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

Vol. 31, No. 1, March 2021, pp. 27–35; https://doi.org/10.17736/ijope.2021.jc804

http://www.isope.org/publications

Numerical Study on Interaction of Focused Waves with a Fixed Vertical Cylinder by HOBEM

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An investigation on the interaction between extreme waves and monopile support structures is presented. A time-domain nonlinear potential flow model is developed based on the weak-scatterer approximation. On the free surface, the fourth-order Runge–Kutta scheme with an arbitrary Lagrangian–Eulerian approach is adopted in the time-marching process. The corresponding boundary value problem is solved by the higher-order boundary element method at each time step. A comparative study has been performed to investigate the interaction of steep focused wave groups with a fixed vertical cylinder. The present numerical results of wave elevations and dynamic pressures recorded at different positions are provided and compared with the experimental data. Then the wave runup and inline force are analyzed in the time-frequency domain based on wavelet transforms.

INTRODUCTION

In ocean and coastal engineering, the safe and economic design of offshore structures needs an accurate description of hydrodynamic loads, particularly in extreme events. High-frequency wave loads occurring in extreme wave events have been identified in recent years. The high-frequency wave loads are typically excited on tension-leg platforms (TLPs) or gravity-based platforms (GBSs), and they may generate vibrations at the resonance period of the structure. The high-frequency resonant phenomenon is called "ringing" because of its sudden appearance. Unlike springing, ringing usually occurs during the passage of steep wave crests and can generate fairly high levels of stress within a burst of only a few oscillations. Ringing may also occur in offshore wind turbines, which has recently been a topic of particular interest since ringing-induced loads may be a concern with regard to extreme loads and fatigue damage. However, proper evidence and analysis models of these forces and responses are generally lacking.

The phenomenon of ringing has motivated several theoretical and experimental studies. The experimental studies have been mainly carried out in wave tanks with incoming focused wave groups and steep random waves (e.g., Chaplin et al., 1997; Bachynski et al., 2017; Riise et al., 2018). The primary focus of the theoretical studies has been to capture the wave loads up to the third-harmonic component in regular waves (Faltinsen et al., 1995; Malenica and Molin, 1995). In view of the simplification of these approaches, neither of these theoretical studies involves the condition of steep transient waves or breaking waves; nor is the region of validity of the approximation clear even in the case of regular waves. Some fully nonlinear potential flow models have also been developed (Ferrant, 1998; Shao and Faltinsen, 2014) as well as the computational fluid dynamics (CFD) models (e.g., Paulsen et al., 2014; Chen et al., 2014). However, both the fully nonlinear models and CFD models remain time-consuming for practical applications and present some weaknesses in terms of robustness.

A weakly nonlinear approach based on the weak-scatterer hypothesis (Pawlowski, 1992) may be a good alternative. The scattered waves caused by the influence of the structure are assumed to be small with respect to the incident waves. Under this condition, fully nonlinear free-surface conditions can be linearized around the incident wave elevation. This is advantageous for meshing algorithms, since the geometry of the computational domain is known explicitly at every time step, although it should be newly set up on the exact body surface and incident free surface during the time-marching process. As a result, this approach seems more robust and efficient than the fully nonlinear method. Despite the fact that a large number of applications in offshore renewable energy industry satisfy this condition, particularly point-absorber wave energy converters and monopile foundations for offshore wind turbines, very few models have been developed using this class of approximation.

In this paper, a time-domain nonlinear potential flow model based on the weak-scatterer approximation is developed. The corresponding boundary value problem is solved by the higher-order boundary element method (HOBEM) at each time step. The fourth-order Runge–Kutta (RK4) time-integration scheme with an arbitrary Lagrangian–Eulerian (ALE) approach is adopted for the nonlinear free-surface time-marching process. In addition, two efficient algorithms have been integrated for dealing with the mesh deformations. A comparative study has been performed to investigate the interaction of steep focused wave groups with a fixed vertical cylinder. The numerical results of wave elevations around the cylinder and dynamic pressures on the cylinder are provided and compared with a series of experimental data (Sriram, Agarwal and Schlurmann, 2021).

MATHEMATICAL FORMULATION

Weak-Scatterer Hypothesis and Boundary Value Problem

We consider a three-dimensional fluid domain Ω, bounded by a free surface S_F, a body surface S_B, and a flat-bottom surface S_D. The fluid is assumed to be incompressible and inviscid, and the

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Received August 18, 2020; updated and further revised manuscript received by the editors October 15, 2020. The original version (prior to the final updated and revised manuscript) was presented at the Thirtieth International Ocean and Polar Engineering Conference (ISOPE-2020), Shanghai, China, October 11–16, 2020.

KEY WORDS: Weak-scatterer approximation, HOBEM, focused wave, wave elevation, dynamic pressure.