The 2013 World Congress on
Advances in Structural Engineering and Mechanics (ASEM13)
Jeju, Korea, September 8-12, 2013

EXPERIMENTAL STUDY ON THE HYDRODYNAMIC BEHAVIORS OF TWO CONCENTRIC CYLINDERS

*Jeong-Rok Kim[1], Hyeok-Jun Koh[2], Won-Sun Ruy[3] and Il-Hyoung Cho[4]

[1), 3), 4)] *Department of Ocean System Engineering,*
Jeju National University, Jeju-do, Korea
[2)] *Multidisciplinary Graduate School for Wind Energy,*
Jeju National University, Jeju-do, Korea
[1)] wodqks1005@jejunu.ac.kr

ABSTRACT

This paper focused on introducing the new-concept wave energy converters for the extraction of energy from waves and some results of an experiment on concentric two-body system composed of the hollow exterior cylinder and interior cylinder floating inside the exterior cylinder. Electricity is generated from the Power take-off system using relative vertical motion of two concentric cylinders. In order to maximize the relative vertical motion, the resonance, so called piston mode resonance, was used. The model test contained a series of experiments concerning two concentric cylinders arrangements(radius and draft). The heave motion responses of two concentric cylinders have been recorded using accelerometer, and compared with analytical prediction. Representative experimental data and their comparisons with analytical predictions will be presented in this paper, together with the description of the experimental test.

1. INTRODUCTION

The experiment is investigating the heave motion response according to the change of the concentric cylinders arrangement when they are exposed to the action of monochromatic wave trains. The geometric configuration of two concentric cylinders is shown in Fig. 1. In our model, an inner fluid region of an exterior hollow concentric cylinder is formed that is totally enclosed between two cylinders and open to the fluid

---

[1)] Graduate Student
[2)] Graduate Student
[3)] Professor
[4)] Professor

region beneath the bodies. This inner fluid domain, which in the present case is of annular form, is usually referred to as “moon pool” and represents a characteristic feature of bottomless floating bodies. In recent years, an increasing interest on such type of floating structures is reported especially in connection with their use as wave energy converters or as oscillating water columns (OWC) devices for energy transfer by induced resonance of the fluid motion (Evans and Porter, 1997). Furthermore, in the offshore field of applications several types of rigs are frequently constructed with moon pools.

The fundamental hydrodynamic properties of isolated truncated hollow cylinders have been investigated some time ago (Garrett, 1970; Mavrakos, 1985, 1988; Chau and Yeung, 2010) using matched eigenfunction expansion method. Mavrakos (2004) extended the formulation to the linear hydrodynamics of two concentric cylinders. All previously mentioned studies showed that important parameters for the hydrodynamic behavior of concentric cylinders are the radial extend of the annulus between the interior and the exterior cylinder, the drafts of the cylinders, as well as the wall thickness of the exterior cylinder. Thus, scope of the present model test is to investigate in more details the effect that these parameters has on the hydrodynamic behavior of two concentric cylinders, especially the heave motion responses.

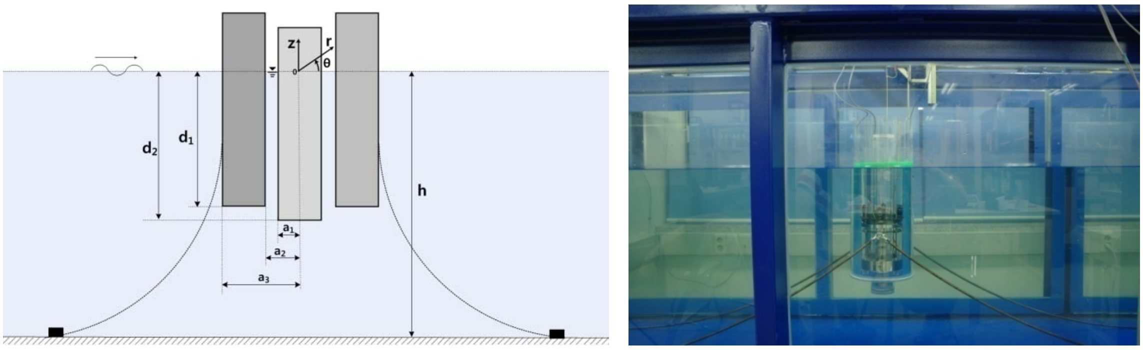


Fig.1 Schematic representation and experimental model of two concentric cylinders.

2. DESCRIPTION OF THE EXPERIMENTS

In accordance with the scope of the parameter study, six different configurations of two concentric cylinders have been tested. The experimental arrangement of two partially submerged concentric cylinders is shown in Fig. 1 The outer radius a_3 and draft d_1 of the exterior cylinder was kept constant, equal to 0.1m and 0.35m, whereas the inner radius of the exterior cylinder was a_2= 0.05m and 0.04m. Three variants of the draft of interior cylinder were chosen, i.e. d_2= 0.29m, 0.35m and 0.40m for fixed radius of interior cylinder a_1 = 0.037m. The water depth was 0.6m. A series of experiments were conducted in the two-dimensional wave tank (20-m long, 0.8-m wide, and 1.0-m deep) located at Jeju National University. The glass-walled wave tank is equipped with a dry-back, piston-type wave maker capable of producing regular and irregular waves. The concentric cylinder model was placed at 6.50m from the wavemaker. Regular waves were generated by a user-defined time-voltage input to the wavemaker. The wave period range used in our experiments was from 0.80 to 1.50sec. The range of the wave steepness H/λ is from 0.009 to 0.015 according to the wave amplitudes. The concentric cylinder model was made of acrylic. The experimental model was attached at the desired position by four soft springs clamped to the tank bottom. The incident wave elevation was measured at 4.10m from the wavemaker with a capacitance wave gauge having an accuracy of ± 0.1 cm. The vertical motion responses of two concentric cylinders have been measured using the accelerometers.

3. EXPERIMENTAL RESULTS AND ANALYTICAL PREDICTIONS

In order to compare the experimental results with analytical solution, based on the linear potential theory, the viscous damping coefficients of each concentric cylinder have to be measured by a free-decay test. The viscous damping coefficients in the equations of motion are defined as $b = 2\kappa\rho g S / \omega_o$. The non-dimensional damping factor κ and undamped natural frequency ω_o can be determined from a free-decay test in still water. The viscous damping factors κ for each cylinder are listed at Table 1.

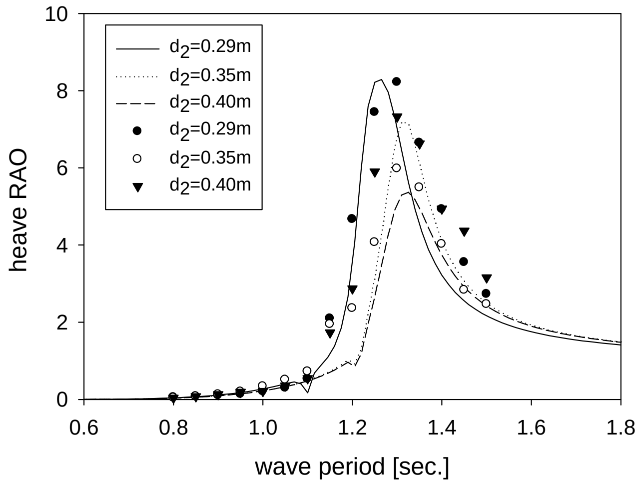
Table 1 Viscous damping factors obtained from free-decay test.

	Exterior cylinder	interior cylinder		
Draft [m]	0.35	0.29	0.35	0.40
Damping factor	0.053	0.0200	0.0377	0.0404

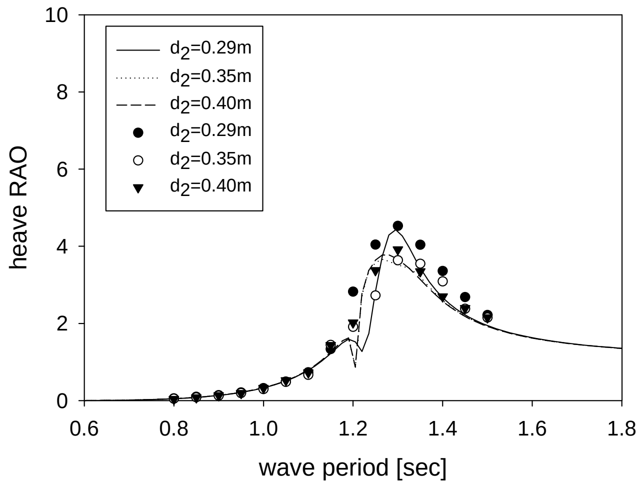
Representative experimental results for the heave RAO and their comparisons with corresponding analytic solutions using eigenfunction expansion method are given in Figs. 2 and 3. A very good comparison between the analytic and experimental results can be obtained. It is shown that the heave RAO of the interior cylinder is much larger than that of the exterior cylinder especially around resonant periods. The heave RAO of the interior cylinder is highly amplified near the wave periods where piston resonance mode occurs in the annular fluid region between interior and exterior cylinder. The wave periods of the piston resonance mode, which corresponds to the peak of the RAO curves, are well captured by the analytic predictions. Fukuda (1977) suggested the following formula for the calculation of the natural period *T* for piston mode resonance, of the moon pool. Fukuda made use of an increased draft($d' = 0.41\sqrt{S}$) to take account of the added mass effect.

$$T = 2\pi\sqrt{\frac{d + 0.41\sqrt{S}}{g}}. \quad (1)$$

where *d* is the draft of the confined fluid region and *S* is its water surface area.



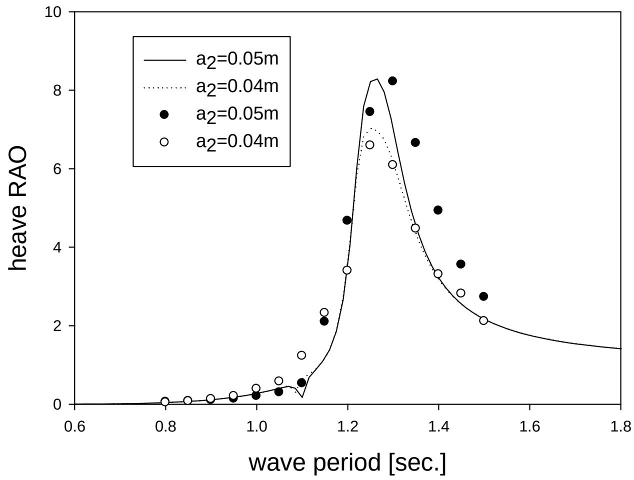
(a) interior cylinder



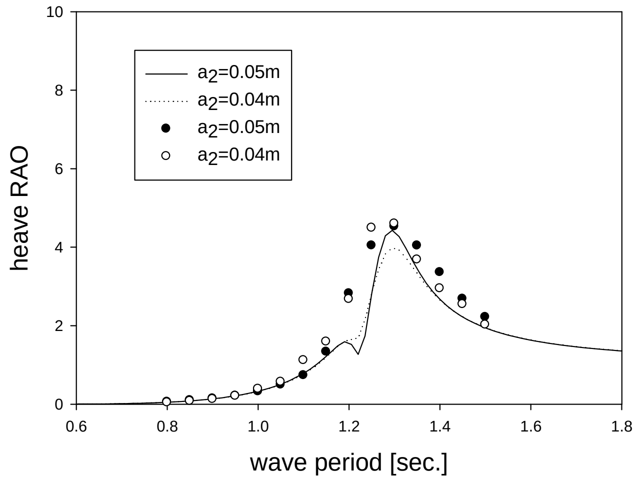
(b) exterior cylinder

Fig. 2 Comparison between the analytic solutions and experimental results as function of the draft of interior cylinder and wave period (lines: analytic solution, symbols: experimental result) for a_1 = 0.037m, a_2 = 0.05m, a_3 =0.1m, and d_1 =0.35m.

The effects for three different drafts of the interior cylinder (i.e. $d_2 = 0.29, 0.35, 0.40m$) are also shown in Fig. 2. It can be observed that the increase of the draft of the interior cylinder has the resonant peak of the interior cylinder decrease and pushes the resonant period to the long period region. But the variations of the draft have practically very little effect on the heave RAO of the exterior cylinder. If applying Fukuda's empirical formula to our experimental model shown at Fig. 3 ($d = 0.35m, S = \pi a_2^2 = 0.00785m^2$), the natural periods are T=1.25rad/sec. This formula seems to give a good estimation of the natural frequency when comparing with experimental results and analytic prediction.



(a) interior cylinder



(b) exterior cylinder

Fig. 3 Comparison between the analytic solutions and experimental results as function of the inner radius of the exterior cylinder and wave period (lines: analytic solution, symbols: experimental result) for a_1= 0.037m, a_3=0.1m, d_1=0.35m, d_2=0.29m.

Fig. 3 shows the results of the different inner radius of the exterior cylinder. A good correlation between the measured and the computed values can be also in this case found. It is evident that decreasing a_2 decreases the peak value of heave RAO of the interior cylinder, also the resonant period moves to the shorter period region, although small value, with decreasing a_2. This can be explained by substituting $a_2 = 0.04m$ into Eq. (1).

ACKNOWLEDGEMENT

This work was supported by the New and Renewable Energy of the Korea Institute of Energy Technology Evaluation and Planning(KETEP) grant funded by the Korea government Ministry of Knowledge Economy.(2010302007 0080).

REFERENCES

Chau F. P. and Yeung R.W. (2010), “Inertia and damping of heaving compound cylinders”, Proceedings, 25th international workshop on water waves and floating bodies, Harbin, China.

Evans, D.V. and Porter, R. (1997), “Efficient calculation of hydrodynamic properties of OWC-type devices”, J. Offshore Mech. and Arctic Eng. 119, 210-218.

Fukuda, K. (1977), “Behaviour of water in vertical well with bottom opening of ship, and its effect on ship motions", Journal of the Society of Naval Architects of Japan, 141, 107-122.

Garrett, C.J.R. (1970), “Bottomless harbours”, Journal Fluid Mechanics, 43, 433 - 449.

Mavrakos, S.A. (1985), “Wave loads on a stationary floating bottomless cylindrical body with finite wall thickness”, Applied Ocean Research, 7, 213 – 324.

Mavrakos, S.A. (1988), “Hydrodynamic coefficients for a thick – walled bottomless cylindrical body floating in water of finite depth”, Ocean Engineering, 15, 213 – 229.

Mavrakos, S.A. (2004), “Hydrodynamic coefficients in heave of two concentric surface-piercing truncated circular cylinders”, Applied Ocean Research, 26, 84 – 97.