International Journal of Advance Research and Innovation
Vol. 2(2), Apr-Jun 2014, pp. 125-129
Doi: 10.51976/ijari.221419

Article Info
Received: 02 Apr 2014 | Revised Submission: 20 Apr 2014 | Accepted: 20 May 2014 | Available Online: 15 Jun 2014

Study on the Surge Motion of a Circular Cylinder Placed in the Propagating Wave

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ABSTRACT

With the rapid development of offshore wind turbines, research about the stability of floating structure comes to be significance. This study aims at observing the movement characteristics of a circular cylinder . To simulate ocean wave, the demonstrative experiment was performed in a small-scale wave flume combined with a wave generator and a wave absorber. Moreover, to precisely visualize the oscillation of the circular cylinder, we have prepared
(1) water level gauge (CH-601, KENEK, operation range±100mm);
(2) circular cylinder with a set of light emitting diode illuminators;
(3) a high-speed charge-coupled device camera.
Through the wave generator under a variety of wave conditions such as different wave heights and periods, this study as a fundamental research aims to observe surge motion of a circular cylinder placed in the propagating wave.

Keywords: *Wave Maker; High Speed Camera; Sinusoidal Wave; Wave Height; Wave Length*

1.0 Introduction

Wind power, as an alternative to fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation. Obviously there are much more benefits for siting the offshore wind turbine than onshore wind turbine.

With the development of offshore wind turbines toward to the deep sea, the offshore wind turbine market of the sub-structure design has been gradually expanding.

Among the floating sub-structures in deep sea, the spar has been expected to be the most economical type of sub-structure.

In order to simulate the movement of s sub-structures in the sea, most prior work has involved full-scale field experiments, which are costly and time-consuming.

Therefore, by installing a wave generation and absorption device in a short-distance water channel, we have developed a wave generator in a small-scale wave flume to simulate offshore ocean environment.

In addition, in offshore wind development, the stability of the sub-structure under the wind, wave and current load is very important for generating stable energy from the oncoming wind. To simulate the real environment, we generated various types of regular periodic wave in the wave flume. This study undertakes a assessment of the surge movement of a circular cylinder placed in the propagating wave which generated in the wave flume. The majority of experiments were performed in a small-scale wave flume located in the Renewable Energy and Fluid Mechanics (RFM) laboratory in the School of Mechanical Engineering at Pusan National University (PNU).

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The wave-generating facility at PNU was constructed and commissioned by PNU Manufacturing Center Ltd. To simulate the ocean

2.0 Design of Laboratory Experiments

2.1 Experimental set up

Fig 1: Schematic View of the Wave Generation Wave Flume

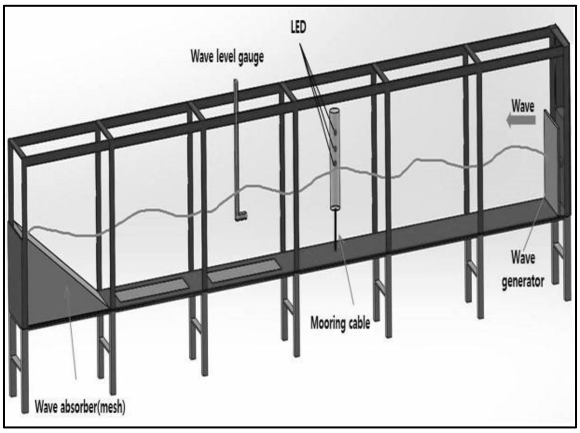
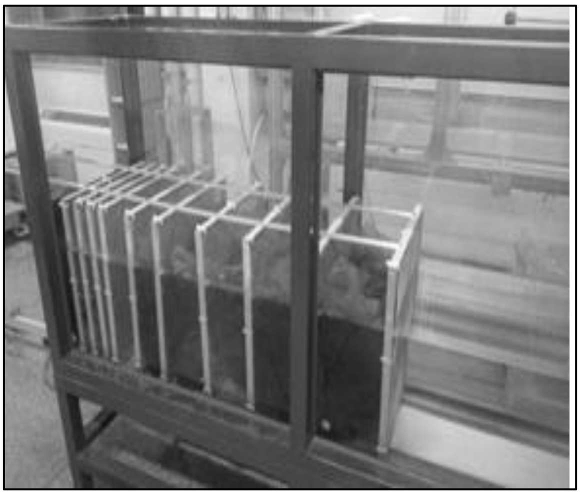


Fig 2: The Snapshots of the Wave Obsorber



environment in a small-scale flume in the laboratory, a wave flume was equipped with the wave generator, as shown in Fig.1.

The size of the wave flume is approximately 5,000mmlong×400mmwide×700mmhigh. To continuously generate two-dimensional regular waves, the flat vertical board connected to the shaft and linear guides located at the far end of the water flume is designed to move back and forth periodically. The main shaft of the flat vertical board is connected to that of the serve motor(see Fig.2) and two 10-Nm couplings in between are used to connect the two shafts together at their ends for transmitting power. An AVR128 control device connected to a personal computer electrically controls the serve motor used to operate the wave board.

Fig 3: The Snapshots of the Wave Generator

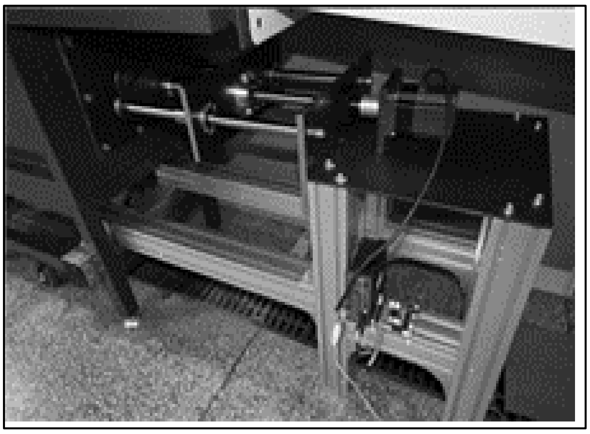


Figure 2 shows the wave generator and absorber. The facility was parametrically tested in terms of length, size, and performance for further application in offshore engineering. To use the current shape in the field experiment, a 1:200 scaled-down model was built. For general and simple applications, a cylindrical shape was chosen for the floating model (Fig.3). The cylindrical models were made of an acrylic pipe and a flat circular plate, (thickness 2mm) to generate a sufficient buoyancy force to support the body weight. The floating structure was sealed at the sides and corners to waterproof it and prevent leaks in a wet environment. The aspect ratio (width-to-height ratio) was chosen as 1:3 (i.e. the diameter is one-third of the body height), which corresponds to a body 60mmwide×180mmhigh. The floating body was located in the middle of a water flume, and the wave was generated by the wave generator located in one side of the flume, the wave absorber placed at the other side. To understand the effect of the mooring cable attached to the floating body, the mooring cable was made of high-strength string and a weaker spring (spring constant k=0.89N/m) that replaced and simulated the stiffness and damping of the real cable.

The elastic mooring cable was connected directly to the floating body and the flume bottom with a silicon bond to smooth over the wall surface and prevent secondary flow between the wave flow and the rest of the body.

The majority of experiments were performed to analyse the surge movement of floating structures placed in on coming waves with a variety of periods, i.e. 0.906, 1.084, 1.269, and 1.46s.

2.2 Visualization of a cylindrical fio-ating body and image processing

In order to visualize and analyze the movement of a floating cylindrical body, we designed cylindrical body with a set of LED illuminators and a high speed CCD camera as shown in Fig. 1.

In the Fig. 3, three LED illuminators attached on the floating body are set at every 25mm from the top surface of the body.

The test image sequences are obtained by a high speed CCD camera at the frame rate of 24fps (frames per second) in AVI format with 480×272pixels resolution.

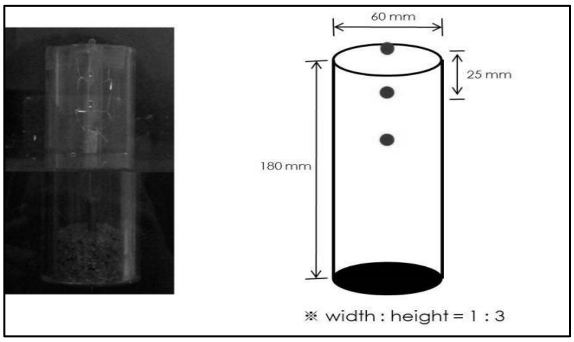
Once the images from the camera are captured, they need to analyze and find the exact centroid of the LED location, which can be defined as the outer edge of the object. In order to extract the centroid of the object of interest, an image processing is well known and summarized in brief.

The processing can be divided into two categories - the object segmentation and moment analysis. Regarding the object segmentation, the luminance value for each pixel of the input image exceeds a predefined threshold value, then the value of pixel on a binary image is set to 1 (color in black), otherwise 0 (white). The threshold value is empirically chosen as a constant (e.g., 7 out of 255 in this study).

Therefore, the binary image can be acquired as a function of the position (x, y), which represents the pixel value on each image and the point (x, y) ranges over the segmented regions containing moving LED illuminators.

First, for the segmented object, the morphological operations such as dilation and erosion are usually applied for enhancing the connected component labeling is commonly used to detect a connected object in the image, and then apply the object into the foreground pixels to assign a unique label to each foreground object. (see Manohara and Ramapriyan 1989; He et. al. 2009)

Fig 4: Cylindrical Floating Body with a Set of LED binary image. (for the details, see Goutsias and Schonfeld 1991)



Second, the moment analysis provides a lot of useful information about the binary object. In order to find the centroid of a segmented moving region, we employed the zeroth and first moment. The area of the segmented object is given by the zeroth moment as shown in the following expression:

$$M_{00} = \sum_x \sum_y f(x,y) \qquad (1)$$

In addition, the two first order moments can be obtained as follows,

$$M_{10} = \sum_x \sum_y x \cdot f(x,y) \qquad (2)$$

$$M_{01} = \sum_x \sum_y y \cdot f(x,y) \qquad (3)$$

Where,, M10 and M01 represent the first moments for x and y, respectively. The centroids of the image are a very

useful and well known quantity for image-tracking applications. The centroid of a segmented object can be computed by

$$\bar{x} = \frac{M_{10}}{M_{00}} \qquad (4)$$

$$\bar{y} = \frac{M_{01}}{M_{00}} \qquad (5)$$

Where and indicate the actual centroid positions of the object for x and y, respectively. This algorithm generates a set of features for each detected LED light region including its object ID, centroid, pixel values, bounding box and so forth.

2.3 Wave generation and absorption

When generating waves in a flume or tank, it is prerequisite to be able to control both the frequency and the amplitude of the oncoming waves. The frequency of the two-dimensional plane waves is relatively simple as it is the same as the frequency of oscillation as the wave generator.

The more complicated parameter is the displacement amplitude of the wave board. In shallow water, one simple concept by Galvin (1964) for the generation of waves proved that the volume of water displaced by the wave generator should be equal to the volume of water in the crest of the propagating wave, as shown in Fig.4.

For a piston type wave generator with a stroke S which is constant over a depth h. Therefore, the volume of water displaced over a whole stroke equals. $S \cdot h$.

3.0 Results and Discussions

3.1 Wave generation and absorption

In order to understand the characteristics of the wave, firstly, the pure waves were generated from the wave generator and Reflected wave absorbed by a vertical absorber.

Four different periods were generated and captured by a high-speed CCD camera and wave level gauges as shown in Fig. 1. Regarding the wave period, the wave maker could change four different operating cycles, i.e., 0.906, 1.084, 1.269 and 1.46s.

As clearly shown in the figure 5, the difference between the highest and lowest peaks of the on-coming waves was prominent about 20mm when the period was 1.46s.

Figure 6 shows the comparison of the maximum and minimum peak values against the different wave periods. As shown in the figure, the on-coming waves are all different wave heights and gradually increases as the wave period increases.

Figure 7 surge movement of the body without a mooring cable against the wave period. In the figure, the solid lines are the measurement data and the thick solid lines are the linearly fitting curves. SD/WA are the surge displacement data and the thick solid lines are the linearly fitting curves. SD and WA are the surge displacement and wave amplitude, respectively.

Fig 5: Simplified Shallow Water Piston-Type Wave Generator Theory Where the Bolume of Water Displaced Equals the Volume

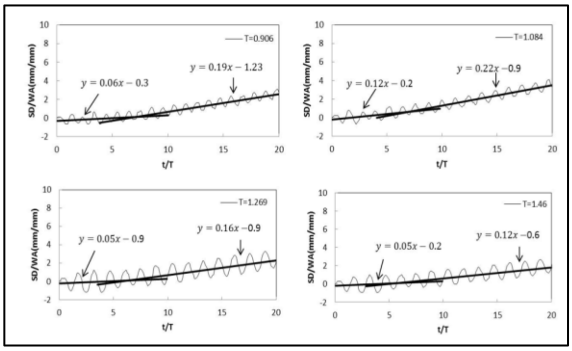
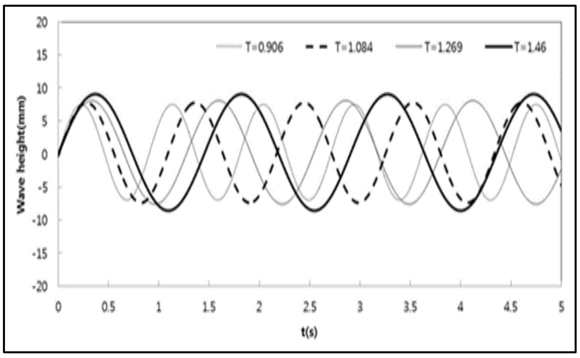


Fig 6: Comparison of the Maximum and Minimum Peak Values Against Four Different Wave Periods. (Curve Fitting)

of Water Displaced (Garvin)



3.2 floating body surge movement

Given that the wave generation and absorption are properly made, the floating bodies are ready to float in the waves. The floating bodies can be multiples, but for simplicity, we focus on a single and cylindrical model for the floating body experiment. Figure 7 shows the surge movement (i.e., on-coming wave direction) of top LED illuminator on the floating structure without mooring cables. For four different wave periods, the all ratios of the surge displacement and wave amplitude monotonically increase. Due to the difference modes of the oncoming wave, the floating body moves downstream and responses in different mode. Interestingly, as the period increases, the unstable region in the early time (i.e., just after the motor starts) is gradually shorter and the convective speed (i.e., the slope of the linear curve) is lower so that the wave amplitudes are substantially improved.

4.0 Conclusion

This study focuses on the displacement and oscillating movement of a floating body depending on a variety of on-coming waves. The small-scale wave flume was nearly manufactured, and the wave generation and absorption were success -fully made. The LED illuminators were installed inside the central floating body to visualize the body movement properly. The study can be summarized as follows:

A. To make a simulated wave in a small-scale wave flume, we built a water flume and generated a variety of waves based on the method proposed by Galvin. The experiments were performed using four different wave periods (i.e. 0.906, 1.084, 1.269, and 1.46s) and the simulation of regular waves was successfully realized.

B. The surge motion of circular cylinder was in a similar manner over a range of wave period. The expanding periodic wave region in the early period (i.e. just after the motor starts) gradually decreased and the convective speed (i.e. the slop of the linear curve) decreased as well, so that the wave amplitudes improved substantially.

Acknowledgement

This work was supported by the Human Resources Development of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Knowledge Economy (No. 20114010203080, 20113020020010). This research was also supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF2013R1A1A2005347).

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Nomenclature

S: Stroke of the wave generator
h: Water depth
SD: Surge Displacement
WA: Wave amplitude