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Hydrodynamic Interactions of Multiple Bodies with Water Waves

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A hierarchical wave interaction theory is reviewed as an innovative idea for treating hydrodynamic interactions among a great number of bodies rigorously in the framework of linear potential theory. We also introduced experimental results that were obtained using a structure consisting of 64 truncated vertical circular cylinders arranged in a periodical array of 4 rows and 16 columns. From the observation of measured results and their comparison with computed results, the effects of multiple-body interactions on the wave elevation and local steady forces are noted with respect to the wave frequency and the spatial position inside the structure. It is observed that the characteristics of wave interactions clearly change depending on whether the wave frequency is below or above the near trapped-mode frequency. Overall agreement between measured and computed results is very good, although slight differences attributed to viscous effects are observed.

INTRODUCTION

In free-surface hydrodynamic problems of the ship and ocean engineering, there exist a number of examples in which hydrodynamic interactions among multiple bodies are of critical importance. Some of the examples in ship hydrodynamics are the wave interactions between demihulls of a catamaran (Kashiwagi, 1993) and the side-wall interference effects on a ship advancing in waves in a waterway with vertical side walls (Kashiwagi and Ohkusu, 1991). The latter problem can be analyzed by the method of mirror images reflected in both of the parallel side walls, and thus the wave interactions among an infinite number of bodies must be considered. However, since the pattern of ship-generated waves may change drastically depending on the ship's forward speed U and oscillation frequency ω in waves, it is said that the effect of wave interactions becomes less important when the value of parameter $\tau = U\omega/g$ (where g is the gravitational acceleration) is larger than 1/4.

On the other hand, looking at ocean-engineering problems, the forward speed of an ocean structure is normally zero or very small. Thus the effects of wave interactions must be taken into account in the wave-related hydrodynamic analyses for a structure with several surface-piercing columns that support an upper deck (e.g. Newman, 2001). However, when the number of interacting bodies is not large, no special theoretical treatment is needed, and a conventional free-surface Green-function method, for instance, can be applied directly to the entirety of interacting bodies as a single structure.

For a special type of floating structure consisting of a large number of supporting columns, it becomes prohibitive to apply that kind of direct computation method because of an extremely large number of unknowns. When the number of interacting bodies is of the order of several tens and especially when the geometry of those bodies is identical, the so-called wave interaction theory (for example, see Kagemoto and Yue, 1986) can be effectively applied. However, if we will consider a column-supported type of very large floating structure (VLFS) to be used as a floating airport or another such specific facility, it is said that the number of columns could exceed the order of 1,000. In such a case, even the wave interaction theory cannot be used owing to the huge amount of computer memory and computation time required. To surmount this difficulty, a hierarchical wave interaction theory has been developed by Kashiwagi (2000) that enables us to treat hydrodynamic interactions rigorously in the framework of linear potential theory, even if the number of interacting bodies is of the order of several thousands.

In this review paper, attention is focused mainly on the hierarchical wave interaction theory and also on physical interpretation of the phenomena of complicated wave interactions. Numerical computations by hierarchical interaction theory have been implemented for column-supported-type structures with 1,280, 2,880, and 5,220 equally spaced truncated circular cylinders, and computed results for the wave pattern around the structure are shown.

Experiments have also been conducted using a structure consisting of 64 identical circular cylinders with finite draft, placed in a periodical array of 4 rows and 16 columns (Kashiwagi and Yoshida, 2001). Measurements were made for the wave elevation along the centerline of the structure (Kashiwagi, 2002a) and for the steady wave drift forces both on the whole structure and on each of 6 selected elementary cylinders (Kashiwagi, 2002b). Those measured results are compared with corresponding numerical results computed by the wave interaction theory. Through observation of measured results and also comparison with computed results, variation characteristics are noted of the wave elevation and the local steady forces, which are markedly different depending on the measured position inside the structure and on the frequency of incident wave. Since the steady wave drift force on a structure is closely related to the reflection of incident wave by the structure, we can see a certain similarity in the variation characteristics between the wave elevation and the local steady force, which is also noted in this paper.

FORMULATION

As an example of hydrodynamic interactions among a great number of floating bodies, we consider a column-supported-type VLFS with a thin deck and a great number of buoyancy columns. Theoretically, the geometry and arrangement of elementary columns can be arbitrary, but in this paper identical and equally

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