

LABORATORY-SCALE EXPERIMENTAL STUDY OF A PROPOSED WAVE ENERGY CONVERTER

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INTRODUCTION

Wave energy converters (WECs) are devices designed to capture wave energy and transform it into electricity. Chile, with its extensive coastline and favorable wave conditions, presents high potential for this technology. However, the development of efficient and structurally robust devices remains a technical challenge. This work addresses the construction of a model at laboratory scale of a submersible WEC based on a truss-type structure and Kaplan turbines conceptually developed by Etymol Ocean Power SpA. The second aspect addressed in this work is the numerical determination of focused structural strength, stability, and buoyancy under static conditions that mimic wave elevations. A preliminary energy analysis was performed, considering internal hydraulic losses due to singularities. This exercise allowed for the estimation of the ideal hydraulic and electrical power generated by a Kaplan turbine under standard conditions.

MATERIALS AND METHODS

The principle of the working system is shown in **Figure 1**. It is based on the conversion of the wave energy into an internal flow directed towards the turbines. This hydraulic energy flux is ultimately converted into electricity.

The scaled model was made of Polyethylene Terephthalate Glycol by 3D printing; a material selected due to its water resistance and good dimensional stability. Additionally, AISI 304 bars were employed for the WEC's exoskeleton. One of the main challenges of scaling lies in the differences between the mechanical properties of

the materials used in the model and those considered at the real scale, which affect the resulting stiffness and strength. Furthermore, the impossibility of simultaneously satisfying Reynolds and Froude similarity limits the accurate representation of the internal flow. Finally, the energy conversion factor is another challenge. Their estimations differ from the real-scale expectations.

According to the classification proposed in Saez (2018), the prototype can be categorized as a third-generation wave converter (WEC-KPI < 1,000 [ton/MW]). Regarding structural safety, the Load and Resistance Factor Design (LRFD) criterion based on the offshore standard DNVGL-OS-C101, DNV GL (2017), was applied, resulting in a global factor greater than 3, covering uncertainties and ensuring integrity under dynamic loads and extreme conditions at the selected site.

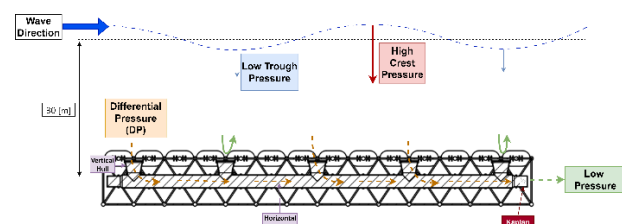


Figure 1.- Example of the proposed system.

The analysis was performed under regular and extreme wave conditions using Stokes II theory, and the dispersion relation curves shown in **Figure 2** were obtained from DNVGL-RP-C205 (2017), where the horizontal axis represents the relative depth (d/L) and the vertical axis the relative wave height (H/T^2), with d the water depth [m], L the wavelength [m], H the wave height [m], and T the wave period [s].

The regular and extreme wave conditions (**Table 1**) were plotted in this diagram based on data from Camus et al. (2017), and a representative depth of $d=70$ [m] from the Bathymetric Map of Chile, SERNAGEOMIN (2000) for Chiloé, southern Chile. These parameters (d, L, H, T) were scaled according to Froude similarity with a scaling factor of $\beta=100$, enabling the representation of both conditions in the diagram.

RESULTS

The resulting physical model build according to the geometrical scale is presented in **Figure 3**.



Figure 3.- Laboratory-scale physical model.

The main wave characteristics used for modelling are reported in **Table 1**, resulting in two different wave conditions as illustrated in **Figure 4** used for the analysis. The energy estimation was performed using the simplified equation $P=\rho gQH\eta$, where ρ is the water density [kg/m^3], g is the gravitational acceleration [m/s^2], Q is the volumetric flow rate through the turbine [m^3/s], H is the effective hydraulic head [m], and η is the global efficiency. This produces a net power of 0,77 [W] per Kaplan turbine. Applying Froude similarity with $\beta=100$ ($Pr = Pm \cdot \beta^{3,5}$), this corresponds approximately 15,5 [MW] in total (two turbines) in real scale.

Table 1.- Wave parameters in Chiloé: regular values and extreme events (100 years), on a real and model scale.

Parameter	Regular Wave		Extreme Wave (100 years)	
	Real	Model	Real	Model
Wave height H [m]	2,810	0,0281	10,200	0,1020
Wavelength λ [m]	72,500	0,7250	210,300	2,1030
Wave period T [s]	9,000	0,900	12,500	1,250
Angular frequency ω [rad/s]	0,698	6,976	0,502	5,027
Wave number k [rad/m]	0,050	4,970	0,026	2,570
Depth d [m]	70,000	0,700	70,000	0,700

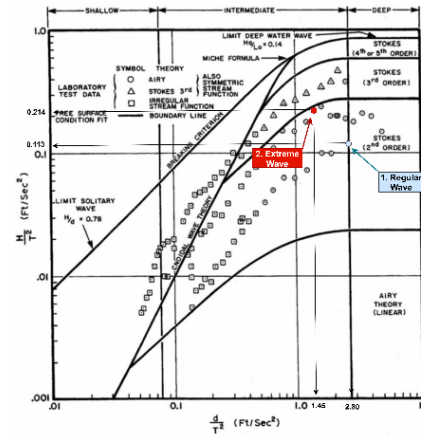


Figure 2.- Dispersion relation curves. The theoretical models used in CFD analysis are indicated.

CONCLUSIONS

Experimental hydrodynamic testing was not possible within the scope of the present work, nevertheless the physical model helps to better understand constructive aspects for future prototypes at real scale. Preliminary energy analysis was performed, considering internal hydraulic losses due to singularities, allowing the estimation of the ideal hydraulic and electrical power generated by a Kaplan turbine under standard conditions, providing a reference value for future design stages.

Furthermore, the construction experience was highly positive, and it is considered essential to continue research towards real-scale implementation and testing of this clean technology.

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