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PERFORMANCE OF DIFFERENT RAMP CONFIGURATIONS CHARACTERIZING AN OVERTOPPING WAVE ENERGY CONVERTER USING JOINT PROBABILITY DENSITY FUNCTIONS: PRELIMINARY NUMERICAL RESULTS

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ABSTRACT

The Overtopping BReakwaters for Energy Conversion (OBRECs) are a form of Wave Energy Converters (WEC) embedded in traditional rubble mound breakwaters. These devices have a ramp that allows water waves to be overtopped and generate energy. Port of Ancona in Italy will undergo some construction activities such as a new seawall with an embedded OBREC and after statistical analysis of the wave climate on offshore, Joint Probability Density Functions were used to select waves as inputs for the shallow water solver. FUNWAVE-TVD (Wave-resolving model) was used to propagate the waves from offshore to the port. FLOW-3D was used to compare different ramps to determine the optimal configuration. The outcome of this research which is a simulation chain is expected to provide insights regarding the port of Ancona where a seawall with embedded OBRECs will be built which could be considered as a form of harvesting power from renewable energy.

Keywords: Wave energy converters, Wave overtopping, Protype OBREC, Ramp shapes.

1. Introduction

Ocean waves are a renewable and environmentally friendly energy source, offering several advantages such as high energy density, ease of predicting wave characteristics, and minimal energy loss during propagation. However, there are also significant drawbacks that limit their widespread use. These include the high variability of wave characteristics, the exposure of wave energy converters (WECs) to strong environmental forces, and high production costs, making wave energy less competitive. (Iuppa et al. 2016) (Vicinanza et al. 2014). Overtopping BReakwater for Energy Conversion (OBREC) is a new type of system which allows to harvest energy from ocean waves. This technology is in its first stages and only one device in prototype scale was installed in the world. These devices are embedded to current operating or future breakwaters to reduce the cost of construction and maintenance. The protype of this device is planned to be built in the Port of Ancona.

2. Literature review

Cavallaro et al. (2020) suggest that the OBREC performs optimally and offers high economic viability in regions with mild or less intense wave climates. They note that this is not necessarily a disadvantage, as OBREC, like other seaport protection breakwaters, is typically constructed in naturally sheltered coastal areas. Their findings also revealed that the device's monthly average power output was highly variable.

Di Lauro et al. (2020) used the IH2VOF numerical model to assess the performance of OBREC. The results showed that long waves are minimally affected by the presence of the OBREC device mounted on the caisson, resulting in only a slight reduction in total forces compared to those calculated for a conventional vertical-faced structure.

Kralli et al. (2019) employed the Harmony Search Algorithm (HSA) as an optimization technique for refining the shape parameters of these structures, specifically the reservoir width and crest freeboard. They explored 27 scenarios under different wave directions, with wind strengths ranging from 3 to 11 on the Beaufort scale. The study suggests further optimization by selecting the appropriate pipe diameter and electrical equipment. A Kaplan turbine was utilized in their simulations.

3. Materials and Methods

3.1. Data Selection and Wave Transfer

Wave rose in the location of buoy which is located in almost 30 Km from Port of Ancona is shown in Fig. 1. The selected time series were between 2021-07-01 00:00 and 2023-12-28 13:30. It Could be seen that there are three main wave directions including NNE, ESE, and NNW.

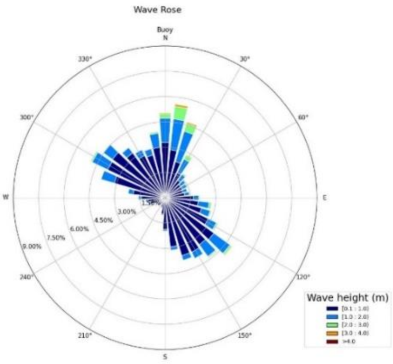

Fig. 1. Wave Rose in Buoy location.

Data for input parameters are selected based on the statistical analysis shown in Fig. 2 . This illustrates the joint probability density function (PDF) with density equal to 0.05 referring to the wave data from buoy.

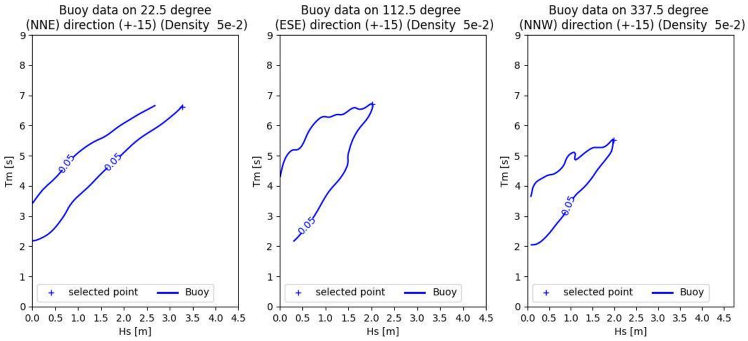

Fig. 2. Bivariate density contour lines of Tm and Hs corresponding to $p = 0.05$

Once waves experience shallow water, their heights and directions will be affected by refraction, shoaling and breaking processes. To evaluate these changes, Goda's (2010) approach was applied, an analytical model to transfer the wave characteristics from deep to shallower waters over a constantly sloping beach. Such an approach led to the wave propagation from the buoy location (~70m) up to a depth h_1=15m, i.e. just offshore of the port. The results in terms of significant height (H_s) and peak period (T_p) are shown in Table 1

The wave height could be calculated in shallow water using the following equation:

$$H_s = K_r\left\{min\left[\left(\beta_0 H_{s,0} + \beta_1 h\right), \beta_{max} H_{s,0}, K_s H_{s,0}\right]\right\} \quad (1)$$

where β_0, β_1 and β_{max} are parameters depending on both deep-water wave steepness ${H_{s,0}}/{L_{p,0}}$ and seabed slope i.

The incidence angle of waves at the target location θ are also functions of the incident deep-water angle θ_0 and relative water depth, ${h}/{L_0}$. $L_{p,0}$ is the deep-water peak length.

$$\theta = f\left(\theta_0, {}^{h}/_{L_{p,0}}\right) \quad (2)$$

Waves typified by an ESE direction do not reach the location of analysis due to the shape of the port. Hence, this direction is not taken into account. On the other hand, the wave characteristics relevant to the other two incoming directions are used to force a numerical Boussinesq-type model, i.e. the FUNWAVE-TVD(Shi et al. 2011) with the aim to simulate the wave propagation within the port of Ancona, up to the location where the OBREC is planned to be built.

To run the FUNWAVE-TVD model, the angle $\alpha_{p,h1}$ that must be imposed at the offshore boundary, has been found starting from the incidence angle θ (see Table 1).

Table 1. Transformation and Deformation of Sea Waves

		NNE	NNW
Density 0.05	Hs (m)	2.53	1.67
	Tp (s)	7.81	6.51
	$\alpha_{p,h1}$ [°]	35.00	27.00

3.2. *Waves in the port area*

For evaluating the performance of the OBREC, FUNWAVE-TVD was used to simulate waves in intermediate to shallow waters. In Fig. 3, water surface fluctuations based on FUNWAVE-TVD output in NNE direction and gauge's locations are shown.

3.3. *Wave-structure interaction*

For this evaluation, the FLOW-3D model is used (Flow Science 2023). Free surfaces are modelled with the Volume of Fluid (VOF) technique. It utilizes Navier-Stokes equations, while structured mesh can only be used.

In the present section, the actual size of the breakwater is used, while the FUNWAVE outputs (i.e. water level at gauge 4, almost 200 m from the OBREC location) are exploited as a wave boundary condition for FLOW-3D.

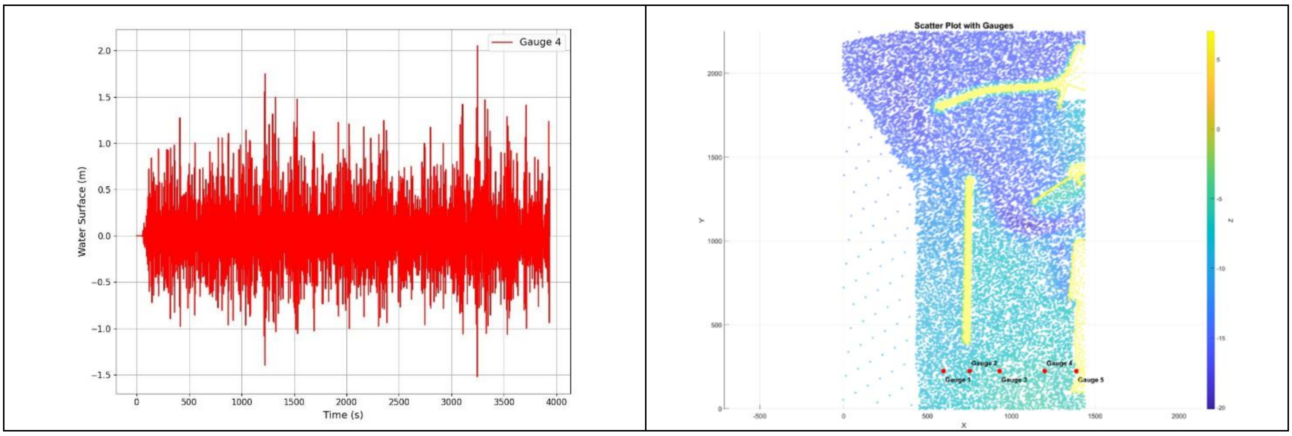

Fig. 3. Outputs of FUNWAVE for Water surface and the numerical domain for FUNWAVE-TVD .

The water depth in front of the breakwater is about 3 m. The grid sizes were set to 0.2 m in 2 directions (X and Z) and 5 cells in Y direction (total number of 199,325 cells). The numerical domain has 227 m length, 4.7 m width and 7 m height and simulation time was 200 s. The shape of the upper part of the breakwater is shown in Fig. 4. Model 1 is similar to the shape of the designed breakwater, which is going to be built in the port. The other models show a smaller ramp slope, in the perspective of a larger overtopped water discharge. In Model 4, there is no berm after the ramp. In Fig. 4, the volume of overtopped discharge is compared for different ramp slopes. Model 4, which has the lower slope (23 degrees) provides a higher water volume, as the slope increases, the amount of volume of fluid decreases (except from Model 3 to Model 2). Model 3 with 26-degree ramp slope provides the lowest value.

4. Conclusion

Based on results from real-breakwater tests, the reduction of the ramp slope provides an increase of the amount of water discharge, except for models 2 and 3. By reducing the grid sizes the volume of fluid in the reservoir was limited to around a specific value. The results with real-world ramp on the designed breakwater will be discussed in depth at the conference, in view of the OBREC installation at the Port of Ancona.

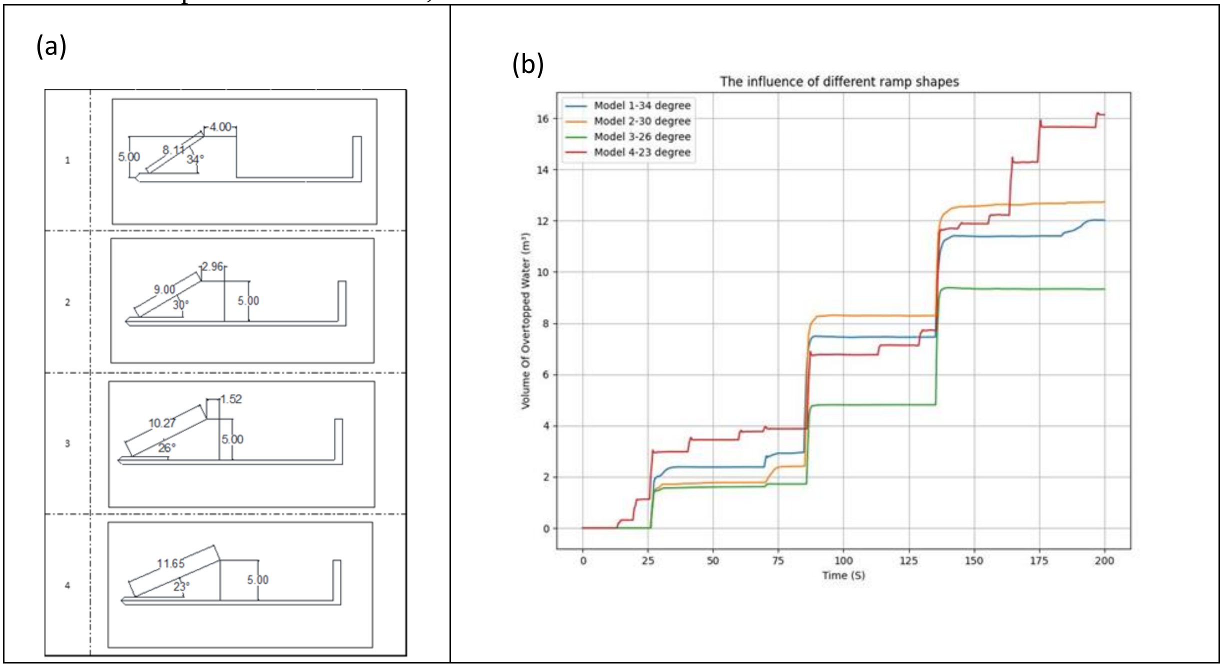

Fig. 4. (a) Shape of OBREC in real scale and (b) the influence of ramp slope in Volume of overtopped Water.

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