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A numerical study on the dynamic behavior of a floating wave energy converter

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STATEMENT

This thesis is submitted as partial fulfillment of a Ph.D. degree in Engineering Mechanics, Faculty of Engineering, Ain Shams University, Abbassia 11517, Cairo, Egypt.

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or qualification at any other scientific entity.

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Abstract

The improvement of wave simulation techniques in numerical tanks represents the key factor in ocean engineering development to save time and effort in research concerned with wave energy conversion. The multiplicity of renewable energy sources represents the biggest challenge for environmental scientists and engineers. Wave energy represents one of the major sources of renewable energy. For this purpose, the present thesis introduces a numerical simulation method to generate both regular and irregular waves using a Flap-Type wavemaker. A 2D numerical wave tank model is constructed with a Numerical Beach technique, and the independence of the numerical beach slope is tested to reduce the wave reflections. The different governing parameters of the Flap type wavemaker were studied such as periodic time dependency and length of the flapping stroke. The linear wave generated was validated against the wavemaker theory WMT, and the numerical results agreed with WMT. The Pierson-Moskowitz model is used to generate irregular waves with different frequencies and amplitudes. The numerical model succeeded to generate irregular waves which were validated against published experimental data and with the Pierson-Moskowitz spectrum model using Fourier expansion theory in the frequency domain. Useful results are presented in this research based on numerical simulation to understand the characteristics of the waves. This research produces a full guide to generating both regular and irregular waves numerically using the high-performance ANSYS-CFX software to solve the 2D Unsteady Reynolds Averaged Navier-Stokes Equation (URANS).

The present thesis introduces a mathematical model and a numerical study to analyze the dynamic behavior of point absorber wave energy converter PAWEC. Two different models were constructed to predict the hydrodynamic response of the wave energy converter in both free and damped oscillations under

the action of incident waves and external mechanical damping. The differential equations governing the motion of a floating body on an exciting water surface are presented and solved numerically using Runge-Kutta fourth-order model RKFOM, this numerical solution was used to study different shapes of WEC. CFX multiphase model is constructed to solve the 3D (URANS) using the 2-way Fluid-Structure Interaction (FSI) technique. Grid densities and solver settings were performed. The numerical results in both models, CFD and RKFOM, are validated against published experimental and numerical data under the same conditions, the numerical results agreed with both published data. CFX provides a wide range of reliable and accurate results compared to other CFD approaches, two additional designs for the body bottom, conical and spherical shapes, were analyzed based on the presented numerical method and compared with the flat-bottom shape to understand the characteristics of WEC. The damping coefficient and added mass are obtained for each design in the case of heave motion only. This study introduced a mathematical method to convert the system of WEC with different shapes and flow conditions to a simple spring-damping system.

Keywords: *Computational Fluid Dynamics, CFD, CFX, Fluid-Structure Interaction, FSI, Numerical Beach, WMT, Regular waves, Irregular waves, Renewable energy, Wave energy, wave generation, wave energy converter, WEC, numerical wave tank, NWT.*

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LIST OF ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
BE	Boussinesq Equation
CB	Conical Bottom
CFD	Computational Fluid Dynamics
CNWT	CFD-based NWT
DOF	Degree of Freedom
FB	Flat Bottom
FFT	Fast Fourier Transform
FFB	Far Field Boundary
FVM	Finite Volume Method
FWL	Free Water Level
HDE	Hydrodynamic Efficiency
LWT	Linear Wave Theory
NB	Numerical Beach
NWT	Numerical Wave Tank
MDOF	Multi Degree of Freedom
MDWEC	Multi Degree of Freedom Wave Energy Converter
ODE	Ordinary Differential Equation
OWC	Oscillating Water Column
OWSC	Oscillating Wave Surge Converter
PA	Point Absorber
PAWEC	Point Absorber wave energy converter
PDE	Partial Differential Equation

PTO	Power take-off
RANS	Reynolds Averaged Navier-Stokes Equation
RLWT	Random Linear Wave Theory
RKFOM	Runge-Kutta Forth Order Model
SB	Spherical Bottom
SDOF	Single Degree of Freedom
SWL	Sea Water Level
VF	Volume Fraction
VOF	Volume of Fluid Method
URANS	Unsteady Reynolds Averaged Navier-Stokes Equation
WEC	Wave Energy Converter
WMT	WaveMaker Theory