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Hydrodynamic forces and wave run-up on concentric vertical cylinders forming piston-like arrangements

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1. Introduction

It is the purpose of this study to compare theoretical predictions and experimental data on the linear and nonlinear hydrodynamic loading and wave run-up on concentric cylinders the geometry of which forms an internal annular domain, widely known as "moonpool". In fact the arrangement which is considered could be characterized as piston-like and could be used for wave energy conversion.

The experimental data which are presented were taken during a campaign that was carried out in CEHIPAR wave basin in Madrid, Spain. The experiments dealt with the evaluation of the first- and second-order hydrodynamic exciting forces and wave run-up on single concentric cylinder arrangements as well as on arrays of them when they are exposed to the action of mono- and bi-chromatic wave trains. The geometric configuration of the single body consists of an exterior partially immersed toroidal structure of finite volume supplemented by an interior piston-like, free-surface piercing truncated cylinder (see Fig. 1).

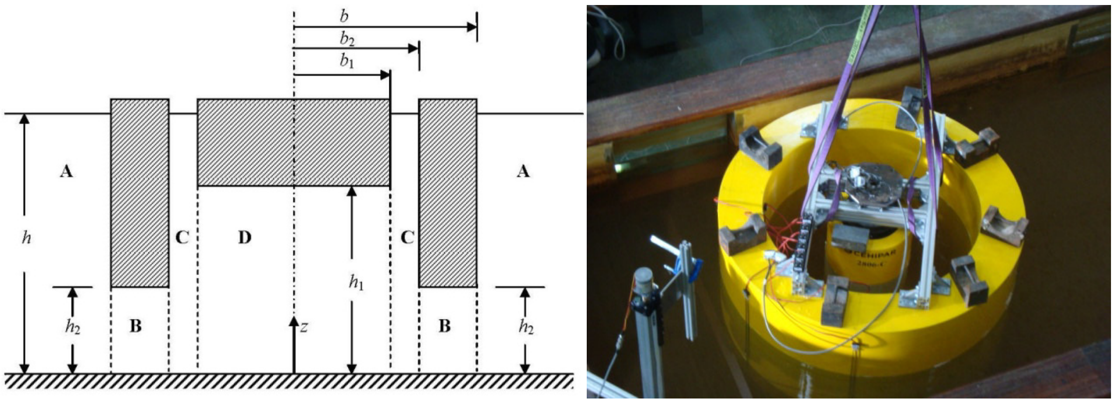

Fig.1: Schematic representation and physical model of a two concentric cylinders arrangement

In this way, an internal free surface is formed that is totally enclosed between the cylinders and open to the exterior fluid domain beneath the bodies. This internal fluid domain, which in the present case is of annular form, is usually referred to as "moonpool" and represents a characteristic feature of bottomless floating bodies having consequences both from the theoretical and the practical point of view. In the last years an increasing interest on such type of structures is reported especially in connection with their use as wave energy converters or as oscillating water columns (OWC) devices for the extraction of energy from waves (Sykes et al., 2007). Furthermore, in the offshore field of applications several types of vessels are frequently constructed with moonpools.

The fundamental hydrodynamic properties of isolated truncated hollow cylinders have been investigated some time ago (Garrett, 1970; Miloh, 1983; Mavrakos, 1985, 1988) using matched axisymmetric eigenfunction expansions. Mavrakos (2004) extended the formulation to the linear hydrodynamics of concentric cylinders, Mavrakos and Chatjigeorgiou (2009) tackled the corresponding second-order diffraction problem around this type of structures whereas Chatjigeorgiou and Mavrakos (2008) treated the second-order radiation problem of the heaving motions of the piston. All previously mentioned studies showed that crucial parameters for the hydrodynamic behavior of concentric cylinders are among others the radial extend of the annulus between the internal and the external structure, the draughts of the bodies, the shape of the interior body, as well as the wall thickness of the exterior cylinder. Thus, scope of the experimental campaign was to investigate in more details the effect that these parameters has on the hydrodynamic behavior of single or multiple interacting arrays of concentric cylinders.

2. Description of the experiments

In accordance with the scope of the proposal, seven different configurations of concentric cylinders were tested. The first four concerned concentric cylinders of the type shown in Fig.1 The radius b_2 was kept constant, equal to 0.5m, whereas two variants of the internal cylinder radius were chosen, i.e. b_1 = 0.2m and 0.4m, and two variants also of the external radius of the toroidal body, i.e. b = 0.6m and 0.7m. The draughts of the internal and external cylinders were kept constants, being equal to 0.4m and 0.5m, respectively. The next two configurations consisted of external torus with the same as previously radial dimensions and draughts, but with internal body configured as a compound vertical cylinder (Fig.2). The small radius of the compound cylinder at the waterline was equal to 0.15m whereas the large radius at its bottom was equal to 0.3m. The submerged depth of the small cylinder was 0.14m, while the height of the submerged large diameter cylinder was equal to 0.14m. All the models were constructed by CEHIPAR.

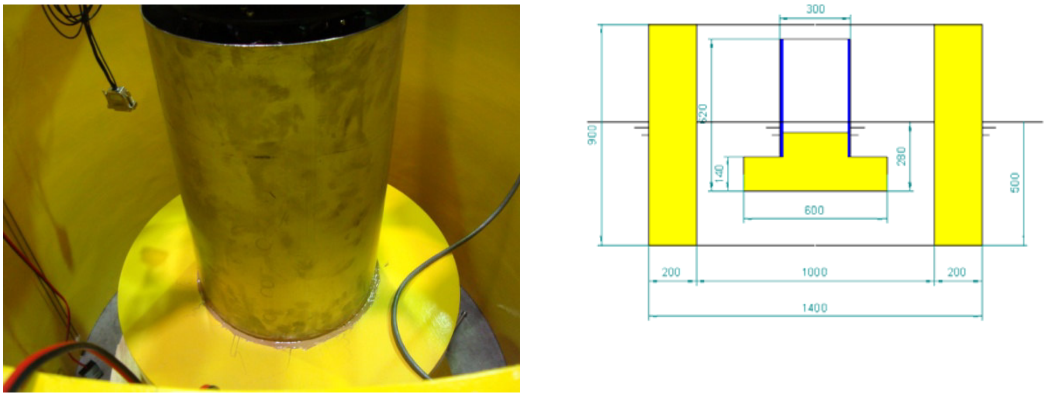

Fig. 2: Physical model of the compound cylinder and schematic representation of the 6^{th} configuration

Finally, a multi-body arrangement of concentric vertical cylinders was tested. It consisted of three piston-like assemblies that had been arranged transversal and quarterly to the direction of the incoming waves. The distance of the bodies' axes were set equal to 2m, whereas as individual concentric cylinder arrangement was selected the one corresponding to the dimensions of the third configuration given above with an internal cylinder radius equal to 0.4m and an external torus radius equal to 0.6m.

Exciting wave forces and moments, as well as wave run-up were measured on both external and internal cylinders. The recorded data were analysed by Fast Fourier Transformation to obtain the power spectral content up to the third order component of the concerned hydrodynamic quantities. The wave run-up was measured at three locations on the wetted surface of the external cylinder and three locations on the interior.

3. Experimental results against numerical predictions

Representative experimental results for the first- order exciting wave loads and their comparisons with corresponding numerical predictions for the second configuration are given in Figs. 3 and 4. It is immediately apparent that at first-order the comparisons are very favourable. Also, the wave periods of the resonant fluid motions inside the moonpool, which corresponds to the peaks of the curves, are well captured by the numerical predictions.

Measured and computed mean second-order drift forces in regular waves for the same as above configuration are given in Fig. 5. A good correlation between the measured and the computed values can be also reported.

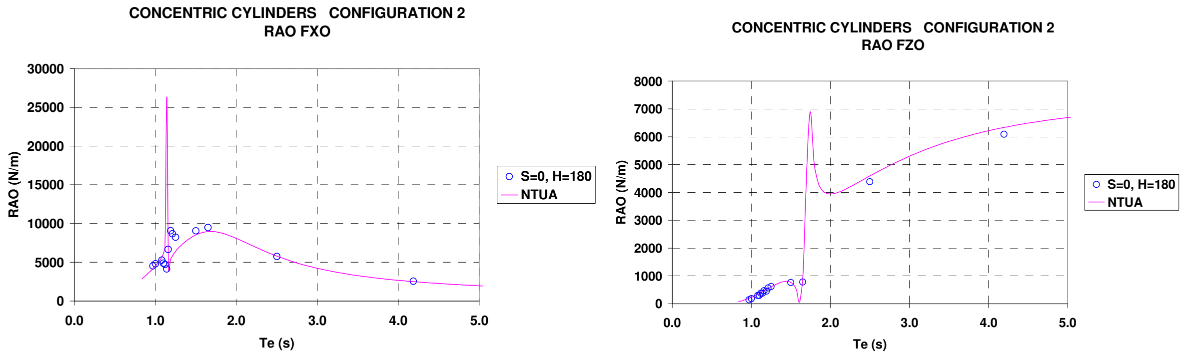

Fig. 3: Horizontal and vertical first – order exciting wave forces on the external torus

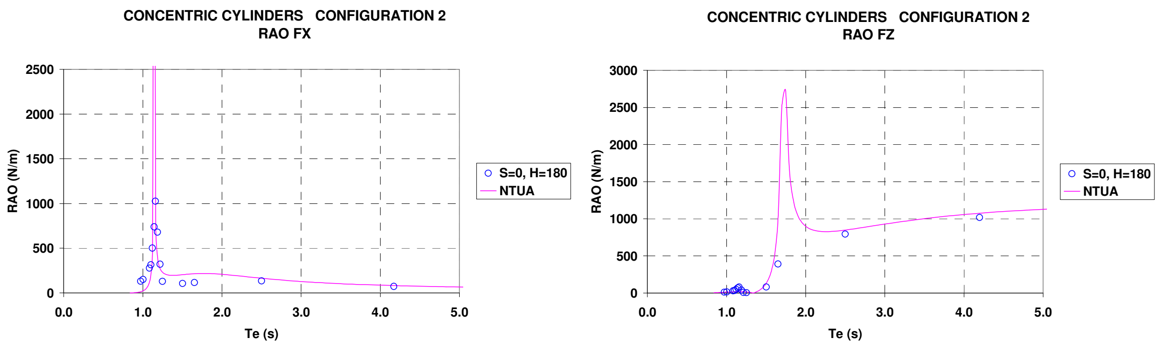

Fig. 4: Horizontal and vertical first-order exciting wave forces on the internal cylinder

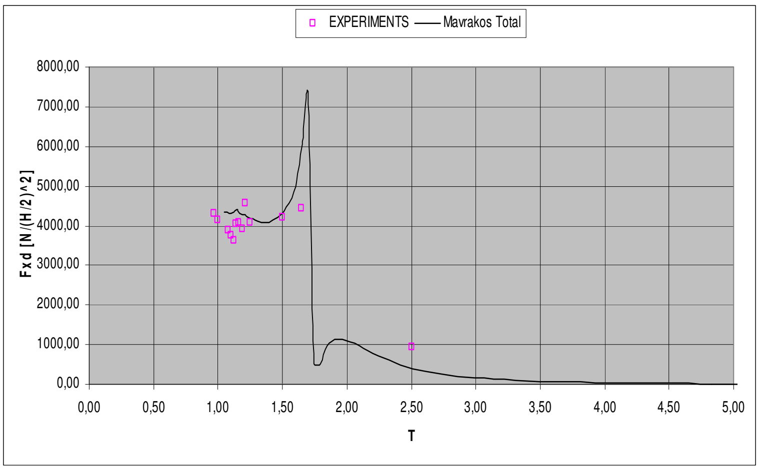

Fig. 5: Mean second-order horizontal wave forces on the external cylinder, 2^{nd} configuration

Experimental data with their associated numerical predictions for the time-harmonic second-order forces on the external cylinder are given in Fig.6. The numerical calculations demonstrate the occurrence of two peaks in the range of investigation. The first (high wave frequency peak at ω=5.19rad/s) occurs at exactly the first-order resonance and obviously affects the second-order contributions. The second peak is induced by the second-order components and occurs at ω=3.69rad/s. The fact that the second peak is not excited at exactly the half of the first peak frequency is an issue that requires further investigation. This feature was discussed recently by Mavrakos and Chatjigeorgiou (2009) through extensive numerical calculations which exhibited the same behavior. Finally, in Fig. 7 the measured and computed second-order wave run-up on the exterior cylinder is given over several azimuthal directions. The results compare also here very well.

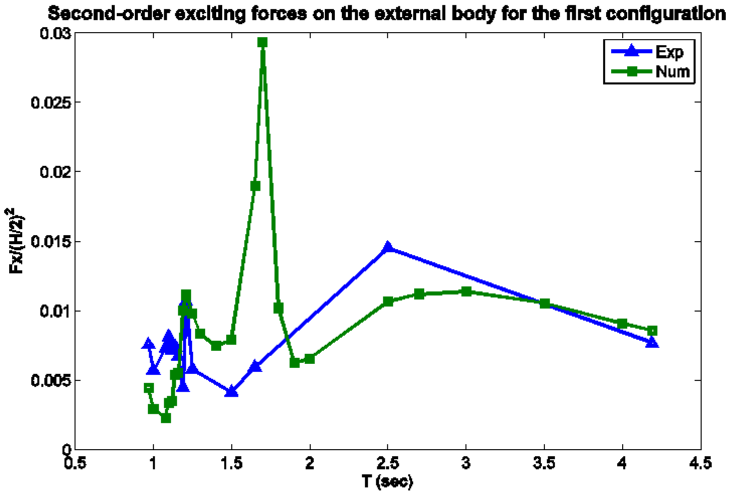

Fig. 6: Time-harmonic second-order horizontal forces on the external cylinder.

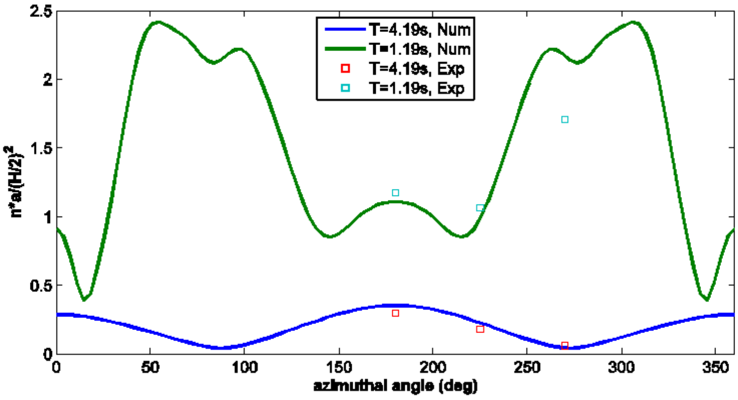

Fig. 7: Second-order wave run-up on the exterior cylinder.

Acknowledgments

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