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Laboratory Study on Steep Wave Interactions with Fixed and Moving Cylinder

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In this paper, a new set of experiments on the focused wave (using the second-order wavemaker theory) and current interactions with cylinders is being carried out. To represent a uniform current in laboratory, a cylinder is towed with a velocity opposite to the wave propagation directions. This paper discusses the experimental setup and test cases that were released for the comparative study at the ISOPE-2020 meeting. To obtain good correlation with different runs, the repeatability of the experiments is confirmed by comparing the surface elevation measurements at the fixed wave gauge location near the wave paddle, and an uncertainty analysis was carried out. The details on different test cases with varying frequency bandwidths of the focusing waves, speeds of the cylinder, and the locations of focusing are reported in this paper. Furthermore, a comparison of the dynamic pressure on the cylinder is reported between experiments with focusing waves with but without the towing condition. The present experimental campaign can be used as a validation case for state-of-the-art numerical models.

INTRODUCTION

Any structure that is deployed in the ocean should be studied extensively because of the significant costs involved in construction and deployment. Furthermore, many offshore structures have been and will be designed and operated for offshore and marine engineering, including the emerging technologies for harnessing marine renewables and offshore wind energy. The characteristics and effect of a wave on the structure must be analyzed as a part of the design process. A vast amount of work has been studied and written about the wave characteristics. Various linear and nonlinear theories have been developed, and different orders and approximations of wave models are available for determining the wave characteristics and its interactions. These theories and models hold well for nonbreaking cases. But in the offshore environment, steep waves or breaking waves over the structure play a major role in creating a very high impact pressure. The kinematics of the steep/breaking waves is not well understood, as they exhaust the limits of assumptions of most theories and can have additional complexities such as air entrapment. Therefore, this is a current topic of intense research. Estimation of wave loads on structures is generally done using Morison's equation, which includes the drag and inertial forces but ignores scattering and radiation. These linear assumptions and tuning constants in this method are therefore valid only for a limited range. For steep, breaking, and postbreaking waves, these assumptions will provide incorrect results. For example, on applying linear wave theory, the measured wave forces can be four times higher than the actual value.

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Because of this, the testing of the wave–structure interactions for extreme cases requires experimental investigations. However, the offshore structures are often exposed to steep waves coexisting with currents, especially in shallow water regions. In design practices, the analysis on the effects of the waves and the currents are taken into account separately without considering the interaction between the waves and the current. In fact, the current not only imposes loads on the structures but also interacts with steep waves and influences the formation of extreme waves, particularly for focusing wave groups (Yan et al., 2010). Nevertheless, relevant studies of cylinders under the actions of focusing/freak waves coexisting with the current are rarely found in the literature.

The monopile or cylinder is a simple shape and frequently used in the construction of offshore structures, such as, for example, the legs of jacket platforms, pile supports, and the foundation of offshore wind turbines. To assess the reliability and survivability of the offshore structure, one needs to consider the load on the structures in extreme waves—for example, focusing waves and freak/rogue waves, which are, in fact, more frequent than rare (Liu and Pinho, 2004) and may be generated by many mechanisms, including the spatial-temporal focusing, wave–current interactions, and so on (see the review in Sriram et al., 2015). Two important reviews of freak waves (Kharif and Pelinovsky, 2003; Dysthe et al., 2008) reported that there is no unique definition of freak waves, but it is generally agreed that they belong to the extreme tail of the probability distribution. Most commonly, a wave is said to be a freak wave when the wave height exceeds a threshold related to the significant wave height. Solutions to these based on linear or other simplified theories may be insufficient, and therefore fully nonlinear theory is necessary.

A great effort has been devoted to the study of extreme wave loads on monopiles or cylinders and associated wave dynamics/kinematics. For example, the extreme wave impact on structures shows a significant nonlinearity of higher than fifth order (Zang et al., 2010; Feng et al., 2020), such that wave loads may be amplified, almost by a factor of 3, when a slamming force caused by breaking wave impact is involved (Wienke and