International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 28, No. 2, June 2018, pp. 164–170; https://doi.org/10.17736/ijope.2018.ak26

http://www.isope.org/publications/publications.htm

CFD-Based Study of Steep Irregular Waves for Extreme Wave Spectra

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Offshore structures are exposed to irregular sea states consisting of breaking and nonbreaking waves. They perpetually experience extreme wave loads after installation in the open ocean. Thus, the study of steep waves is an important factor in the design of offshore structures. In the present study, a numerical investigation is performed to study steep irregular waves in deep water. The irregular waves are generated using the Torsethaugen spectrum, which is a double-peaked spectrum defined for a locally fully developed sea and which takes both the sea and swell waves into account. Thus, the generated waves can be very steep. The numerical investigation of such steep waves is quite challenging because of their high wave steepness and wave–wave interaction. The present investigation is performed using the open-source computational fluid dynamics (CFD) model. The wave generation and propagation of steep irregular waves in the numerical model are validated by comparing the numerical wave spectrum with the experimental input wave spectrum. The numerical results are in good agreement with experimental results. The changes in the spectral wave density during the wave propagation are studied. Further, the double-hinged flap wavemaker is also tested and validated by comparing the numerical and experimental free-surface elevations over time. The time and the frequency domain analysis is also performed to investigate the changes in the free-surface horizontal velocity. Complex flow features during the wave propagation are well captured by the CFD model.

INTRODUCTION

Offshore wind turbines are exposed to extreme irregular sea states. Extreme waves exert extreme hydrodynamic loads on substructures. Thus, the study of such irregular waves is very important in the design of offshore wind turbines. Several experimental and field investigations have been performed in the past to study extreme waves. Such spectra exhibit two peaks, because of the presence of swell and wind waves. Ochi and Hubble (1976) carried out a statistical analysis of 800 measured wave spectra in the North Atlantic Ocean. They derived a six-parameter double-peaked spectrum that is composed of two parts: the first primarily includes the low-frequency wave components and the second contains the high-frequency wave components. Each part of the wave spectrum is represented by three parameters. The six-parameter spectrum represents almost all stages of the sea conditions associated with a storm. Guedes Soares and Nolasco (1992) analyzed wave data from the North Atlantic and the North Sea and proposed a four-parameter double-peaked spectrum. This double-peaked spectrum was formulated by superimposing individual spectral components of the JONSWAP-type single-peaked spectrum. Torsethaugen (1996) used a similar approach of combining two individual JONSWAP spectra for different frequency ranges; instead of averaging, Torsethaugen used other parameters of the JONSWAP spectrum. Violante-Carvalho et al. (2004) studied the influence of swell waves on wind waves by using buoy data measurements in deep water in the South Atlantic sea. Other researchers have also made efforts in this direction to study the double-peaked spectra (Masson, 1993). Pákozdi et al. (2015) performed laboratory experiments with breaking irregular waves using the Torsethaugen spectrum to measure the global impact loads on offshore structures. Their study highlighted the importance of double-peaked spectra for a better representation of extreme sea states. The real state is composed of the sea and swell. Most of the widely used spectra, like the JONSWAP and PM spectra, do not consider both sea states. The Torsethaugen spectrum provides an opportunity to study the real state more closely (Torsethaugen, 1996).

Computational fluid dynamics (CFD) can be used as an effective tool to study such double-peaked spectra. CFD has been used previously by many researchers to numerically study breaking and nonbreaking waves. Alagan Chella et al. (2015, 2016, 2017) and Kamath et al. (2016) studied breaking waves and breaking wave forces on a vertical slender cylinder over an impermeable sloping seabed and they observed a good match with experiments. Bihs et al. (2016b) investigated the interaction of breaking waves with tandem cylinders under different impact scenarios. Bredmose and Jacobsen (2010) investigated breaking wave impacts on offshore wind turbine foundations for the focused wave groups using CFD. They compared the numerical and theoretical free surface and wave forces in the time-domain by using the linear reconstruction of waves. Östman et al. (2015) performed CFD investigations with irregular waves using the Torsethaugen spectrum. They

Received August 9, 2017; updated and further revised manuscript received by the editors November 7, 2017. The original version (prior to the final updated and revised manuscript) was presented at the Twenty-seventh International Ocean and Polar Engineering Conference (ISOPE-2017), San Francisco, California, June 25–30, 2017.

KEY WORDS: Irregular waves, CFD, double-peaked spectrum, double-hinged flap wavemaker.