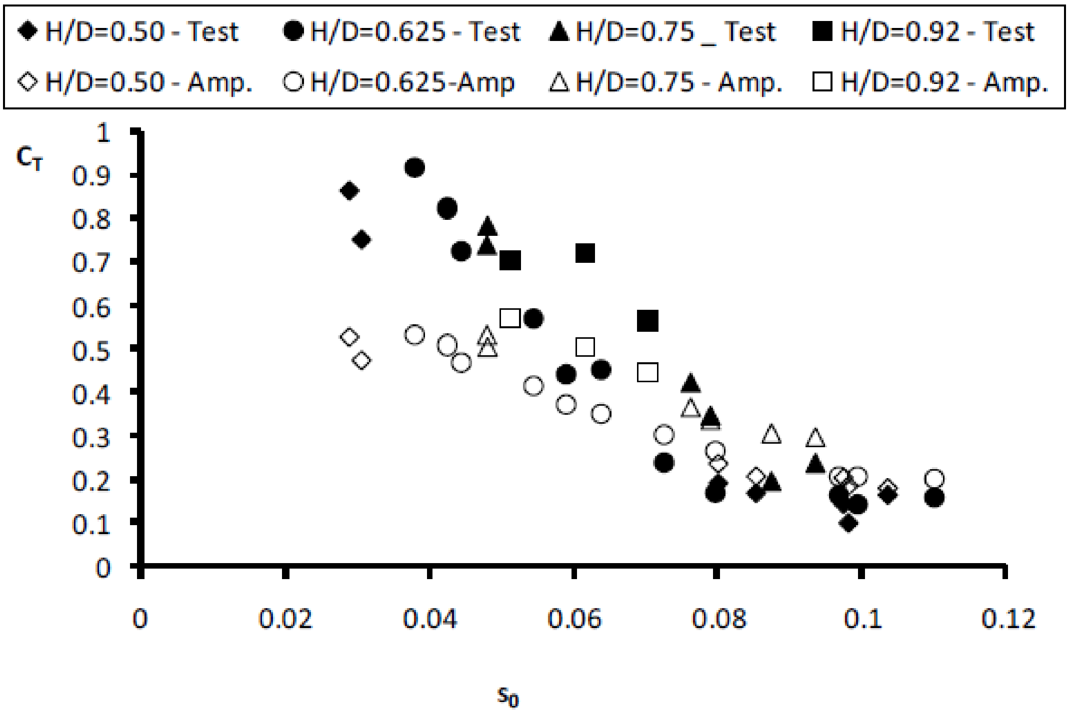

Figure 5. Analysis of the change in the transfer coefficients (-Amp) obtained from the experiments (-Test) and Min. (3) with respect to wave steepness.

CONCLUSION

Modular floating breakwaters have become attractive structures in recent years due to their ease of manufacture and maintenance, as well as their adaptability to meet specific needs.

In this study, the performance of a modular floating breakwater constructed using "Wave Breaker" modules manufactured by PMS Inc. was investigated using two-dimensional physical modeling techniques. In tests using 35 regular wave series, the transmission coefficients for the studied configuration were obtained, and the variation of the transmission coefficients with the dominant parameters of relative width and wave steepness was examined and presented graphically.

The system was observed to be effective for relative width values of 0.5 and greater, while the damping performance exceeded 70% for values of 0.7 and greater. For comparison, the transmission coefficients were compared with a continuous, rigid barrier of the same dimensions using the Macagno equation, and the transmission coefficients obtained from the experiments were compared with the values obtained from the empirical equation for the rigid body based on the wave steepness parameter. It was observed that the existing system provided lower damping compared to the rigid structure at low wave steepness, and this difference is believed to be due to the flexibility of the structure. It is believed that the tested system can be used as an effective wave damper in mild to moderate wave climates.

SOURCE

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