New design options for the improvement of the Mutriku power plant

U. Izquierdo, I. Bidaguren, I. Albaina, G.A. Esteban, A. Peña, Oier Peña Vega, J.M. Blanco

Abstract— **This research studies several possibilities to improve the efficiency of the Mutriku breakwater wave power plant. The experimental work has been carried out in the 12.5 m long wave flume located at the laboratory of Fluid Mechanics of the Energy Engineering Department (UPV/EHU). The physically constructed oscillating water column device corresponds to one of the 16 chambers of the Mutriku breakwater wave power plant, according to the construction plan and applying a 1:36 scale. All the experiments were carried out at two tides that correspond to the medium and maximum tides of Mutriku location. A constant incident regular waves of 30 mm were generated at several periods; 0.7<T[s]<1.7 for the medium tide and 0.7<T[s]<2.1 for the maximum tide. The obtained results reveals that the promising configuration corresponds to the one containing lateral walls, so that the influence of harbour walls will be further studied.**

Keywords— **OWC, Mutriku, RAO, L-shape, U-shape.**

I. Introduction

THE research based on the development of oscillating water column (OWC) devices continues growing and nowadays there are endless options that have already been studied. From the type of turbine and its control, to the most efficient energy conversion system or design, the OWC technology needs to be further developed in order to be economically attractive.

This research studies several possibilities to improve the efficiency of the Mutriku breakwater wave power plant (WPP). For that purpose, first the type of WPP based on OWC working principle itself must be considered. Among the different types of WPP, the most common ones based on OWC principle, are: (i) Conventional [1]–[7], (ii) L-Type [8]–[10], (iii) U-Type [11]–[16] or (iv) inclined [17], among the most representative ones.

The type of WPP known as conventional (Fig. 1- b) corresponds to the initial design at Mutriku. However, as detailed in [18], after a tidal wave the plant had to be rebuilt with an L-type design, which corresponds to image c in Fig. 1. In addition, several researchers [13], [19]–[23] have shown that the so-called U-type plant (Fig. 1- a) obtains better yields than the conventional one. However, there is not enough research to prove or disprove that an L-type plant obtains better or worse results than a conventional or U-type plant. In the literature, only one article based on simulations has been found in which the results obtained by an L-type plant are better than those obtained with a conventional plant. In addition, there are other research that ensures the improvement when lateral walls, or the so-called harbour walls, are installed in all these type of configurations [12], [24]–[26].

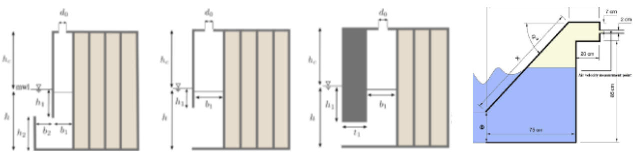

Fig. 1. Most common OWC WPP designs. From left to right: a) U-Type, b) Conventional, c) L-Type and d) Inclined.

In this study, a series of combinations between the most commonly used geometries for the design of WPP based on the principle of the OCW have been proposed. To this end, the authors propose the combination of the Mutriku power plant (Type L), with the concept of what would be

Part of a special issue for EWTEC 2023. Original version published in EWTEC 2023 proceedings at https://doi.org/10.36688/ewtec-2023-483. Manuscript submitted 13 December 2024; Accepted 4 February 2025. Published 31 May 2025.

This study was conducted within the framework of the project PIBA-PUE of the Basque Government (PIBA21/02). The authors would like to express their gratitude for the support provided by the Research Groups of the Basque Government (IT1514-22), as well as the support provided by the Joint Research Laboratory on Offshore Renewable Energy (JRL-ORE).

All the authors belong to the Energy Engineering Department at the Bilbao School of Engineering of the University of the Basque Country (UPV/EHU), Plaza Ingeniero Torres Quevedo I – 48013 – Bilbao.

U. Izquierdo is Associate Professor (urko.izquierdo@ehu.eus).

I. Bidaguren is Assistant Professor (i.bidaguren@ehu.eus).

I. Albaina is Associate Professor (i.albaina@ehu.eus).

G.A. Esteban is Associate Professor (gustavo.esteban@ehu.eus).

A. Peña is Associate Professor (alberto.bandres@ehu.eus)

O. Peña is Ph.D. student (oier.pena@ehu.eus).

J.M. Blanco is Professor (jesusmaria.blanco@ehu.eus).

Digital Object Identifier: https://doi.org/10.36688/imej.8.13-19

a Type U power plant. In other words, installing a wall in front of the Mutriku power plant with the aim of creating an L+U combination, which has not been previously studied.

II. Experimental wave flume

This work, which is completely experimental, was carried out in the laboratory of Fluid Mechanics of the Department of Energy Engineering at the University of the Basque Country (UPV/EHU). This laboratory is equipped with a wave flume (Fig. 2) of 12.5 m long, 0.6 m width and 0.7 m height.

Fig. 2. General view of the experimental wave flume.

This research facility has been previously descried in several works carried out by the authors [18], [27]. However, a new equipment has been self-developed by the authors that facilitates the calibration of the resistive type probes by doing this operation automatically (see Fig. 3). It consists of a structure supported by two threaded rods, joined by a bar that acts as a gantry, from which the resistive type meters hang. The length of this bar is measured in millimeters in order to know the exact distance between the consecutive resistive type gauges when characterizing the waves produced. Using two servomotors that are installed on threaded rods, the vertical position of the gauges is modified to perfectly defined levels.

Fig 3. Overview of the automatic calibration device.

The experimental campaign has been the same as the one carried out by I. Bidaguren et al. [18]. In addition, another tide has also been tested, corresponding to the maximum, in order to be able to test a wider period range into the Stokes range. Then, a constant incident regular waves of 30 mm were generated at several periods for the two tides, h=163 mm and h=232 mm; 0.7<T[s]<1.7 for the medium tide and 0.7<T[s]<2.1 for the maximum tide. The reflection phenomenon was avoided ending the tests before the reflected wave reached the structure. As observed in Fig. 4, although most of waves are Stokes type waves, two waves are Cnoidal type in order to study their performance into de chamber.

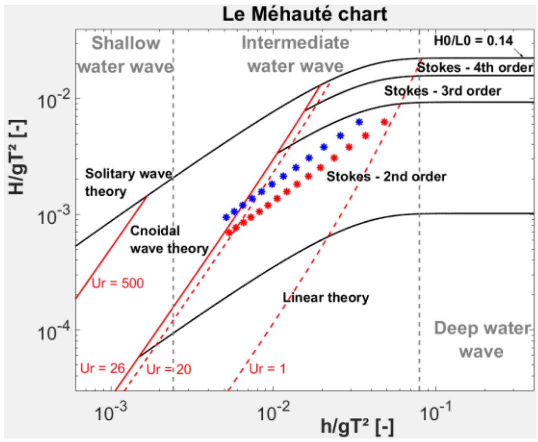

Fig. 4. Experimental campaign plotted in the Le Méhauté chart.

III. Experimental set-up

A. *The model of the Mutriku power plant*

The dimensions of the current Mutriku breakwater were used in order to create a 1:36 scale model (see Fig. 5a) of one of the chamber of the Mutriku breakwater power plant. The model's overall width is 173 mm, and it lands on the seabed of the wave flume, which has a width of 600 mm (see Fig. 5b). A water level sensor is installed at the top model in order to measure the surface elevation of the interior of the chamber. Therefore, the sloshing was not measured. In this study, the Response Amplitude Operator (RAO) was measured, assuming that a higher amplification implies higher efficiency.

Fig. 5. a) General view of the scaled (1:36) Mutriku power plant. b) The model at the centre of the wave flume with the gauge.

B. *Instruments and methods*

The equipment of the laboratory has been properly specified in [28], and consist basically of a wave generator that uses a Delta-ASDA (V5) commercial software. Once the desired wave is generated, surface oscillation data are acquired using two resistive-type wave probes to precisely characterize the parameters of the incident waves (H, T, λ). In addition, the oscillation data of the free surface level inside the chamber signal is also measured using another resistive probe. All data is controlled using an ad-hoc

LABVIEW program that obtains experimental values of free surface displacement as a function of time. The data acquisition system consists of a CompactRIO controller (National Instruments, cRIO-9063 model) with an inputs voltage module (National Instruments-9205, C-series).

C. *The tested new designs*

After the literature review specified above, mainly focused on the geometric configurations of the power plants, the following structures were tested in the laboratory:

1. *Two transversal walls* (TW, see Fig. 6) with heights of 80 and 40 mm consecutively. This configuration option tries to simulate the L+U combination using a completely transversal wall, which could be applicable in the real Mutriku plant to all the cambers using a unique front wall. Therefore, the aim using this first configuration lies in the search of the optimum distance fron the breakwater as well as the height of the wall itself. For this, the corresponding tests were carried out at different distances, from 40 mm to 520 mm, analyzing the influence of each wave as the transversal wall moves away 30 mm in each experiment.

Fig. 6. Transversal wall (TW) of 80 mm installed in front of the model representing the Mutriku power plant.

2. *Tests using only the lateral walls* (LW, see Fig. 7). The use of lateral walls (the so-called harbour walls) has demonstrated an improvement in the water surface displacement inside the chamber, resulting in an increase of the RAO.

Fig. 7. Lateral wall (LW) with heights of 364 mm installed in the Mutriku power plant.

The higher amplification is due to the channel generated by the lateral walls, which direction the water flow into the chamber of the power plant. Then, the influence of the distance of the vertical LW will be studied.

3. *Lateral walls joined by walls* with heights of 80 and 40 mm consecutively (LW+W, see Fig. 8). This new option combines the previously described two concepts, using the lateral walls and installing a transversal wall that joins the two walls. In the real plant, it would imply the installation of lateral walls in each chamber, which could be relatively easy, feasible and applicable.

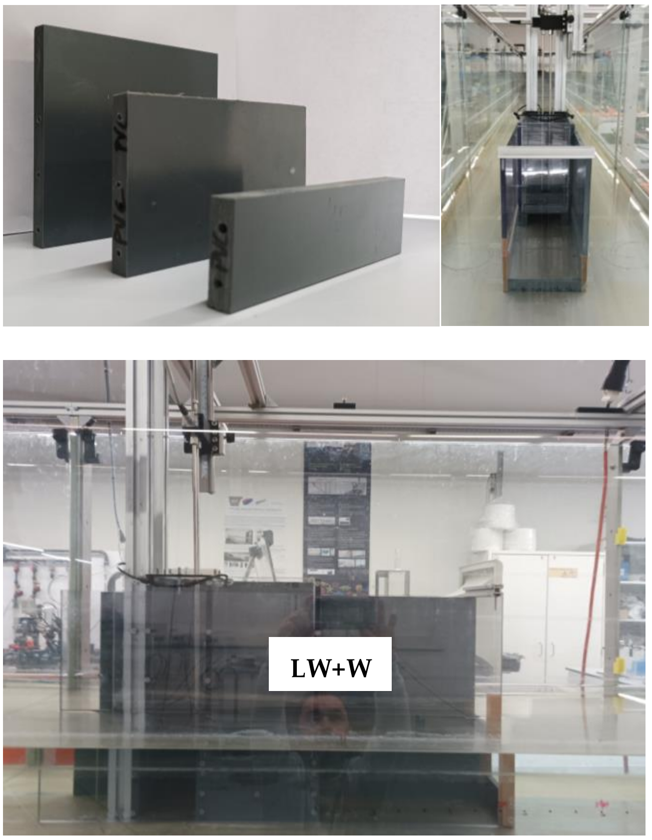

Fig. 8. Top: Tested front walls (W) with heights of 40, 80 and 120 mm. Bottom: The model inside the flume, once the Lateral Walls (LT) are joined with the W. Front view of the LW+W of 40 mm.

In Fig. 8 the tested walls can be observed. In this new configuration is more evident the L+U combination, as it is design in a similar way than the U-type plant are. Although the height of the wall is the main parameter under investigation, in this work the distance of the front wall (in addition to its height) has been modified, in order to determine the influence in terms of chamber amplification.

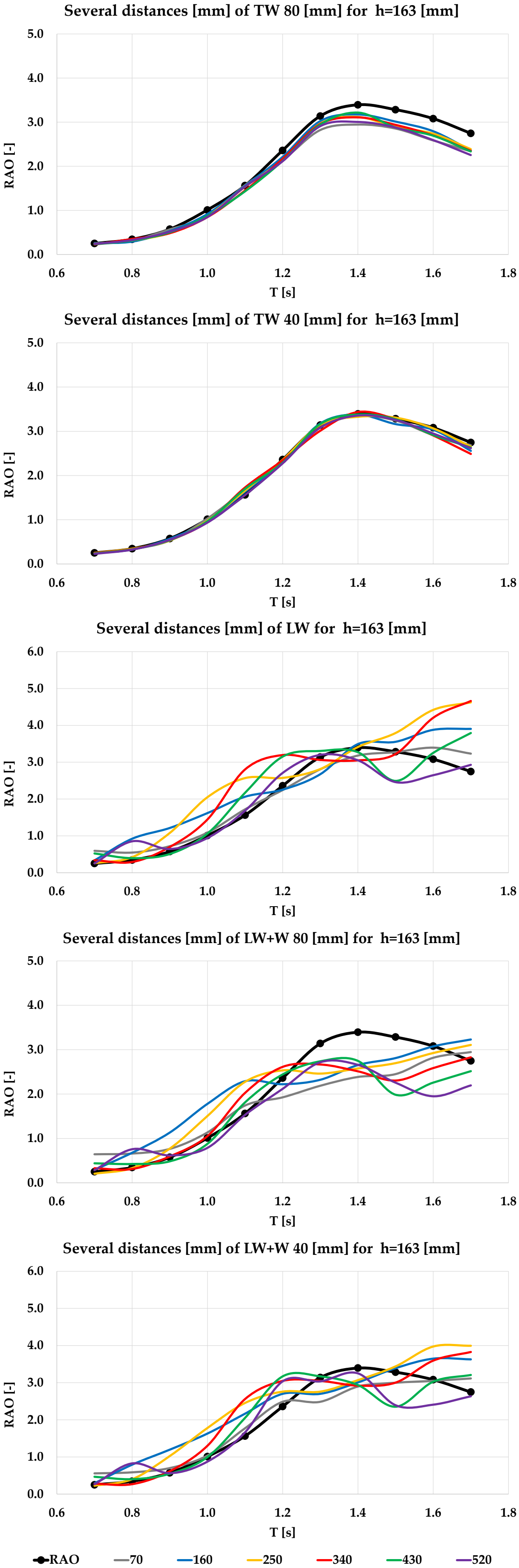

Fig. 9. Results obtained for the 163 mm tide.

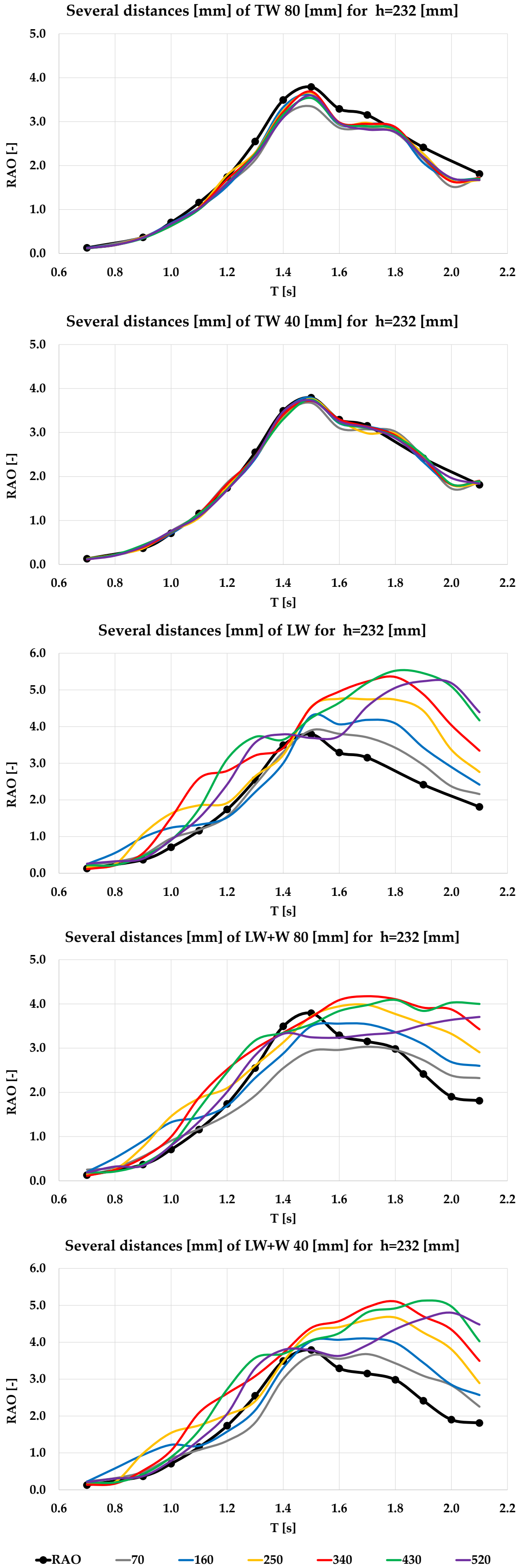

Fig. 10. Results obtained for the 232 mm tide.

This configuration opens new research options because of two reasons: first, the geometry of the lateral walls; in this study vertical walls have been designed, but the geometry of the LW can be further modified to improve the directionality of the flow towards the chamber and enhance the displacement of the free surface. Second, the capacity of the Mutriku power plant to install lateral walls; focusing on the plan of the plant [18], there is a significantly long distance between consecutive chambers, which is a part of the front wall of the breakwater, where a complete reflection of the waves occurs. This distance (40.15 mm at each lateral of the model) can be used in order to install the most efficient option of lateral walls to improve the efficiency of the power plant.

IV. Results

In the following section, the obtained results will be presented and interpreted. The experiments for the structures that modified the original geometry of the Mutriku WPP were performed once. However, for the RAO of the original Mutriku WPP were repeated three times, obtaining relative errors between the mean values and the obtained values always less than 5 %.

1. First the *two transversal walls* (TW) with heights of 80 and 40 mm were tested, for the tides of 163 and 232 mm. For all the drawings, the dotted curve represents the RAO of the original Mutriku WPP, without any type of structural modification. The rest of the lines represent the distance at which the front wall was placed from the breakwater of the plant. In the first two drawings of Fig. 8 and 9 can be observed, both for the 163 mm tide and for the 232 mm tide consecutively, that in none of the cases (80 mm and 40 mm wall) was possible to increase the amplification inside the chamber. This fact may be due to two reasons: the first one may be related to the fact that the front wall is not attached to the chamber, and therefore only obstructs the way and negatively affects to the properties of the wave, and, as a consequence, its amplification inside the chamber. The other reason may be related to the fact that with the design of the Mutriku power plant, Type L, the amplifying effect of a U-Type power plant is not achieved, since the wall of this type of power plants is attached to Conventional Type power plants.

2. *Tests using only the lateral walls* (LW). In the test using LW much better results were measured almost for all the period and the distances. Focusing on the results obtained operating with a tide of 163 mm, for the distances of 250 and 340 mm the highest amplifications were measured at T=1.6 s and T=1.7, which are the periods with the highest frequency of occurrence at the Mutriku power plant. Surprisingly, the mayor amplification occurs after the maximum amplification measured for the original plant and for the periods with higher frequency of occurrence, which makes this solution especially attractive. On the other hand, focusing on the results obtained operating with a tide of 232 mm, for the distances of 340, 430 and 520 mm the highest amplifications were measured at $1.6 < T[s] < 2.0$. These type of periods, attending to the frequency of occurrence, are present during the 35 % of the time at Mutriku coast. Also for this tide, the amplification at the mentioned distances and periods is significantly higher than the one measured for the original plant.

The option of LW presented very promising results, and it is an option that could be relatively easy to be implemented. Therefore, the last design modification tries to improve even more the results obtained using only the LW, by introducing a front wall between the two LW, that was denoted as LW+W. Although the results obtained using only the FW were unsatisfactory, the thought of reproducing a U-Type plant together with a L-Type one pursued to test this option.

3. *Lateral walls joined by walls with heights of 80 and 40 mm consecutively*. The inclusion of a front wall (W) finally did not give the expected results. In all the cases that were tested (even with a 120 mm wall that is not shown in the results section), the results were worse compared to the results obtained operating only with the LW. Worst results for both tides, at all the distances and for all the periods. This could be related to the resonance of the L-Type plants chamber, which is negatively affected when combined with a front wall, regardless the configuration and the characteristics of the front wall.

V. Conclusion

The study carried out covered the design and testing of three types of structural modifications for the Mutriku WPP: a transverse wall (TW), the installation of lateral walls (LW) and the combination of both (LW+W). The main conclusion achieved are listed below:

- For the L-Type OWC plants, the option of installing a front wall to emulate a U-type plant does not improve the amplification inside the chamber. Neither of the two tested options has achieve any improvement.
- The response of the chamber of an L-Type OWC plant as it is Mutriku, in terms of free surface displacement or amplification, do not follow the same behavior as a conventional one. This is because of the channel that gives the L-Type configuration, which its design (length, height or inclination) could be also studied.
- The lateral walls (LT) seemed to be the best option to reach higher RAO values. They can be further modified in length and shape in order to improve the RAO. Therefore, this research will continue studying their optimum design.
- Focusing on the results obtained with LW, the best results were achieved for h=163 mm at T=1.6 s and 340 mm away from the breakwater (RAO value of 4.66), and h=232 mm at T=1.8 s and 430 mm away from the breakwater (RAO value of 5.52).

- For all the conditions in which the RAO is maximized, compared to the RAO measured for the actual Mutriku power plant, the periods at which the RAO is improved correspond to values in which the frequency of occurrence of the waves is maximum. This means, that the improvement using LW occurs in most common range of waves at Mutriku. According to [10], the 37 % of the waves that interact with the Mutriku power plant are in the range between 9.5<T[s]<12.5, or 1.58<T[-]<2.08 applying the 1:36 scale.

ACKNOWLEDGEMENT

The authors would like to express their gratitude to the laboratory technicians, Isaac Casas and Daniel de Miguel, for their contribution in this work.

REFERENCES

[1] Z. Deng, P. Wang, and P. Cheng, "Hydrodynamic Performance of an Asymmetry OWC Device Mounted on a Box-Type Breakwater," *Front. Mar. Sci.*, vol. 8, no. June, pp. 1–14, 2021.

[2] A. Elhanafi, A. Fleming, G. Macfarlane, and Z. Leong, "Numerical energy balance analysis for an onshore oscillating water column–wave energy converter," *Energy*, vol. 116, pp. 539–557, 2016.

[3] I. López, B. Pereiras, F. Castro, and G. Iglesias, "Holistic performance analysis and turbine-induced damping for an OWC wave energy converter," *Renew. Energy*, vol. 85, pp. 1155–1163, 2016.

[4] F. Mahnamfar and A. Altunkaynak, "OWC-Type Wave Chamber Optimization Under Series of Regular Waves," *Arab. J. Sci. Eng.*, vol. 41, no. 4, pp. 1543–1549, 2016.

[5] K. Rezanejad, J. Bhattacharjee, and C. Guedes Soares, "Stepped sea bottom effects on the efficiency of nearshore oscillating water column device," *Ocean Eng.*, vol. 70, pp. 25–38, 2013.

[6] I. Simonetti, L. Cappietti, and H. Oumeraci, "An empirical model as a supporting tool to optimize the main design parameters of a stationary oscillating water column wave energy converter," *Appl. Energy*, vol. 231, no. September, pp. 1205–1215, 2018.

[7] I. Simonetti, L. Cappietti, H. Elsafti, and H. Oumeraci, "Evaluation of air compressibility effects on the performance of fixed OWC wave energy converters using CFD modelling," *Renew. Energy*, vol. 119, pp. 741–753, 2018.

[8] A. A. M. Rodríguez, J. M. B. Ilzarbe, R. S. Casarín, and U. I. Ereño, "The influence of the chamber configuration on the hydrodynamic efficiency of oscillating water column devices," *J. Mar. Sci. Eng.*, vol. 8, no. 10, pp. 1–27, 2020.

[9] Y. Torre-Enciso, I. Ortubia, L. I. López de Aguileta, and J. Marqués, "Mutriku Wave Power Plant: from the thinking out to the reality," *8th Eur. Wave Tidal Energy Conf. (EWTEC 2009)*, pp. 319–328, 2009.

[10] Y. Torre-Enciso, I. Ortubia, L. I. López de Aguileta, and J. Marqués, "Mutriku Wave Power Plant: from the thinking out to the reality," *8th Eur. Wave Tidal Energy Conf. (EWTEC 2009)*, no. August, pp. 319–328, 2009.

[11] P. G. F. Filianoti, L. Gurnari, M. Torresi, and S. M. Camporeale, "CFD analysis of the energy conversion process in a fixed oscillating water column (OWC) device with a Wells turbine," *Energy Procedia*, vol. 148, no. Ati, pp. 1026–1033, 2018.

[12] A. George, I. H. Cho, and M. H. Kim, "Optimal design of a u-shaped oscillating water column device using an artificial neural network model," *Processes*, vol. 9, no. 8, 2021.

[13] G. Malara, R. P. F. Gomes, F. Arena, J. C. C. Henriques, L. M. C. Gato, and A. F. O. Falcão, "The influence of three-dimensional effects on the performance of U-type oscillating water column wave energy harvesters," *Renew. Energy*, vol. 111, pp. 506–522, 2017.

[14] G. Malara and F. Arena, "Analytical modelling of an U-Oscillating Water Column and performance in random waves," *Renew. Energy*, vol. 60, pp. 116–126, 2013.

[15] D. zhi Ning, B. ming Guo, R. quan Wang, T. Vyzikas, and D. Greaves, "Geometrical investigation of a U-shaped oscillating water column wave energy device," *Appl. Ocean Res.*, vol. 97, no. September 2019, p. 102105, 2020.

[16] C. Xu, Z. Liu, and G. Tang, "Experimental study of the hydrodynamic performance of a U-oscillating water column wave energy converter," *Ocean Eng.*, vol. 265, no. August, p. 112598, 2022.

[17] M. Iino, T. Miyazaki, H. Segawa, and M. Iida, "Effect of inclination on oscillation characteristics of an oscillating water column wave energy converter," *Ocean Eng.*, vol. 116, pp. 226–235, 2016.

[18] I. Bidaguren *et al.*, "Experimental characterization of the Chamberturbine coupling damping of mutriku breakwater power plant at 1:36 scale model," in *Proceedings of the European Wave and Tidal Energy Conference*, 2021, pp. 2032-1-2032–10.

[19] T. Vyzikas, S. Deshoulières, M. Barton, O. Giroux, D. Greaves, and D. Simmonds, "Experimental investigation of different geometries of fixed oscillating water column devices," *Renew. Energy*, vol. 104, pp. 248–258, 2017.

[20] P. Boccotti, "Comparison between a U-OWC and a conventional OWC," *Ocean Eng.*, vol. 34, no. 5–6, pp. 799–805, 2007.

[21] B. N. Fox, R. P. F. Gomes, and L. M. C. Gato, "Analysis of oscillating-water-column wave energy converter configurations for integration into caisson breakwaters," *Appl. Energy*, vol. 295, no. January, p. 117023, 2021.

[22] X. L. Zhao, D. Z. Ning, and D. F. Liang, "Experimental investigation on hydrodynamic performance of a breakwater-integrated WEC system," *Ocean Eng.*, vol. 171, pp. 25–32, Jan. 2019.

[23] D. Ning, B. Guo, R. Wang, T. Vyzikas, and D. Greaves, "Geometrical investigation of a U-shaped oscillating water column wave energy device," *Appl. Ocean Res.*, vol. 97, no. February, p. 102105, 2020.

[24] D. H. Yacob, S. Sarip, H. M. Kaidi, J. A. Ardila-Rey, and F. Muhammad-Sukki, "Oscillating Water Column Geometrical Factors and System Performance: A Review," *IEEE Access*, vol. 10, pp. 32104–32122, 2022.

[25] N. P. Juan, V. N. Valdecantos, M. D. Esteban, and J. S. L. Gutiérrez, "Review of the Influence of Oceanographic and Geometric Parameters on Oscillating Water Columns," *J. Mar. Sci. Eng.*, vol. 10, no. 2, 2022.

[26] D. D. Raj, V. Sundar, and S. A. Sannasiraj, "Enhancement of hydrodynamic performance of an Oscillating Water Column with harbour walls," *Renew. Energy*, vol. 132, pp. 142–156, 2019.

[27] U. Izquierdo, G. A. Esteban, J. M. Blanco, I. Albaina, and A. Peña, "Experimental validation of a CFD model using a narrow wave fl ume," *Appl. Ocean Res.*, vol. 86, no. December 2018, pp. 1–12, 2019.

[28] U. Izquierdo, L. Galera-Calero, I. Albaina, A. Vázquez, G. A. Esteban, and J. M. Blanco, "Experimental and numerical determination of the optimum configuration of a parabolic wave extinction system for flumes," *Ocean Eng.*, vol. 238, no. July, pp. 1–11, 2021.