Ocean Engineering 145 (2017) 1–14

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Numerical models for the motion and forces of point-absorbing wave energy converters in extreme waves

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ARTICLE INFO

Keywords:
Wave power
CFD
Peak force
Extreme wave
Physical experiment

ABSTRACT

Reliable simulation tools are necessary to study the performance and survivability of wave energy devices, since experiments are both expensive and difficult to implement. In particular, survivability in nonlinear, high waves is one of the largest challenges for wave energy, and since the wave loads and dynamics are largely model dependent, each device must be studied separately with validated tools. In this paper, two numerical methods based on fully nonlinear computational fluid dynamics (CFD) are presented and compared with a simpler linear method. All three methods are compared and validated against experimental data for a point-absorbing wave energy converter in nonlinear, high waves. The wave energy converter consists of a floating buoy attached to a linear generator situated on the seabed. The line forces and motion of the buoy are studied, and computational cost and accuracy are compared and discussed. Whereas the simpler linear method is very fast, its accuracy is not sufficient in high and extreme waves, where instead the computationally costly CFD methods are required. The OpenFOAM model showed the highest accuracy, but also a higher computational cost than the ANSYS Fluent model.

1. Introduction

1.1. Background

The realization of full-scale wave energy systems requires fast and reliable simulation tools that can study the performance of the system with many degrees of freedom and for a large range of parameters. A wave energy converter (WEC) system is most thoroughly described by solving the Navier-Stokes and power take off (PTO) equations (often non-linear) simultaneously. This approach is very computationally time consuming, and even though it may be necessary for extreme design cases, it is not a suitable approach for optimization design studies. A wide range of simplifications and restrictions are possible, from assuming a linear PTO to using linear potential flow theory for the simulated waves. During the 1970s extensive work was done to optimise the energy absorption of point-absorbing floating points restrained by linear PTO systems, for example (Salter, 1974; Budal and Falnes, 1975; Mei, 1976; Evans, 1976; Falnes, 2007). If a linear PTO and regular waves with small amplitude are assumed, the hydrodynamic forces on the floating body can be decomposed into hydrodynamical parameters, and numerical modeling can be used to simulate the WECs behaviour in the frequency domain (Falcao, 2010; Evans, 1981). Time-domain modeling based on the hydrodynamical parameters was developed in the 1980's (Jefferys, 1980). This linearisation is widely used, and has been proven to show acceptable agreement for low and moderate sea states, for example (Payne et al., 2008; Sjökvist et al., 2014). However, in order for wave energy to be a viable energy option, the survivability in harsh offshore environments must also be guaranteed, which includes surviving forces in extreme wave events. The magnitude of these forces and the dynamic behaviour of the WEC must be found, so that the WEC can be properly designed.

For high sea states and extreme waves, the flow behaviour around a

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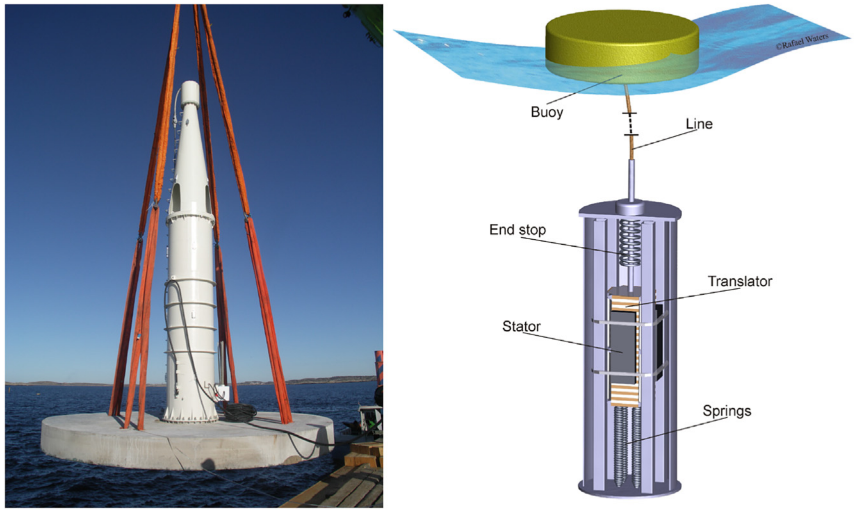
http://dx.doi.org/10.1016/j.oceaneng.2017.08.061
Received 22 December 2016; Received in revised form 29 June 2017; Accepted 24 August 2017



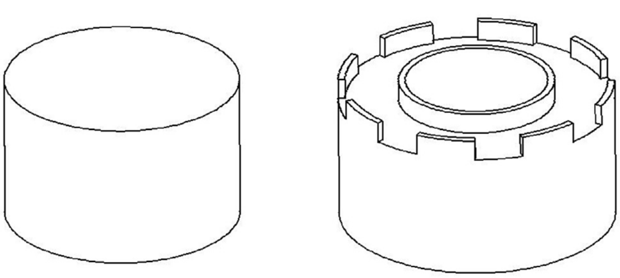
(a) A linear generator before deployment

(b) The main parts of the WEC

Fig. 1. a) A full scale WEC generator is photographed just before offshore deployment. This particular prototype is known as the L9 generator and is here mounted on a concrete gravity based foundation. The buoy was connected the day after the generator deployment. b) The translator is directly driven by the floating buoy, generating electricity as it moves inside the stator.

Table 1
WEC and system specifications.

Parameters	Symbol	Values
Buoy outer radius CYL/CWM	R	1.7 m/2 m
Buoy inner radius CWM	R_{in}	1.03 m
Buoy height CYL/CWM	h	2.12 m/2.12 m
Buoy draft CYL/CWM	d	1.3 m/1.6 m
Buoy mass CYL/CWM	m_b	5736 kg/8592 kg
Translator mass	m_t	6240 kg
Upper endstop spring	κ	776 kN/m
Upper endstop spring length	l_κ	0.6 m
Maximal stroke length upper/lower	ξ_{up}/ξ_{down}	1.8 m/1.8 m
Spring constant of connection line	Λ	300 kN/m
Generator damping	μ	0, 18, 59, 83 kN
Water depth	D	50 m



(a) Cylindrical buoy (CYL).

(b) Cylindrical buoy with moonpool (CWM), and water damping top.

Fig. 2. The geometry of the modelled buoys. The height is 2.12 m for both buoys. For the CYL buoy, the radius is 1.7 m, and for the CWM buoy, the outer and inner radius are 2 m and 1.03 m respectively.

WEC will be turbulent, overturning and often highly nonlinear and can be approximated using, for example, the Reynolds Average Navier-Stokes (RANS) equations together with a turbulence model (Wolgamot and Fitzgerald, 2015). Numerical models based on the finite element method (FEM) or the finite volume method (FVM) can then be used to solve the RANS equations, and the interface between two phases can be calculated using the volume of fluid method (VOF). RANS-VOF is an accurate nonlinear model (Eskilsson et al., 2015), and can be used both to identify hydromechanical parameters or full state dynamics of floating bodies (Davidson et al., 2015, 2016), or to model a complete WEC system during an extreme wave event. Several CFD models of WECs have been experimentally verified; in reference (Schmitt and Elsaesser, 2015) the motion of a flap type WEC modelled in OpenFOAM shows good agreement with experiment; in (Yu and Li, 2013), a 2-body point-absorber is modelled in heave motion; in (Ransley, 2015) and (Ransley et al., 2017a) a point-absorbing WEC with linear-elastic mooring, moving in six degrees of freedom, is modelled showing good agreement with wave tank experiments, and; in reference (Ransley et al., 2017b), another point-absorber was modelled both fixed and freely floating.

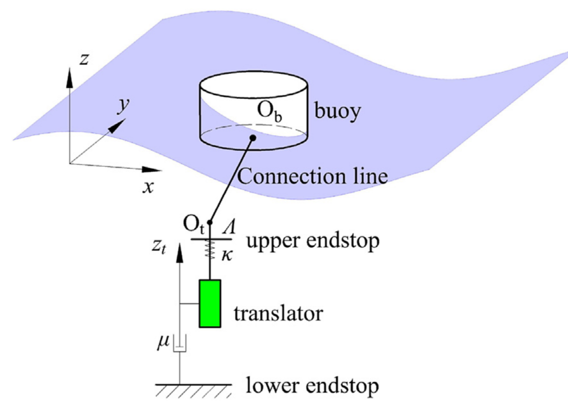


Fig. 3. Schematic figure of the system. The buoy and the translator are connected by a connection line. Whereas the translator is restricted to move only vertically, the buoy is free to move in several degrees of freedom.

For the WEC concept developed at Uppsala University, Sweden, the line force has been measured offshore at full scale during normal operating conditions (Leijon et al., 2008; Savin et al., 2009) and in a scaled model test with linear springs instead of a generator in larger seas (Svensson, 2014). However, the offshore environment does not provide the controlled environment needed to make a qualitative analysis. In a