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Hydrodynamic analysis of three–unit arrays of floating annular oscillating–water–column wave energy converters

D.N. Konispoliatis [a], T.P. Mazarakos [a], S.A. Mavrakos [b,a,*]

[a] Laboratory for Floating Structures and Mooring Systems, Division of Marine Structures, School of Naval Architecture and Marine Engineering, National Technical University of Athens, 9 Heroon Polytechniou Avenue, GR 157-73 Athens, Greece
[b] Hellenic Centre for Marine Research, Director and President, Anavyssos, Greece

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ABSTRACT

This paper deals with the hydrodynamic analysis of an array of Oscillating Water Column (OWC) devices, made up of coaxial cylinders, which are floating either independently or as a unit forming a floating platform. The platform is considered either free – floating or as TLP configuration connected to the sea bottom. Numerical results concerning the three boundary value problems, namely, the diffraction, the motion – and the pressure – dependent radiation ones are given. They have been obtained through an analytical solution method using matched axisymmetric eigenfunction expansion formulations. In all cases the interaction phenomena with neighbouring bodies have been taken properly into account using the physical idea of multiple scattering. Numerical results for the first – and the mean second – order wave forces, the hydrodynamic interaction coefficients along with pressure hydrodynamic parameters, inner air pressure and free–surface oscillation amplitude inside and outside of each device are parametrically evaluated and supplemented by experimental data.

1. Introduction

In the last years considerable efforts and advances have been made world–wide in exploiting the energy of ocean waves. Devices based on the oscillating water column concept are widely regarded as the most promising wave energy converters ([1–6]). Most Oscillating Water Column installations presently concern single devices installed onshore [7], whereas lately there are some designs of free floating or moored devices in the open sea ([8,9]).

As far as the case of arrays of those devices is concerned, it is more likely to be deployed in the future in preference to single isolated OWC's in order to increase the exploitable wave energy in an installation site and to facilitate installation and electrical power transmission. The research in this field concentrates primarily on restrained OWC's wave energy converters (WEC). In this context, theoretical studies have been presented in [10–13] together with corresponding experimental ones in [14–16]. As far as the case of arrays of floating OWC's devices is concerned, theoretical studies have been recently presented in the literature ([17–19]). Moreover, in [20] an experimental study of an array of independently floating OWC devices have been presented examining both device and mooring system response to high sea loads in extreme sea states. Recently in [21] a hydrodynamic analysis of an array of floating OWC's is presented, elaborating the first – and mean second – order loads on each device, as well as the wave power efficiency of each OWC as a function of their placement against the wave front.

The most common shape of a floating OWC consists of a vertical cylinder partly submerged as an open bottom chamber in which air is oscillating. The chamber is connected with the outer atmosphere by a duct housing an air turbine. The axial–flow Wells turbine, invented in the mid–1970s, is the most popular self–rectifying turbine, but other types, namely axial and radial–flow self–rectifying impulse turbines, have also been proposed, studied and used ([22,6]).

The present contribution is a follow up of [21] examining an array of multiple interacting new type of OWC's devices either floating independently or as a unit assuming that they are mounted on a floating supporting platform exposed to the action of regular surface waves in finite water depth (Fig. 1). Such type of semi–submersible platforms has been reported in connection with the renewable electricity

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[*] Corresponding author at: Hellenic Centre for Marine Research, Director and President, Anavyssos, Greece.

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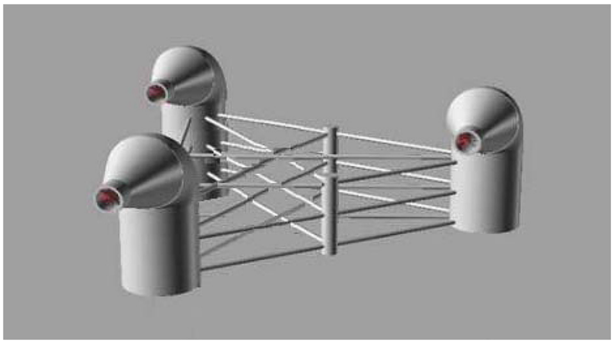

Fig. 1. Group of three identical OWC devices connected as a unit, forming an integrated floating platform.

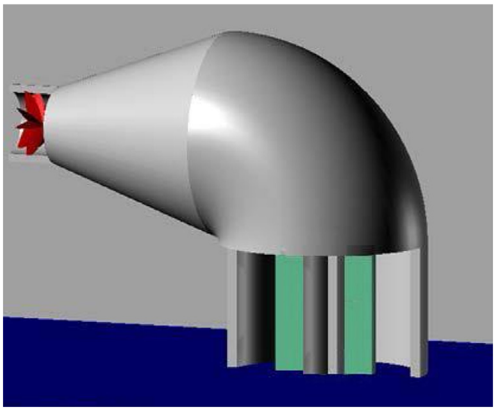

Fig. 2. Floating OWC device consisting of a coaxial vertical cylinder.

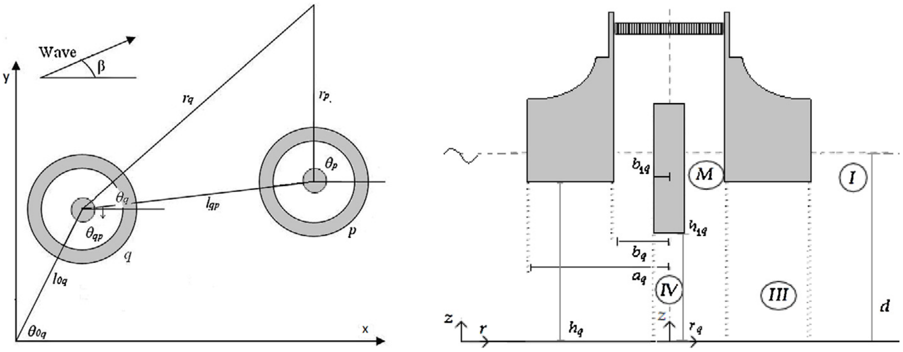

Fig. 3. Definition sketch of the *q* OWC device of the array.

generation from combined wind and wave action [14]. The geometric configuration of each device differs from [21] since it consists of an exterior partially immersed toroidal body supplemented by a coaxial interior truncated cylinder. The latter is conceived to support the possible installation of a wind turbine or to mount tendons of a TLP type mooring system. In the annulus between the internal cylinder and the external torus, a finite volume air chamber is formed in which the oscillating air pressure is developed, see Fig. 2. Numerical results concerning the solution of three boundary value problems, namely, the diffraction problem – each body is fixed in waves, atmospheric pressure in each OWC –, the motion–dependent radiation problem resulting from the forced oscillations of each body in otherwise still water, also under atmospheric conditions in the air chamber of each OWC, and the pressure– dependent radiation problem resulting from pressure oscillation acting on the inner free surface of each OWC are given. The hydrodynamic interaction phenomena among the members of the multi–body configuration have been taken into account through the physical idea of multiple scattering ([23–26]). By properly superposing the incident wave potential and the propagating and evanescent modes that are scattered and radiated by the array elements, exact representations of the total wave field around each body of the array may be obtained. Comparisons between the exact method used here and other approximate methods are given in [27]. In exploiting the multiple scattering approach, the single isolated body hydrodynamic characteristics are required. Here the method of matched axisymmetric eigenfunction expansion as it was implemented either for truncated vertical cylinders ([28–32]) or for arbitrarily shaped vertically axisymmetric compact bodies [33] has been used. According to this method, the flow field around the devices is subdivided in coaxial ring–shaped fluid regions, categorized by the numerals *I, III*, *M* and *IV* (Fig. 3) in each of which appropriate series representations of velocity potential can be established [8].