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CONSTRUCTAL DESIGN APPLIED TO THE GEOMETRIC OPTIMIZATION OF THE HYDROPNEUMATIC CHAMBER DIMENSIONS OF AN OSCILLATING WATER COLUMN WAVE ENERGY DEVICE

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Abstract: *This paper presents a preliminary evaluation of the operating performance of an Onshore Oscillating Water Column (OWC) converter submitted to a typical southern Brazilian coast wave. The numerical modelling has been performed using the FLUENT CFD code based on the Finite Volume Method (FVM). The mixture water-air flow is considered to be two-dimensional, laminar and unsteady. The Constructal Design has been applied in order to determine the optimum dimensions of the air chamber of the OWC device. The optimization purpose is to investigate the* H_1/L_1 *ratio that reaches the highest power extracted from the device.*

Key words: *OWC, Wave Energy, Constructal Design, FLUENT.*

1. Introduction

The wave energy flux on the southern Brazilian coast is substantial being estimated in 30 kW per metre of wave front [1]. This fact has motivated studies regarding the wave energy extraction. The Oscillating Water Column (OWC) is currently one of the most analysed systems for wave energy conversion both theoretically and experimentally [2]. An Oscillating Water Column applies a significant amount of moving water as a piston in a cylinder. The air is forced out of the column as a wave rises and air is drawn in as the wave falls. This movement of air turns a Wells Turbine at the top of the column.

Although it is reaching the stage of commercial exploitation, serious doubts still remain concerning the OWC feasibility and there is much to be investigated about its operating performance. Thence, there is a high demand for evaluating its performance and efficiency.

Therefore, the analysis of technical factors that influence the equipment efficiency when availing the energetic resource constitute the main objective of the present study.

It is intended to evaluate the performance

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of an OWC onshore wave energy converting system when submitted to a monochromatic wave whose characteristics are similar to the ones found on the southern Brazilian coast.

The commercial Computational Fluid Dynamics (CFD) code FLUENT® based on the Finite Volume Method (FVM) has been used to perform the numerical analysis. The free surface modelling has been performed applying the VOF (Volume of Fraction) Technique. Concerning the geometric optimization, the Constructal Design has been applied in order to set the optimum dimensions of the air chamber of the OWC equipment respecting the geometric constraint imposed by the system that fixes the measure of the hydropneumatic chamber area.

2. Objectives

This study aims globally to evaluate the influence of the hydropneumatic chamber dimensions of an onshore OWC converting system over its operating performance. Thereunto, the degree of freedom defined as the ratio between the chamber's high and length has been varied. The purpose is to determine for which value of ratio the maximal performance is reached; in other words, for which value of ratio the average hydrodynamic power transmitted to the OWC is maximum.

It is also intended to quantify the temporal variations of the volumetric and mass flow that passes through the duct of the turbine and the temporal variation of the average pressure differential between a point situated at the beginning of the duct and another one located at the end of it. Moreover, it is objectified to calculate the average hydrodynamic power transmitted to the OWC, and, finally, the average amplification factor. The purpose is to evaluate the influence of the elevation of the free surface inside the chamber over the power developed by the system.

3. Study Case and Methods

In the present study, the flow has been assumed as two-dimensional, laminar, unsteady and incompressible. A monochromatic wave of 1.00m high (*H*), 65.40m length (*L*) and 7.50s period (*T*) propagates along a channel of 10m draft (*h*) that contains an onshore Oscillating Water Column device placed at its ending. This configuration is schematically illustrated in Figure 1. The OWC's front wall thickness and length are, respectively, 0.5m and 5.0m. The duct that contains the Wells Turbine, which hasn't integrated the considered domain, is 1.0m length, 0.6m diameter and is placed at the top of the posterior wall of the equipment. The chamber's area when the water level remains still, defined as the product between the chamber's high (H_1) and length (L_1), is equal to 80.0 m². The chamber's high (H_1) and length (L_1) are variable quantitates that assume different values according to the H_1/L_1 ratio adopted in each tested configuration. A specific value of ratio between the length and the height of the chamber has been established as a reference based on the existing OWC PICO plant's dimensions. All other ratio values that have been settled for analysis represent short variations around this adopted reference value.

The numerical modelling has been performed applying the CFD code FLUENT® V 6.3.26 [3]. The wave propagation is achieved in the program by setting an UDF (User- Defined Function). The third order MUSCL (Monotone Upstream-centered Schemes for Conservation Laws) and the PRESTO! (PREssure STaggering Option) schemes are adopted, respectively, for momentum and pressure interpolations.

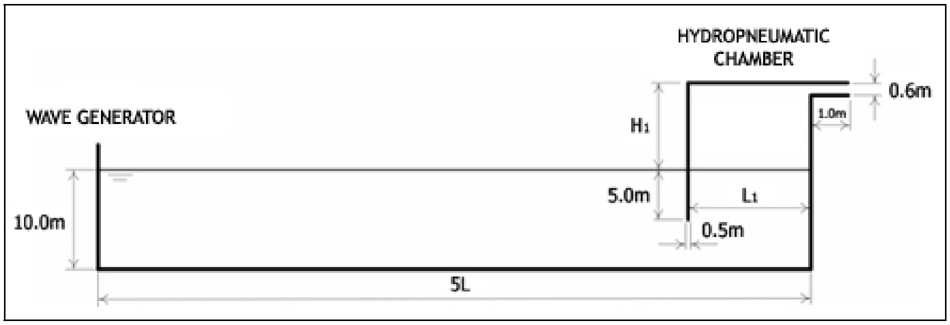

Fig. 1. *Study case schematic configuration*

The explicit scheme is selected to the volume of fraction formulation and the Modified HRIC (High Resolution Interface Capturing) scheme is applied for its discretization. Once defining the explicit volume of fraction scheme, it is required to apply the unsteady formulation with first-order discretization for time.

The geometries and the meshes are created utilizing the grid generator software Gambit® V 2.4.6. The wall boundary condition, representing the no-slip requirement, has been set for chamber's structures as well as for the bottom of the channel. The pressure outlet boundary condition has been established for the top part of the channel as well as for the duct ending. It is know from previous tests that a grid size of approximately $L/60$ in the "x" direction and of $H/20$ in the "y" direction and a temporal time step of $T/600$ ensure numerical accuracy. The gride size on the regions of the hydropneumatic chamber and next to the wave propagation, as well as the regions close to the free surface and the channel's bottom are considered even smaller once that requires more accuracy for its importance. The meshes that have been applied contain an average number of nodes equal to 92235 nodes.

The optimization methodology has been based on the Constructal Theory [4]. In the present study, five configuration of chamber with five different adopted values for the H_1/L_1 ratio are evaluated. Table 1 indicates the assumed values for this ratio, as well as the chamber's high and length values employed. The chamber's area, equal to 80.0 m², consists in this problem restriction and remains, thence, the same for all cases. The average hydropneumatic power has been elected the objective function and it has been calculated for each case in order to enable the identification of the configuration that transmits the highest power to the OWC maximizing, thus, the objective function.

Adopted values for the H_1/L_1, H_1 and L_1 quantitates in each chamber's configuration

Table 1

H_1/L_1	0.20	0.80	1.00	2.00	5.00
H_1 **[m]**	4.00	8.00	8.94	12.65	20.00
L_1 **[m]**	20.00	10.00	8.94	6.34	4.00

4. Results and Discussions

Primarily, a comparison between the free surface elevation values provided by a probe placed 32.5m from the channel beginning and the o nes predicted by the linear (Airy) wave theory [5] is illustrated in Figure 1. There have been a g ood agreement between the free surface values elevation registered by a prove located at the 32.50m position and those predicted by the linear (Airy) theory, assuring the possibility of its usage in rep resenting the physical phenomena. This was the expected since the wave that has be en considered in the present s tudy has small amplitude in comparison with its length and the channel's draft.

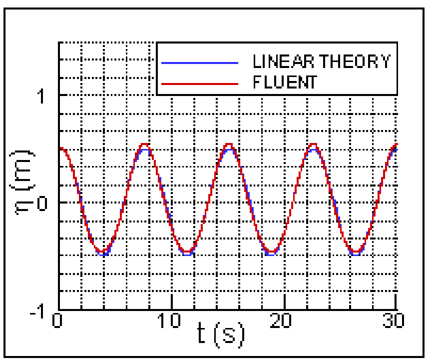

Fig. 2. *Comparison between the elevation values provided by the 32.50m probe and the ones predicted by the linear theory*

Hereafter, are exhibit curve s containing the RMS values of some characteristics for each of the f ive proposed configurations. Firstly, the power transmitted to the OWC, which might be defined as t he product between the mass flow rate and the differential of pressure, is presented. By analysing the values of power illustrated in Figure 3, it is possible to conclude that the op timum configuration corresponds to the one for which the H_1/L_1 ratio is set as 1, once that this case provides the highest value of power (558.06 W). The more distant from the optimum ratio H_1/L_1, the lower is the value of power transmitted to the equipment.

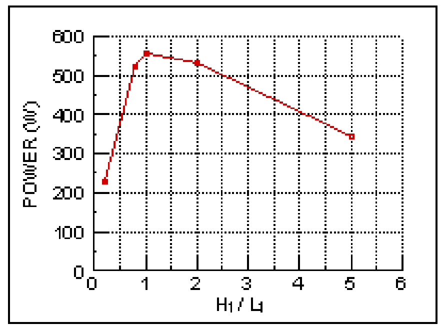

Fig. 3. *Power transmitted to the OWC device*

Figure 4 reveals t hat the mass flow rate that passes through the turbine's duct is approximately the sam e for ratio values varying between 0. 8 and 2, reaching its highest value (8.33 kg/s) for the H_1/L_1 ratio of 0.8.

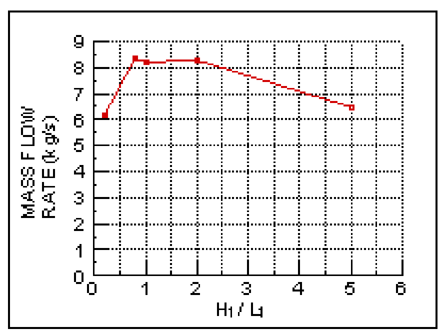

Fig. 4. *Mass flow rate through the duct*

The pressure differential between the duct's beginning and ending parts is displayed in Figure 5. The presented behaviour is quite similar to the power curve behaviour. The maximum value is once again reached for the optimum H_1/L_1 ratio and is equal to 82.65 Pa.

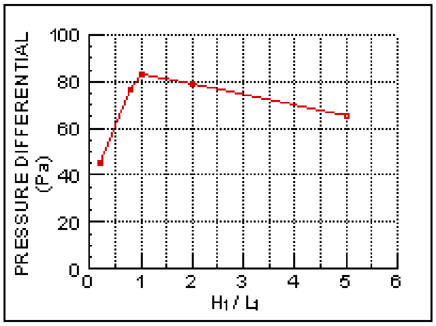

Fig. 5. *Pressure differential between the duct's beginning and ending*

Figure 6 indicates the variation of t he phase angle between the average elevation of the surface inside the h ydropneumatic chamber and the mass flow rate that passes through the du ct. The dephasing between these two characteristics is minimum for the optimum case presenting a phase angle of 59.58° and achieves the maximum value (98.35°) in the case for which the ra tio is more distant from the optimum one.

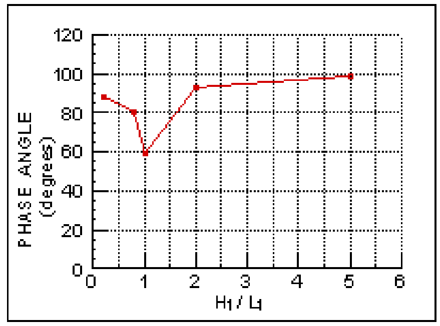

Fig. 6. *Phase angle between the free surface elevation and the mass flow rate*

Finally, are pr esented curves related exclusively to the optimum case for which the power transmitted to the device is maximum. A comparison between free surface elevation records of five probes placed inside the hydropneumatic chamber at the 318.10m, 320.25m, 322.50m, 324.75m and 326.90m position has been perfo rmed and presents also a good agreement as illustrates Figure 7.

Thereafter, are displayed in Figur e 8 the temporal variations of the average free surface elevation inside the chamber, the pressure differential and the mass flow rate through the turbine's duct. The pressure differential and the mass flow rate are in the same phase. On the other hand, there is a dephasing between the elevation and the mass flow rate.

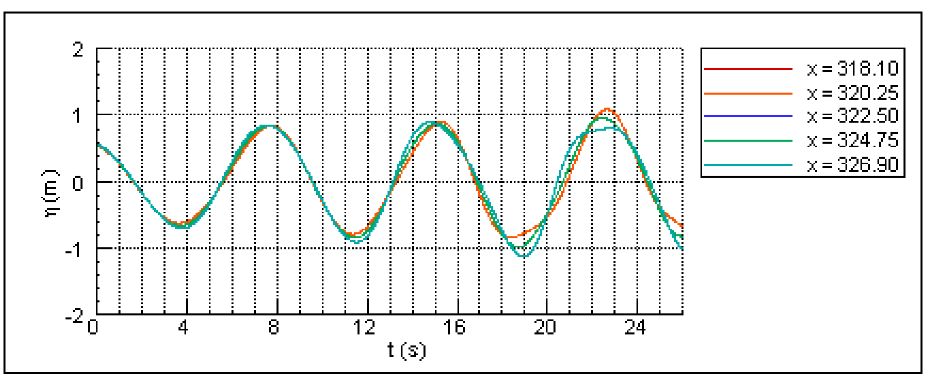

Fig. 7. *Comparison between the elevation values provided by the 318.10m, 320.25m, 322.50m, 324.75m and 326.90m probes*

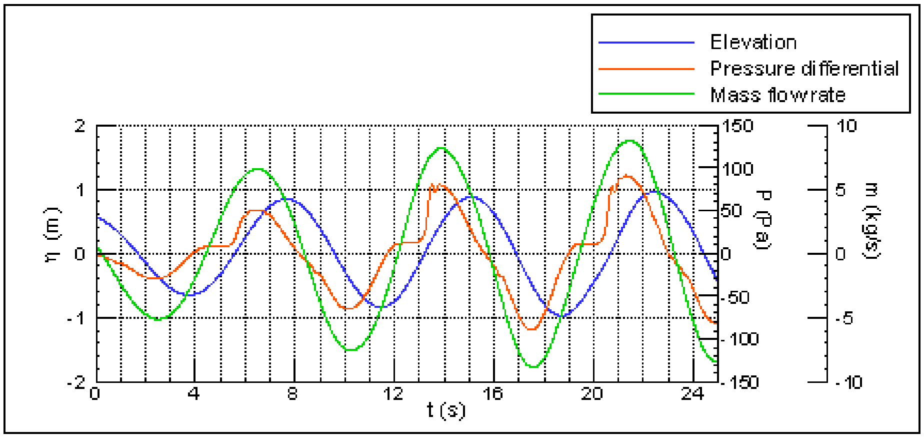

Fig. 8. *Temporal variations of the average free surface elevation inside the chamber, the pressure differential and the mass flow rate.*

5. Conclusions

This paper has presented the optimization of the hydropneumatic chamber dimensions of an OWC applying the Constructal Theory. The numerical modelling has been performed applying the CFD code FLUENT®. The flow has been assumed as two-dimensional, laminar, unsteady and incompressible. Firstly, there have been presented curves containing the RMS values of the power transmitted to the OWC, the mass flow rate, the pressure differential and the phase angle. The optimum configuration has been identified as the one for which the H_1/L_1 ratio assumed the value of 1, once that transmits the highest quantity of power (objective function).

In the second moment, there have been showed three curves concerning the optimum case. A comparison between the elevation values provided by the 32.5m probe and the ones predicted by the linear wave theory has been illustrated showing a good agreement as well as the comparison between elevation values for the five probes placed inside the hydropneumatic. Finally, the free surface elevation, the differential of pressure and the mass flow rate variations along time have been showed.

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