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Three-dimensional Viscous Numerical Simulations of Focused Waves on Bottom-mounted Multiple Rigid Circular Cylinders

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Three-dimensional viscous numerical simulations are conducted in this study concerning the focused wave acting on (1) an isolated bottom-mounted circular cylinder, (2) four identical circular cylinders in a diamond arrangement, and (3) eight cylinders arranged in a chirped array with varied spacing. The numerical model, based on a Navier–Stokes solver of Fluidity, is first validated against available experimental data of the isolated cylinder, and satisfactory agreements are obtained. This work pays attention to the near trapping of a four-cylinder cluster and the rainbow trapping of a chirped cylinder array subjected to transient-focused water waves with a broad frequency spectrum. Viscous numerical results suggest the transient-focused waves result in a rather weak near trapping in the four-cylinder cluster. However, the chirped array creates significant local amplifications through a rainbow trapping mechanism. Wave nonlinearity and viscous effects are also discussed by comparisons with linear potential flow solutions.

INTRODUCTION

Even though an extreme wave occasionally appears in the ocean environment, it may result in significant runup and large wave loads on the marine structures, threatening the safety of field operations. Being a highly nonlinear and transient event, an extreme wave typically arises from an irregular sea state. Direct producing of extreme waves with random wave simulations generally requires very long runs. Alternatively, a focused wave group with a specified wave energy spectrum nearly consistent with the random process will be much more efficient for both experimental and numerical modelling.

By forcing wave paddles in a laboratory to oscillate, with a displacement composed of different sinusoidal components of frequencies, the desired waves with their phases being focused on an expected location can be produced. Following the early work by Longuet-Higgins (1952), attempts to generate the transient focused wave group with large amplitudes in laboratory tests were reported by Baldock et al. (1996), where the idea of superimposing regular wave trains was adopted. Similar to the technique used in physical wave tank, numerical modelling of a focused wave group was also developed for various potential flow models—see, for example, Bai and Eatock Taylor (2007), Ning et al. (2009), Westphalen et al. (2012), Chen et al. (2014), Viré et al. (2016), and Bihs et al. (2017), among others. Relatively speaking, the potential-based numerical model consists of the majority of the up-to-data numerical modelling of focused waves, mainly attributed to their high computational efficiency in capturing the main features of the propagation of wave group.

As a sort of mostly used marine structures, the cylindrical structures with circular cross sections can be applied as either isolated bottom-mounted piles or rigid columns in a group. Predictions of wave runup and impact loads on the surface-piercing stationary circular cylinders are of primary importance for the stage of engineering design. It has been known that when water waves pass through a cylinder group, locally amplified waves may occur at specific frequencies. The underlying physical mechanism is referred to as the near trapping. Numerous examinations on the near trapping have been conducted based on potential flow models for both regular and irregular waves—see, for example, Linton and Evans (1990), Ohl et al. (2001a, 2001b), Cong et al. (2015), Meylan and Fitzgerald (2018), and Lu et al. (2020), among others. However, the case where focused waves act on multiple cir-

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