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Visualization study of wave generation in a short-distance wave maker

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ABSTRACT

Since the installation rate of the on-shore wind turbine has been gradually decreased due to the technical and environmental problems such as the low-frequency noise, the available space of installation and the public complaint, the new business regarding to the large-scale wind farm would be a future barrier. Nonetheless, the offshore energy business will be one of the best candidates for the future development of energy harvesting, which is surely able to make a full size of stable facilities without any distraction to the surroundings. As a preliminary research for studying the offshore floating body, the experimental equipment was designed and built to simulate the wind and wave in the ocean environment. In order to make a precision analysis of the force and wave acting on the bodies, a wave maker was installed inside a water tank. The combination of a water tank and a wave maker was used to generate the same condition as the real ocean environment. A high speed camera and a wave level gauge were used to measure the temporal wave motion and period. Based on the three different period of time (short period – 0.939 seconds, 32mm height, medium – 1.141 seconds, 35mm height and long – 1.302 seconds, 30mm height), the different artificial waves were successfully generated. The visualized waves captured by a high speed camera are all sinusoidal and maintain its shapes around 4 seconds without a wave absorber, but it was substantially improved when the wave absorber was installed.

1. INTRODUCTION

With the development of modern society, more and more energy is consumed and we need to explore more energy for the years to come. As the science and technology develop rapidly with each time, in addition, new environment-oriented energy sources are being exploited due to the lack of fossil fuels (i.e., coals, petroleum and gas) and

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sometimes the serious impact on the public environment such as the BP oil spill catastrophe in the Gulf of Mexico. In this stage, wind energy is one of the more promising alternative energy sources and many scientists are currently in the development stages of what promises to be the world's largest wind turbine in the off-shore as well as the on-shore. Since the on-shore development of wind energy has been gradually decreased due to the technical and environmental problems such as the low-frequency noise, the available space of installation and the public complaint, the new business regarding to the large-scale wind farm would be a future barrier. Nonetheless, the offshore energy business will be one of the best candidates for the future development of energy harvesting, which is surely able to make a full size of stable facilities without any distraction to the surroundings.

In the off-shore wind development, the main study is highly focusing on the wind and wave load of the floating body. In addition, the behavior of upper and lower platform is very important to generate the stable energy from the oncoming wind. If the center of buoyancy is below to center of gravity the body will tilt due to the wind or wave load so that it is important to design the floating body has the center of buoyancy above the center of gravity. Therefore, the performance study of floating body under a variety of ocean environment is a prerequisite to operate the target floating body for a period.

The theoretical study of Bascom(1951) on the wave height against the water depth and the frequency of on-coming wave was one of the first to establish the background on the wave characteristics at near-shore, and Galvin(1964) built a wave maker and simulated the wave theory, which makes a connection between the shape and stroke of the panel (e.g., piston/flap type) and the characteristics of wave such as the water depth and wave length. Since then, there has been a lot of work regarding to the wave theory. Recently, Rahman *et. al.*(2006) suggested VOF(Volume Of Fluid) method to analyze numerically the force acting the mooring cable and compared with the movement of the floating body placed in the wave maker depending on the different shape of wave.

Regarding to the previous studies of off-shore floating structures both the theoretical calculation and numerical analysis have been significantly improved, but the viscous fluid force and the flow interference between fluid and floating body is not easy to make a simple approximation so that it is important to consider the complicated motion of models under the combined forces of wind and wave by using a scaled down test.

This preliminary study focuses on the fundamental research based on the movement of floating body placed on the wave load as well as the wind load so that it would finally be able to analyze the relationship between the wind and wave loads acting on it. In order to understand the behavior of the floating body, a carefully designed wind-wave generator was manufactured enabling to generate the wind and wave at a time. Due to the short distance of the wave maker (i.e., 5m), the validity of the wave generation would be questionable. Therefore, the reliability of the current facility was confirmed in this study. There are several ways to evaluate the validity of the wave generation, i.e., wave length, the durability of the wave and the similarity of wave shape. This study is based on these assumptions and approaching methods.

2. Design of laboratory experiment

In order to simulate the ocean environment such as the wind and wave in the laboratory, a wave tank was equipped with the wave generator (Fig. **1**). The size of wind and wave maker is approximately 5000L $\times$ 400W $\times$ 700H mm^3. In order to move back and forward the flat panel making an ocean wave, it directly connects with a 5-phase stepping motor which can be electrically controlled by an AVR128 control board.

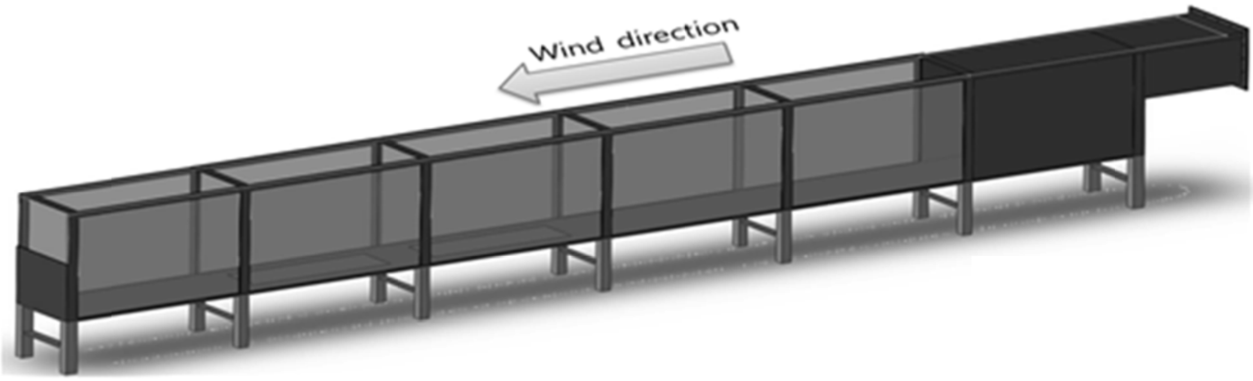

Fig. 1 The schematic view of the wind and wave generation tank

Fig. 2 shows the snapshot of the wave generator and the wave absorber. This device is parametrically tested in terms of length, size and performance so that they would be further applied for the practical use of the floating body.

Fig. 2 The snapshots of the wave generator (left) and the absorber (right) in the wave maker

In order to visualize the wave motion and shape, a high-speed camera was used. The frame rate of the camera was 50 frames per second so that the shape of the wave was clearly captured in terms of time. In addition, for the precise measurement, an artificial mesh grid was placed on the side glass plate and read each measurement time. (see Fig. 3) A wave level gauge (100mm) was also used to compare the visualised data.

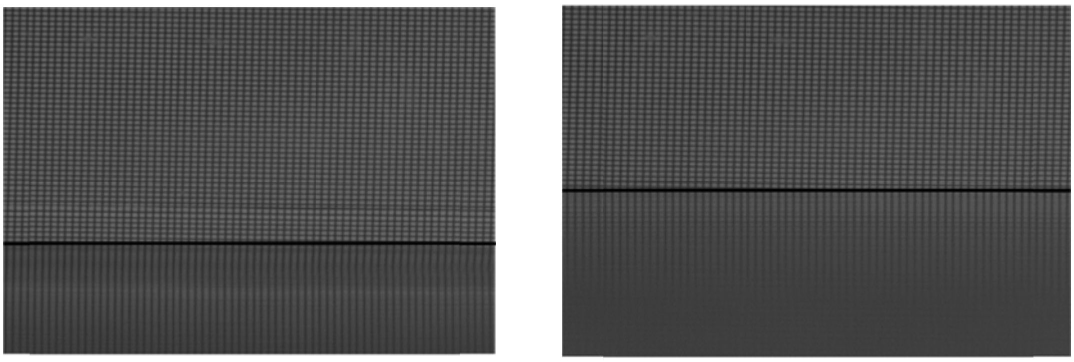

Fig. 3 The visualized images captured by a high speed camera at (a) the minimum wave height (left) (b) the maximum wave height (right)

3. Results and discussion

3.1. Wave height variation without wave absorber

In order to understand the characteristics of the wave, firstly, the pure waves were generated from the wave generator without any absorber. 3 different periods were generated and captured by a high-speed CCD camera as shown in Fig. 4 As clearly shown in the figure, the highest peak to peak wave was about 35mm when the period was 1.141s. Not surprisingly, without the wave absorber, the wave height gradually increases and has a peak to peak value of around 32mm, and it diminishes due to the wave dissipation. Since the wave propagates into the one end to the other continuously, the water surface moves up and down in the same location such as a standing wave, not a propagate wave. Therefore, in order to get a propagate wave in this short distance (i.e., around 5m), Galvin(1964) suggested that the longitudinal size of the water tank should be 2-3 times longer than the length of wave(i.e., 1.3m).

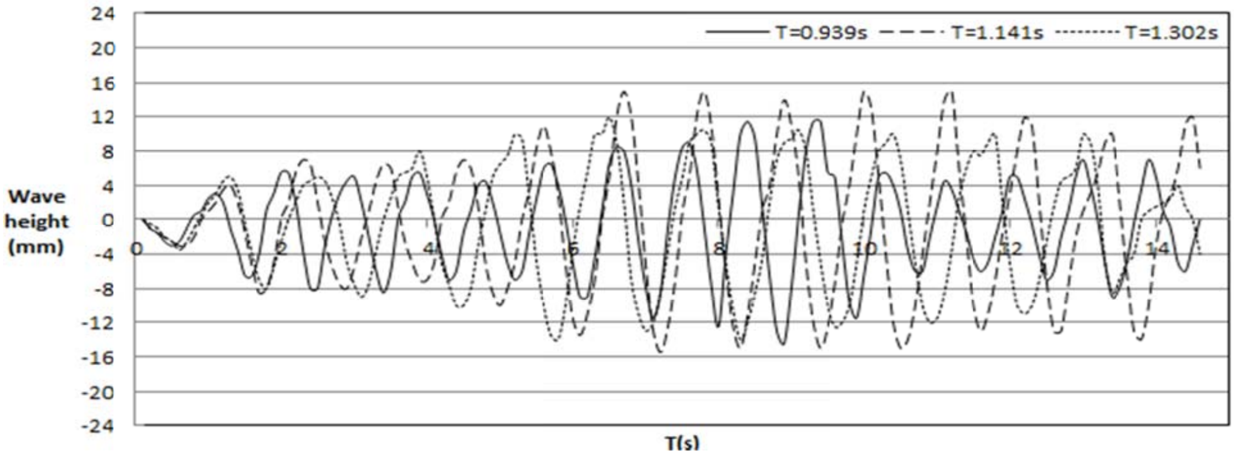

Fig. 4 Temporal variation of wave height without the wave absorber captured by a high speed camera.

To compare with the data from the high-speed camera, the wave level gauge was also used to find the precise wave height. The wave generation was made by the moving panel with the period of t=1.141s. As shown in the Fig. 5, the wave height has no regular pattern and the envelope is gradually increased due to the reflective wave and decreased after turning off the wave maker (i.e., around 35 seconds). The maximum peak to peak distance was about 40mm. Comparing with the data from the high-speed camera was at a glance useful to visualize the motion process, and the figure shows a good agreement.

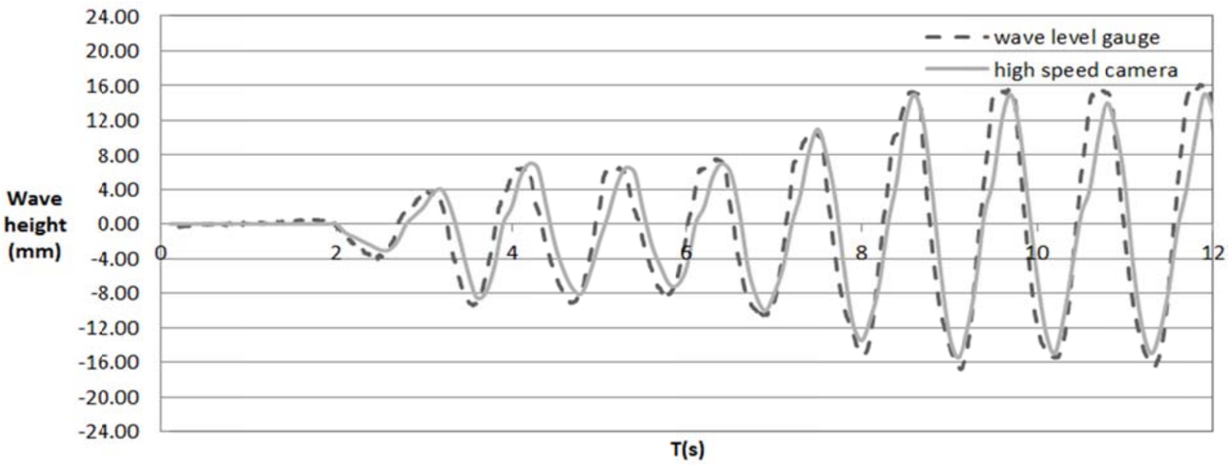

Fig. 5 The temporal variation of wave height without the wave absorber captured by a level gauge

3.2. Wave height variation with the wave absorber

To get rid of the undesirable wave reflection, a wave absorber is placed in the other end of the water tank. Fig. 6 shows the same condition of wave generation as shown in Fig.5, but with the wave absorber.

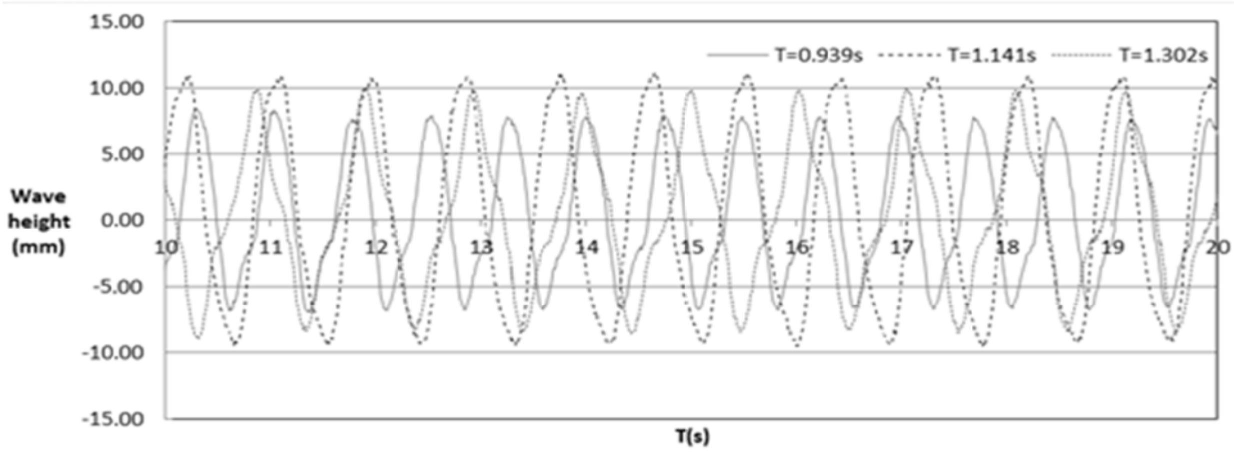

Fig. 6 The same as the Fig.5, but with the wave absorber.

In a shallow water, a simple theory by Galvin(1964) for the generation of waves can be used to validate the current result. In fact, he reported that the water displaced by the wavemaker should be equal to the crest volume of the propagating wave form. For example, consider a piston wavemaker with a stroke S which is constant over a depth h. Therefore, the volume of water displaced over a whole stroke equals S × h (see Fig. 7). In addition, the volume of water in a wave crest is defined as $\int_0^{L/2}(H/2)\sin kx dx = H/k$ so that we equate these two volumes.

$$S \times H = \frac{H}{k} = \frac{H}{2}\left(\frac{L}{2}\right)\frac{2}{\pi} \quad (1)$$

where the 2/π factor represents the ratio of the shaded area to the area of the enclosing rectangle. This equation also can be expressed in Eq. (2)

$$\left(\frac{H}{S}\right)_{piston} = k \times h \quad (2)$$

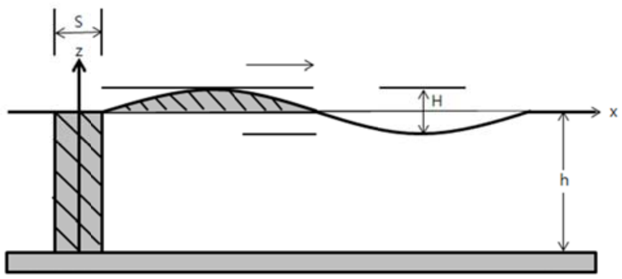

Fig. 7 Simplified shallow water piston-type wavemaker theory where the volume of water displaced equals the volume of water displaced (Dean and Dalrymple, 1991)

Thus, L can be calculated as follow,

$$\frac{H}{S} = kh$$

$$\frac{0.02(m)}{0.0113(m)} = \left(\frac{2\pi}{L}\right) \times 0.32m$$

$$L = 1.14(m)$$

In order to evaluate the theory, a laser distance sensor was used to measure the stroke of the board. In order to measure the wavelength, a section paper was placed on the side of wave tank, yielding the final value of wave length L =1.3m. Therefore, the experiment seems to prove a consistent result with the theory.

Fig.8 shows the wave height variation against a variety of motor pulse. In the experiment, 3100(period T=1.121s), 3200(T=1.141s), 3300(T=1.141s) and 3400(T= 1.141s) pulses was initially used, and the parametric study of the stroke was made as shown in Fig.9, which is the variation of the wave height against the stroke.

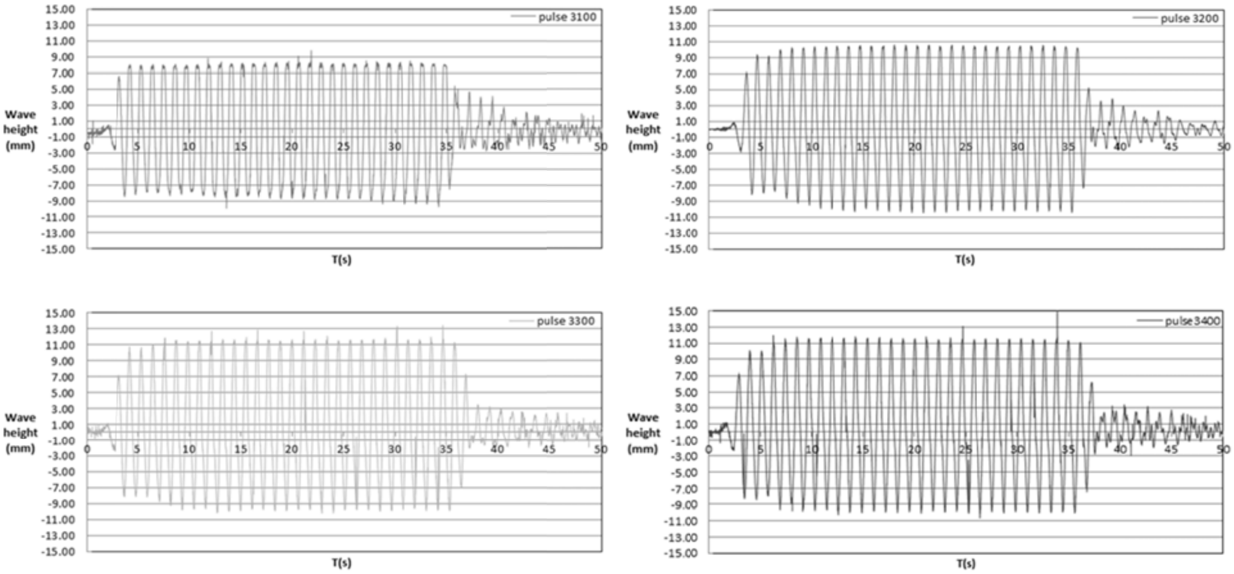

Fig. 8 Wave height variation against the different motor pulses

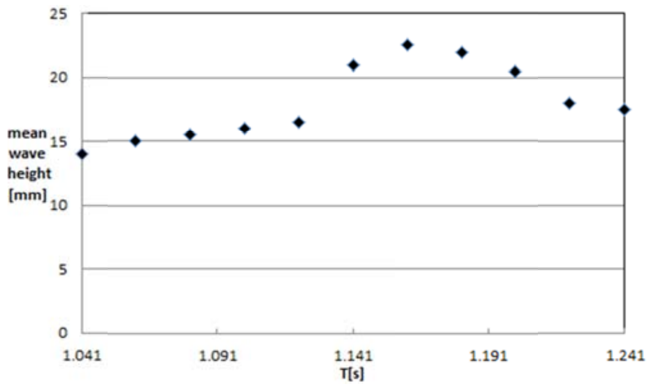

Fig. 9 Wave height variation against the period

Fig. 10 shows the effect of the wave absorber. In the figure, the highest wave height is obtained at T=1.141s, and it clearly shows that the wave absorber has a significant effect on making the regular wave. After turning off the wave maker, the wave absorber simply destroys the wave and quickly dissipates the periodic movement. However, without the wave absorber, the water surface still continues to have an existing oscillation at a period of time and slowly diminish. This result shows that the reflected wave can be absorbed very well in the short-distance wavemaker, and we finally identify this short-distance wave make would be able to generate the wave and the wave absorber absorbs the reflected wave through the experiment.

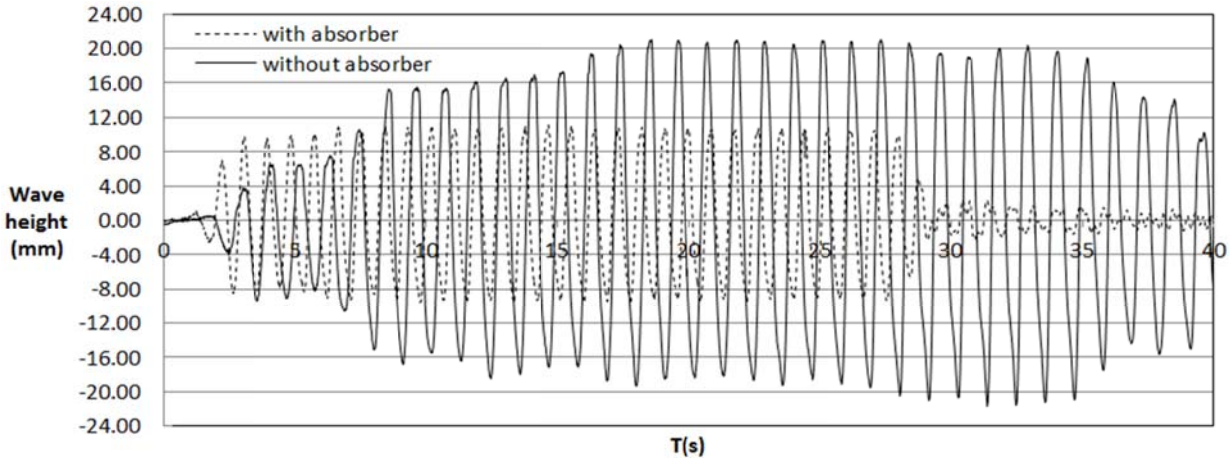

Fig. 10 Comparison between mean wave heights with and without absorber

4. CONCLUSION

In this study, the wave height and the wave length were measured at a wide range of stroke of wave generator. Comparing with previous studies the measured data are all similar under the same condition such as wave period, water depth and stroke. It is certain that the wave absorber reduces the undesirable wave and dissipates quickly small fluctuating wave in this short distance wave tank. The results are summarized as follows:

1) A high speed camera and a wave level gauge are applied to measure the temporal wave motion and the period. Based on three different period of time (short period – 0.939 seconds, 32mm height, medium – 1.141 seconds, 35mm height and long – 1.302 seconds, 30mm height), the different artificial waves are successfully generated.
2) Without the wave absorber, the wave tank generates an irregular wave in the channel. The irregular wave has a range of wave height from 15mm to 23mm.
3) With the wave absorber, the peak to peak distance of the regular wave was 23mm at 1.16s. In addition, this regular wave remains well at certain period of time.
4) Finally, this short-distance wave make would be able to generate the proper wave and the wave absorber absorbs the reflected wave through the experiment.

5. ACKNOWLEDGEMENTS

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