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DESIGN OF PASSIVE ENERGY ABSORBERS FOR THE IMARES-UCR WAVE BASIN.

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ABSTRACT

This paper presents the results of the analysis carried out to design a low-cost passive energy absorber for the multidirectional spectral wave basin of the IMARES-UCR group. The initial analysis was conducted using a small wave flume, which facilitated the execution of tests and the comparison of data with wave dissipaters previously designed by a commercial company what are commonly employe in various wave generation laboratories worldwide. In these initial tests, reflection coefficient values where very similar to those of the compared dissipaters. Once constructed, measurements of the reflection coefficient were performed under different regular wave conditions to determine its behavior. The obtained results are presented, considered acceptable, and enable the proper operation of the wave basin.

KEYWORDS: Wave basin, Reflection coefficients, Passive absorption, Energy dissipation.

1 INTRODUCTION

The Coastal Engineering Group of the Research Institute in Engineering at the University of Costa Rica, IMARES-UCR, develops research projects in its new facilities, which include a multidirectional spectral wave basin. This basin, with a length of 23 meters, a width of 11.5 meters, and a maximum depth of 1.40 meters, is equipped with VTI wave generators controlled by the AWASYS and WAVELAB software from the University of Aalborg, as depicted in Figure 1.

Figure 1. Photograph of the wave simulation basin at IMARES-UCR.

The wave generator in the basin consists of 24 box segments, each 0.47 m wide, with the ability to actively absorb reflected waves. Initially, there were plans to acquire a commercial passive wave absorption system; however, due to budget constraints, the decision was made to design a low-cost absorption system that would allow optimal operation of the wave basin. In coastal engineering physical modeling testing, wave dissipaters play a crucial role. These structures, designed to decrease wave energy in bodies of water, have been strategically integrated into the basin to minimize reflections on the walls, consequently reducing interferences and disturbances in measurements. The dissipaters contribute to establishing a controlled and precise environment for experiments by mitigating reflected waves, facilitating the replication of realistic and reproducible wave conditions.

Tests of the designs developed by IMARES were initially conducted in a wave flume measuring 10 meters in length, 0.3 meters in width, and 0.5 meters in depth. These tests, aimed at achieving reflection coefficients like those of commercial wave dissipaters, were carried out by submitting the structures to the same wave configurations. Once comparable values were obtained, the construction of these designed elements in the wave basin was undertaken.

2 METHODOLOGY

Determining the optimal wave-absorbing structure in a physical wave simulation basin involves a methodological approach that considers various aspects, from absorption efficiency to economic viability. Below, we present a general methodology outlining the factors considered by our laboratory:

- **Identification of Alternatives:**

Various alternatives for wave-absorbing structures available in the market or proposed in the literature were investigated and evaluated. This encompassed both commercial systems and potential custom designs.

- **Definition of Objectives:**

Study objectives, such as desired absorption efficiency, economic feasibility, and the country's material and construction capabilities, were clearly defined.

- **Characterization of Waves:**

The characteristics of the waves expected to be simulated in the basin, including height, frequency, and direction, were analyzed. Ensuring that the selected wave-absorbing structures are suitable for the specific wave conditions for our models.

- **Laboratory Testing:**

Physical tests were conducted in a laboratory environment using scale models or prototypes of the selected wave-absorbing structures.

- **Design Optimization:**

Based on simulation results and laboratory tests, the design of the wave-absorbing structures was optimized to enhance their performance.

- **Economic Evaluation:**

An economic analysis of the considered alternatives was carried out, considering manufacturing, installation, and long-term maintenance costs.

- **Decision-Making:**

For decision-making, all variables and results concerning the best wave-absorbing structure for the simulation basin were thoroughly evaluated.

- **Continuous Validation:**

The selected wave-absorbing structure was constructed and validated in the real simulation basin, with necessary adjustments made. Continuous monitoring of the system over time ensures ongoing performance and evaluates the need for potential improvements. By using this approach, we thoroughly and systematically evaluated structures that absorb waves. This ensured that we selected the better option for the basin. After reviewing relevant documentation, the decisions to use the wave absorbers employed by the VTI company behind the wave generation boxes in our flume and basin as a baseline was taken. These dissipaters are made of rigid plastic and have a beehive-like shape, as depicted in Figure 2.

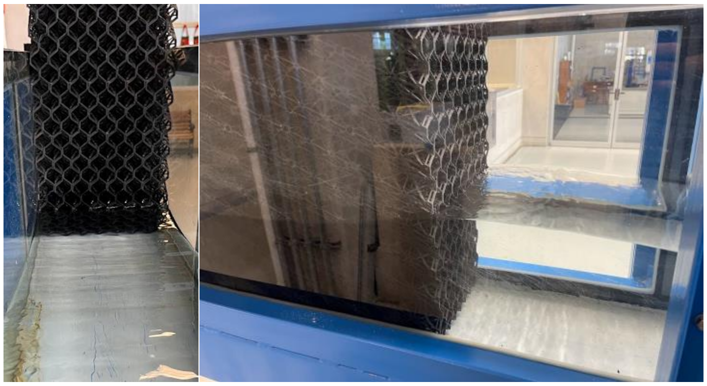

Figure 2. Photographs of the commercial dissipation structure, commercial dissipaters.

The objective was established to find reflection values like those of commercial dissipaters used as a comparative baseline but using materials commercially available in the country. This approach would allow for relatively low costs. Additionally, it was considered that the wave height and period values for the tests would be those commonly used in the laboratory and most closely aligned with the wave characteristics faced by our coasts. Significant wave heights in the 1:20 scale model ranged from 5 to 15 centimeters, while periods varied from 1 to 3.5 seconds, equivalent to prototype periods of approximately 5 to 16 seconds. The tests were also conducted for different water level values.

At the beginning, various options were examined to redirect and then disperse energy. Reduced-scale models were utilized and tested in the small wave flume. Models comprised of PVC elbows and other materials were tested. These designs were assessed by measuring absorption efficiency and evaluating real-world behavior under controlled conditions, considering construction complexity in terms of materials, design, and cost.

One of the most interesting options considered was to use the shape of Torricelli's trumpet in an attempt to capture energy (see Figure 3), redirect it to the backside, and then dissipate it. Although this option was highly attractive, its main challenge lay in finding the appropriate curvature radius for the designed wave. An option that worked well for one wave had very poor results for another, especially when varying the wave period.

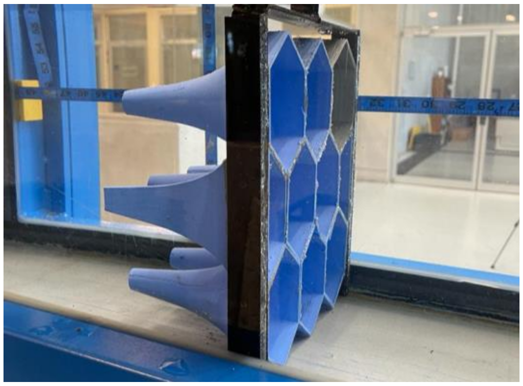

Figure 3. Torricelli's trumpet shape scale model, lateral side view.

Another problem we encountered was that reduced-scale models could be manufactured using 3D printers, but in Costa Rica, the limited metal mechanical industry made the fabrication of such structures on a large scale with a high cost.

Finally, a more traditional scheme was tested using different geotextiles, specifically PVC plastic mesh. These meshes have various aperture sizes changing from 3.8 cm to 0.3 cm and varying rigidity in their PVC material, with rigidity decreasing as the hole size gets smaller. The idea was to double-layer 17 meshes from larger to smaller openings as the waves passed through them. Four different mesh openings were used: mesh 1 with 3.8 cm, mesh 2 with 1.5 cm, mesh 3 with 1.1 cm, and mesh 4 with 0.3 cm, as depicted in Figure 4.

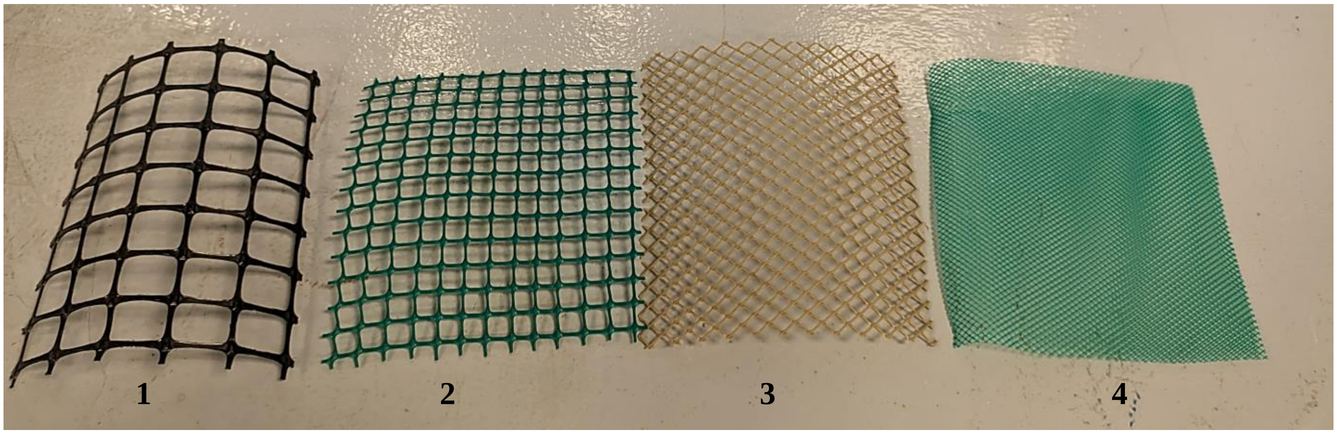

Figure 4. Meshes used.

The design was optimized until the desired reflection values were achieved. It was found that the best configuration consisted of 9 frames of Mesh 1, 3 of meshes 2 and 3, and 2 of mesh 4, all placed in a double layer. This design can be observed in Figure 5.

Figure 5. Energy dissipaters designed and optimized by IMARES.

Finally, tests were conducted in the basin with the already constructed dissipaters, and reflection values were obtained for each of the evaluated wave characteristics.

3 RESULTS

The tests conducted for all the structures and their improvements were analyzed using Awasys software from the University of Aalborg, which used a resistive level sensor placed on the wave generation box and provided reflection values for each of the structures. The commercial dissipaters used as a baseline for this project resulted in the reflection values shown in Figures 6 and 7, corresponding to water levels of 19.5 cm and 30 cm, respectively. Height values of waves between 5 and 10 cm can be observed for each corresponding period.

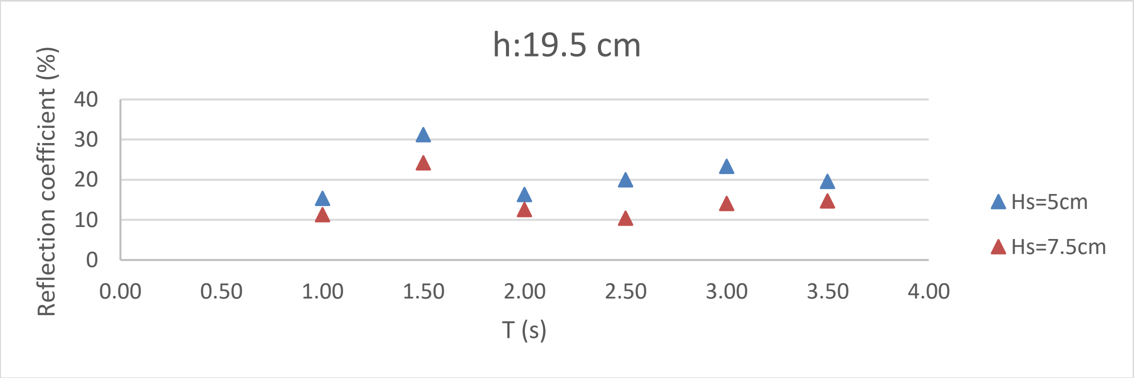

Figure 6. Wave reflection values of the commercial structure for a water level of 19.5 cm and different wave heights.

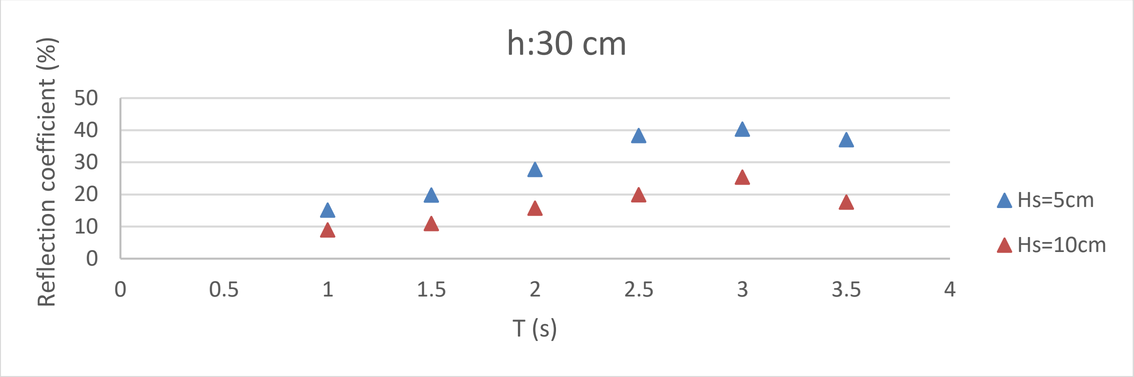

Figure 7. Wave reflection values of the commercial structure for a water level of 30 cm and different wave heights.

It was determined that, for laboratory tests, the wave reflection coefficients of the commercial design structure do not exceed 40%, making it suitable for the operation of our laboratory. Upon conducting tests with the optimized structure, the reflection coefficients shown in Figures 8 and 9 were obtained, representing the data obtained for water levels of 19.5 cm and 30 cm, respectively.

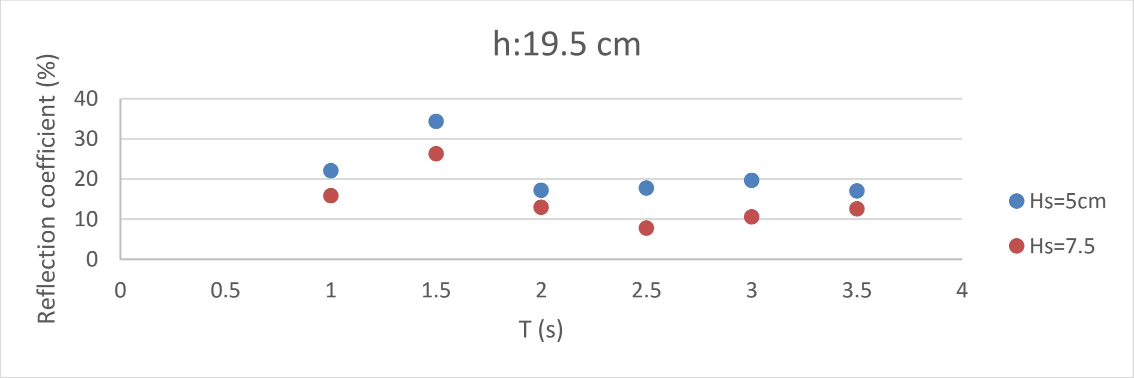

Figure 8. Wave reflection values of the scaled-designed structure for a water level of 19.5 cm and different wave heights.

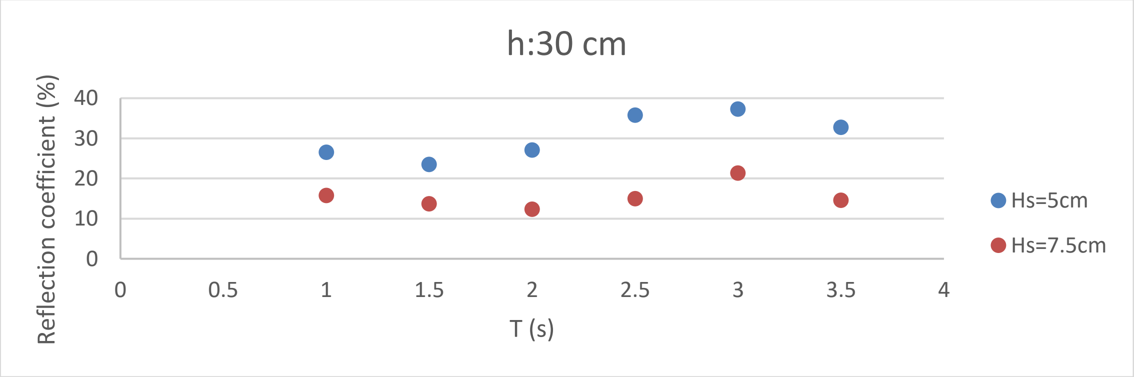

Figure 9. Wave reflection values of the scaled-designed structure for a water level of 30 cm and different wave heights.

The values obtained by the designed dissipating structure are acceptable and even show reflection values lower than desired; therefore, they meet the set objectives, displaying results like those of the commercial design. In Figures 10 and 11, a comparison of the results can be observed for water levels of 19.5 cm and 30 cm, respectively.

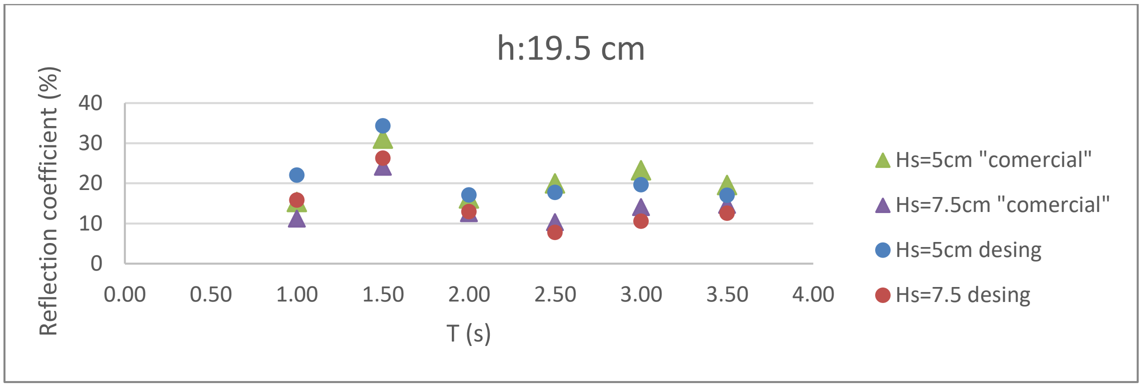

Figure 10. Comparative wave reflection values for a water level of 19.5 cm and different wave heights.

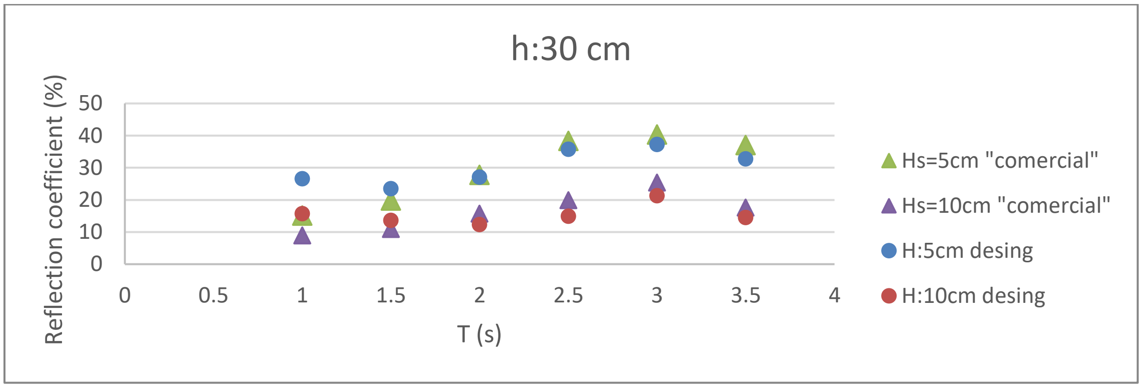

Figure 11. Comparative wave reflection values for a water level of 30 cm and different wave heights.

The final design for the basin consisted of 11 modules, each measuring 1 meter in width, 1.40 meters in height, and 2 meters in depth, as shown in Figure 12. Each module contains 17 frames arranged like the panels of a commercial beehive. The entire construction is made of aluminum to minimize costs and prevent oxidation issues.

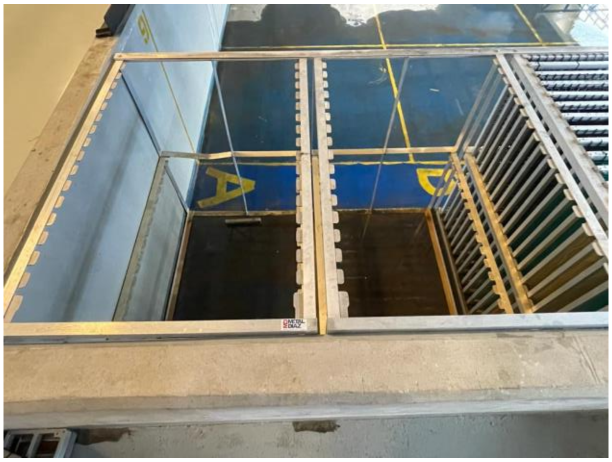

Figure 12. Modules for the placement of frames with meshes.

The frames can be easily inserted or removed, and each frame is covered on the front and back by a plastic mesh with different openings, as shown in Figure 12. The optimal distribution of the meshes was 9 frames with 3.8 cm openings, 3 with 1.5 cm meshes, 3 with 1.1 cm, and 2 with 0.3 cm, in decreasing order in the wave direction, as depicted in Figure 13. Figure 14 shows the final configuration of the energy absorber.

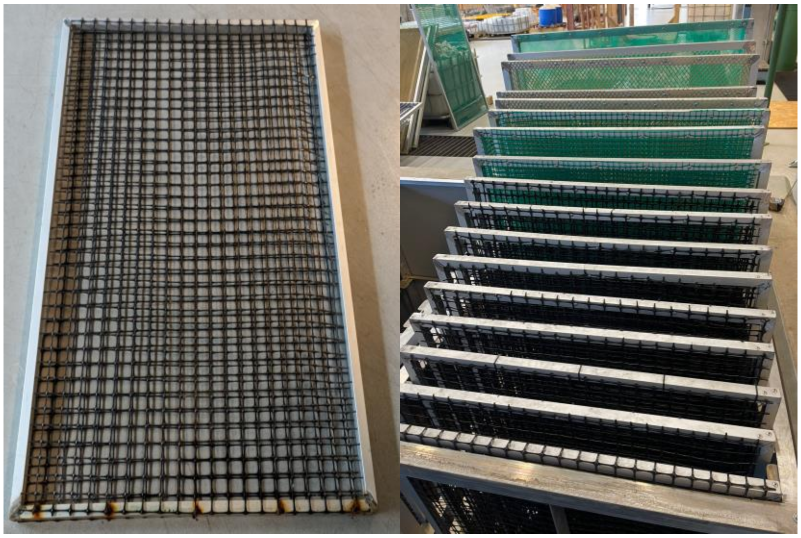

Figure 13. Final design of the aluminum frames, front view.

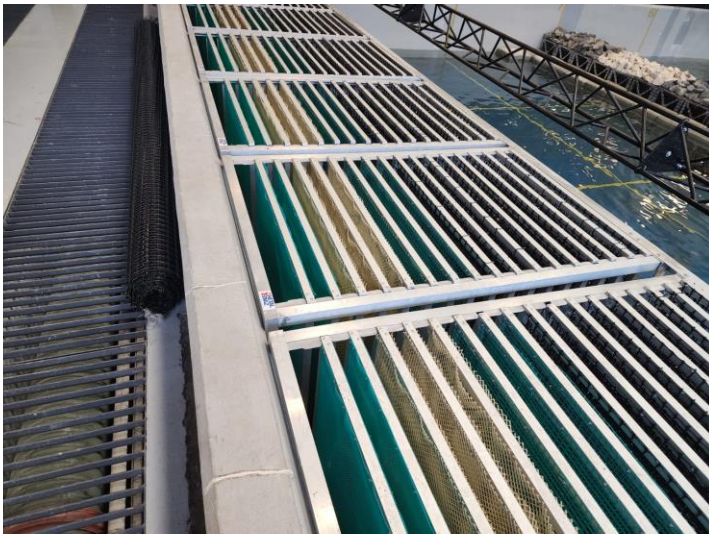

Figure 14. Final configuration of the energy absorber, top side view.

Once the construction was completed, different tests were carried out to evaluate the performance of the energy absorber at full scale. Tests were carried out for different water depths, different periods and wave height. To determine the efficiency of the system, the reflection coefficient was calculated for each of the tests performed (with regular waves). Figure 15 shows the result obtained for 60 cm depth and the figure 16 shows the results for 40 cm.

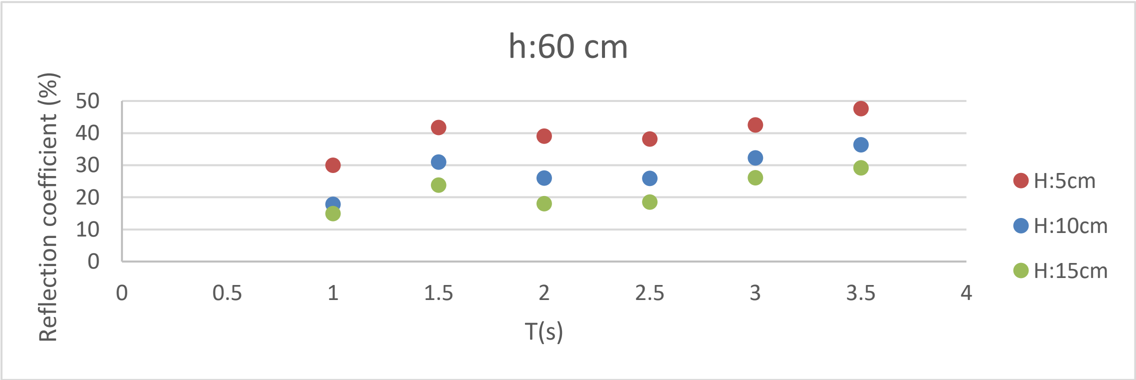

Figure 15. Variation of the reflection coefficient for a depth of 60 cm and different wave heights (5, 10 and 15 cm).

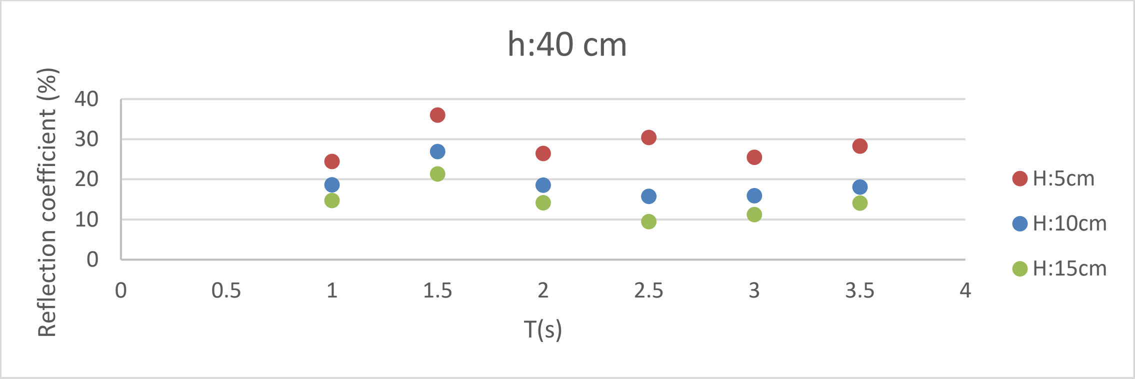

Figure 16. Variation of the reflection coefficient for a depth of 40 cm and different wave heights (5, 10 and 15 cm).

4 CONCLUSIONS

Various alternatives were analyzed for constructing the energy absorber for the wave basin at the IMARES-UCR laboratory. The chosen alternative was a modular design with removable panels, featuring plastic mesh on the front and back of each panel. Tests were conducted with regular waves to determine the final reflection coefficients, varying water depth parameters from 40 to 80 cm, wave heights from 5 to 15 cm, and periods from 1 to 3 seconds. The results were deemed acceptable, and the active absorption system of the wave generators could handle them. Although the dissipater allows the wave basin to operate correctly, the obtained reflection coefficients were significantly higher than expected by the scale model. It is believed that this is caused by the flexibility of the plastic nets, causing substantial displacement in the central zone of the 1.40m frame (almost 3 times the displacement noted in the scale model). Currently, we are in the process of adding supports at half the height of each frame to anchor and " rigidize " the mesh. Once this process is completed, measurements will be repeated to observe the result achieved.

5 REFERENCES

Echavez, G. (1997). Introducción a los modelos hidráulicos de fondo fijo y a la ingeniería experimental. Mexico D. F.: UNAM.