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Dynamic characteristics between waves and a floating cylindrical body connected to a tension-leg mooring cable placed in a simulated offshore environment

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Abstract

Given the rapid progress made in understanding the dynamics of an offshore floating body in an ocean environment, the present study aimed to simulate ocean waves in a small-sized wave flume and to observe the motion of a cylindrical floating body placed in an offshore environment. To generate regular ocean waves in a wave flume, we combined a wave generator and a wave absorber. In addition, to precisely visualise the oscillation of the body, a set of light-emitting diode illuminators and a high-speed charge-coupled device camera were installed in the flume. This study also focuses on the spectral analysis of the movement of the floating body. The wave generator and absorbers worked well to simulate stable regular waves. In addition, the simulated waves agreed well with the plane waves predicted by shallow-water theory. As the period of the oncoming waves changed, the movement of the floating body was substantially different when tethered to a tension-leg mooring cable. In particular, when connected to the tension-leg mooring cable, the natural frequency of the floating body appeared suddenly at 0.391 Hz as the wave period increased.

Keywords: Regular wave; Floating body; Flow visualization; Visual imaging; Ocean waves

1. Introduction

The world population is estimated to exceed 7 billion in March 2012 and continues to rise, whereas the energy resources of the land are being depleted rapidly (see Newton (2012)). In this regard, the worlds nations are competing to search for energy resources in the ocean and in nearby offshore areas (see Pelc and Fujita (2002)). Although the offshore ocean environment has great potential, the primary obstacles to developing these resources are the lack of simple, accessible, and mature technology, grounded in extensive research. In particular, as offshore energy harvesting of ocean resources has moved gradually out of shallow waters and into deep water, recent technology has focused on the development of floating-type offshore structures that use the buoyancy force with or without a tension-leg mooring cable connected to the subsea foundation. Investment and development in the coastal region has been a primary focus of offshore technology development for the past decade; however, more recently, the technology trend has moved out into deep water. Accurately predicting the movement of a floating body has been a key issue because this motion is highly dependent on the buoyancy force as well as on continuous regular and irregular oncoming waves, unlike an existing fixed-jacket or tripod-type body (see Vincenzini et al. (2012)). Therefore, to ensure its proper and safe operation, it is important to analyse the behaviour of a moving floating body and to precisely design this structure using a structural and hydrodynamic approach. There has been

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limited research in the ocean environment because most prior work has involved full-scale field experiments, which are costly and time-consuming. Therefore, through installation of a wave generation and absorption device in a short-distance water channel, a wave generator was designed and built to simulate the offshore ocean environment.

In offshore wind development, most research has focused on the wind and wave load of the floating body. In addition, the behaviour of the upper and lower platform is very important for generating stable energy from the oncoming wind. If the centre of buoyancy is below the centre of gravity, the body will tilt owing to the wind or wave load. Therefore, it is important to design a floating body with a centre of buoyancy above the centre of gravity. Evaluating the performance of floating bodies under a variety of ocean environments is a prerequisite to operating the target floating body under various wave conditions. The study undertakes a preliminary assessment of the appropriate movement of the wave generator and absorber by simulating the ocean environment as closely as possible in a water tank and by observing the movement of a floating body in a regular wave environment.

Regarding previous studies of wave generation in a water tank, Havelock (1929) suggested a theoretical expression based on the wave theory for piston and flap types(see Robert and Hudspeth (1981)). In addition, a systematic study of the impact of waves of various heights onto vessels was done using waves generated by a wave generator. Bascom's theoretical study of the wave height against the water depth and the frequency of oncoming waves was among the first to determine near-shore wave characteristics (see Bascom (1951)). Galvin (1964) built a wave maker to simulate such waves based on wave theory, deriving experimental evidence for the relationship between the size/shape and periodic movement of the panel (e.g. piston/flap/plunger-type wave generator) and wave characteristics including water depth, period (or length), and amplitude. Researchers studying the various types of wave machines have found that the plunger type is the most efficient in deep water, whereas the flap and piston types are effective in shallow water(see Huang (1988)). Since this work, other research has focused on wave theory(see Dong and Huang (2001), Johannes and Chris (2009) and He et al. (2012)).

More recently, studies have evaluated the movement of a floating structure placed in a water tank, a situation that more closely resembles the ocean environment. Rahman et al. (2006) suggested a volume of fluid method to numerically analyse the force acting on a mooring cable compared to the movement of a floating body placed in a wave maker, for different shaped waves. They installed a waterproof load cell on the mooring cable to determine the forces acting on the floating body, which were compared to the numerical results of the tank experiment. In addition, Sannasiraj et al. (1988) installed a gyroscope and observed the movement of floating bodies connected by two mooring cables three different configurations.

In most of the previous work described above, tests were conducted in small laboratory-scale water channels. These measurements are too limited to represent the movement of a floating body in the ocean environment. In addition, various types of regular periodic waves were generated in a water flume and the movement of a floating body was observed in order to predict its behaviour systematically.

This study focused on fundamental research based on the movement of a floating body placed on a wave load to analyse the relationship between the movement of the floating body and the oncoming waves acting on it. To understand the behaviour of the floating body, a carefully designed wave generator for generating various waves was constructed. Because of the short length (5 *m*) of the wave generator, its ability to generate waves was unclear. Therefore, the wave generation and absorption capabilities of the facility were first confirmed using amplitudes, periods, and shapes that satisfy existing wave theory. After establishing this foundation, a floating body was placed in the middle of the wave flume to visualise its movement. This study highlights wave generation and absorption in the wave flume and the observation of the floating body in simulated oceanic waves based on these assumptions and methods.

This paper is organised as follows: Section 2 outlines the detailed configuration of the experimental facilities including the wave generation and absorption method. In addition, it describes the image-processing method used to acquire and convert the images from the model into position data. Section 3 describes the parametric analysis of the simulated wave and the movement of the floating body. Section 4 presents the spectral analysis and the visualisation results of the floating body. Finally, Section 5 discusses the major conclusions.

2. Design of laboratory experiments

2.1. Experimental set up of the floating body and 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). The wave-making facility at PNU was constructed and commissioned by PNU Manufacturing Center Ltd. To simulate the ocean environment in a small-scale flume in the laboratory, a wave tank was equipped with the wave generator (or wave flume), as shown in Fig. 1. The size of the wave flume is approximately 5000 *mm long* × 400 *mm wide* × 700 *mm high*. To continuously generate two-dimensional regular waves, the flat vertical panel connected to the rotating shaft and linear guides located at the far end of the water channel is designed to move back and forth periodically (see Fig. 2). The main shaft of the flat vertical panel is connected to that of the 5-phase stepping motor and two 10-Nm couplings in between are used to connect the two shafts together at their ends for transmitting power. An AVR128 control board connected to a personal computer electrically controls the 5-phase 1-kW stepping motor used to operate the panel.

Fig. 2 shows the wave generator and absorber. The facility was parametrically tested in terms of length, size, and