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Dissertation Overview: Numerical modelling of the hydrodynamics and energy generation of an oscillating wave surge converter system

Dissertation Overview: Modelagem numérica da hidrodinâmica e geração de energia dos dispositivos oscilantes por translação de ondas

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Resumo

Dentre os diversos conversores de energia das ondas do mar estudados e desenvolvidos no cenário atual, destaca-se o dispositivo oscilante por translação de ondas (Oscillating Wave Surge Converter – OWSC). Este sistema é aquele que apresenta um dos maiores potenciais para a geração de energia elétrica, em razão de seu princípio de funcionamento, que absorve a energia contida no movimento horizontal das ondas. Diversas empresas e cientistas se dedicaram ao estudo e ao aperfeiçoamento desta tecnologia ao longo dos anos, destacando o Oyster, o Waveroller e o Langlee como os principais exemplos de OWSCs desenvolvidos. Entretanto, os diversos trabalhos realizados e disponíveis no meio científico não apresentam, até o momento, informações suficientemente detalhadas que possibilitem a correta compreensão da hidrodrinâmica associada, dos parâmetros mais influentes e da produção de energia pelo sistema em situações reais de operação. Assim, o presente trabalho tem como objetivo principal preencher estas lacunas, possibilitando o estudo deste sistema de conversão a partir da modelagem numérica, baseada nas médias de Reynolds (RANS), de ondas regulares de características definidas. O código computacional OpenFOAM v. 4.1 e a sua extensão OLAFOAM são utilizados para a realização das simulações. A superfície livre é modelada segundo o método VOF e a dinâmica de corpo rígido é reproduzida por meio de um modelo que permite a deformação da parte inferior do domínio, a fim de reproduzir numericamente a dinâmica do conversor em regiões muito próximas do fundo. O modelo matemático é validado através de uma comparação com resultados experimentais em situações similares, que se encontram disponíveis na literatura. Por meio dos resultados, verificou-se que a metodologia proposta se mostra bastante adequada para reproduzir o movimento oscilatório da estrutura, possibilitando analisar como importantes características de onda e mudanças na geometria do conversor podem afetar a produção de energia do sistema. Além disso, o modelo aplicado representa uma alternativa a outras metodologias numéricas dinâmicas mais complexas, possibilitando o estudo, o projeto e uma estimativa do desempenho destes conversores.

Palavras-chave: Energia Renovável das Ondas do Mar. Oscillating Wave Surge Converters. Computational Fluid Dynamics. RANS. OpenFOAM. OLAFOAM.

Abstract

Among the main wave energy converters studied and developed in the current scenario, the Oscillating Wave Surge Converter (OWSC) stands out. This system presents one of the greatest potentials for power generation, due to its working principle, which absorbs the energy contained in the horizontal movement of the sea waves. Several companies and scientists have dedicated themselves to the study and improvement of this technology over the years, highlighting the Oyster, the Waveroller, and the Langlee as the main examples of the developed OWSCs. However, the scientific works carried out and available in the literature do not present sufficiently detailed information, which makes it difficult to understand the associated hydrodynamics, the most influential parameters, and the energy production in real operating cases. Thus, the main objective of this work is to fill these gaps, by applying the numerical modelling of regular waves (with defined characteristics) based on Reynolds averages (RANS). Therefore, the computational code OpenFOAM v. 4.1 and its extension OLAFOAM are used to carry out the simulations. The free surface is modeled according to the VOF method, and the dynamics of the rigid body are reproduced by a model that allows the bottom deformation, in order to numerically reproduce the converter dynamics in this region. The mathematical model is validated through a comparison with experimental results in similar cases that are available in the literature. After a detailed analysis of the results, it was verified that the proposed methodology is quite adequate to reproduce the oscillation of the structure, making it possible to analyze how wave characteristics and changes in the converter geometry can modify energy production. In addition, the applied model represents an alternative to other more complex dynamic numerical methodologies, allowing a correct study, design, and estimation of the performance of these converters.

Keywords: Wave Renewable Energies. Oscillating Wave Surge Converters. Computational Fluid Dynamics. RANS. OpenFOAM. OLAFOAM.

1. Introduction

Ocean waves can travel great distances without significant energy loss. In addition, their horizontal movement components are enhanced in areas relatively close to the coast. In this context, the Oscillating Wave Surge Converter (OWSC) technology uses these two important characteristics to promote the generation of electrical energy. Its operating principle is based on the oscillatory movement of a structure (flap), which moves back and forth, promoting power generation through an internal turbine.

This system presents the possibility of installation in different regions of the ocean and can be moored to the ocean floor, fully submerged (Waveroller) or partially submerged (Oyster), or even fixed, partially submerged, on floating offshore platforms (Langlee). These construction options highlight the different wave conditions to which these structures are subjected. In addition, the modifications in the geometric parameters of the flap will also have fundamental roles in the associated hydrodynamics. On the other hand, the work carried out to date does not provide enough information to allow a complete understanding of the hydrodynamics of these converters, making it difficult to design the structure and predict the energy produced by the system.

Considering the highlighted points, the present work proposes the study of this technology through the application of numerical modeling based on the Reynolds Averaged Navier-Stokes methodology (RANS), taking into account the important technological growth observed in the computational area. To accomplish this purpose, the open-source code OpenFOAM v. 4.1 and its OLAFOAM extension, which adds wave hydrodynamics to the solver library, are used to model the problem. They are based on the finite volume discretization methodology, in which the free surface is modeled according to the Volume of Fluid (VOF) method.

The proposed method to represent the rigid body dynamics consists of an adaptation of the Mesh Morphing Method, representing the movement of the structure in regions very close to the bottom of the domain, where other numerical methodologies tend to fail or present convergence problems. The presented model defines a region in which the numerical mesh can be deformed to follow the movement of the flap, also allowing the oscillation of the bottom, which makes it possible to reproduce the most critical situations of the converter, where large angular displacements are observed.

The applied numerical model showed that changes in wave height and wave period, together with variations in water depth, are crucial for energy generation, which can intensify or reduce the oscillatory movement of the structure. In addition, variations in the width and thickness of the flap can cause significant hydrodynamic modifications, which are essential for the correct design of the system and can also be applied to other similar renewable systems to enable high-fidelity simulations.

2. Objectives

The main objective of this dissertation is to analyze how the hydrodynamics of an OWSC and the associated energy production are modified as a function of the characteristics of the incident waves. In addition, it has the following secondary objectives: analyze and understand the main OWSC types (Oyster, Waveroller, and Langlee); verify and validate the applied numerical model (through comparison with experimental cases described in the literature); compare three-dimensional with two-dimensional simulation cases (considering similar conditions); verify the influence of the width and thickness of the flap on the hydrodynamics of the converter; study the effect of wave height and period on the oscillatory motion of the structure.

3. Conclusions

A comparative study with an experimental case available in the literature demonstrated that the model proposed in the dissertation tends to present very satisfactory results, being, therefore, quite suitable for studying the complex dynamics associated with the oscillatory movement of the OWSC. Furthermore, a comparison between similar cases considering the 2D and 3D models showed good agreement of the results, demonstrating that more totalizing analyses can be satisfactorily performed by a two-dimensional model. On the other hand, three-dimensional modeling would be necessary for greater details regarding the flow fields, demanding a higher computational cost.

The study regarding the variation in flap width demonstrated that greater widths result in greater angular displacements and velocities, in addition to an intensification of the horizontal force experienced by the structure. However, it is observed that the increase in these variables for flap widths greater than three times the height of the structure is not so significant. Therefore, it is recommended that the ideal flap width have a value between two and three times its height.

The increase in flap thickness is directly associated with an increase in the inertia of the structure, making it difficult to oscillate and, consequently, decreasing the energy absorbed by the converter. The results demonstrated that the best hydrodynamic performance of the OWSC is achieved at thicknesses between 10% and 20% of the flap height.

An increase in the wave period can have different consequences for the oscillation of the structure. In short periods, the angular displacements and angular velocities tend to increase. This behavior is observed until the moment when the properties reach a maximum value, indicating the wave period that maximizes the power captured by the system. For periods longer than this value, the energy produced tends to decrease slowly, which can be associated with a transient current effect that restricts the oscillation of the converter. On the other hand, an increase in the wave height is always responsible for intensifying the existing hydrodynamic phenomena, which, combined with the effect related to the wave period variation, may favor or decrease the energy produced by the system.

The increase in water depth is, in general, responsible for a decrease in the energy captured by the system. Therefore, one can observe that at depths greater than twice the height of the flap, the energy production no longer significantly depends on this variable, suggesting that the Langlee-type OWSC should be installed at depths greater than this, while the Oyster and the Waveroller perform best at shallower depths.

Finally, the numerical model considered in the dissertation showed great potential regarding the analysis of properties directly related to power generation. Similarly, the flow fields were also correctly reproduced by the model, which demonstrates its great potential for the correct study and design of this technology.

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