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Radiation and Diffraction Forces Acting on an Offshore-Structure Model in a Towing Tank

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ABSTRACT

The integral-equation method is applied to calculate the effects of tank-wall reflections upon the hydrodynamic forces acting on a model of offshore structure. The Green function satisfying the tank-wall boundary condition is provided by first considering an infinite number of mirror images and then seeking a closed-form analytical expression for the resultant infinite series. By the analysis of energy and momentum conservation, the formulas are derived, giving damping coefficient, wave-exciting force, and drift force in terms of only the Kochin function. Numerical computations are performed for a structure, composed of four vertical circular cylinders with horizontal base, both in the open sea and in a towing tank. It is shown that the tank-wall effects on the second-order drift force are greater than those on the linear forces and resultant motions.

INTRODUCTION

Measurements of the hydrodynamic forces on models of offshore structures such as semisubmersibles and tension leg platforms are usually carried out in a towing tank with parallel side walls. If the tank width is not large enough, we must expect some degree of tank-wall effects to be included in the results of experiments.

In order to clarify the degree and nature of the effects of tank-wall interference, a number of theoretical studies have been made. Ohkusu (1975) considered first-order wave forces and second-order drift force on vertical circular cylinders arranged in multiple rows and an infinite number of piles. As Ohkusu's theory was confined only to the case where each cylinder extends to the sea bottom, there exist no evanescent-wave components. Masumoto et al. (1982) applied Ohkusu's idea to a floating structure composed of multiple columns with footing, neglecting the effects of evanescent waves. These two works were not done for the problem of tank-wall effects, but mathematical formulation is equivalent to that of tandem cylinders placed on the centerline of the wave tank.

Srokosz (1980) studied theoretically several hydrodynamic relations for the interaction of regular waves with a body in a canal. The obtained results can be regarded as an extension of Newman's (Newman, 1976) for the open-sea problem. Miles (1983) also analyzed theoretically the problem of a submerged circular duct that is centrally placed between parallel tank walls, with the limitation of tank width being small compared to the wavelength.

Eatock Taylor and Hung (1985) provided an exact analytical representation for the velocity potential, which has no restrictions regarding the position of the cylinder in a wave tank. Computational results were also provided for first-order force and mean drift moment on an articulated column, and those were compared with corresponding experimental values. Matsui et al. (1986) made more detailed comparisons between experiments and numerical results based on their own theory. Recently, with a matching technique, Yeung and Sphaier (1989) and Çalişal and Sabuncu (1989) independently studied the effects of channel walls on the hydrodynamic properties of a vertical cylinder. The former gives reasonable behaviors of the hydrodynamic forces at transverse channel-resonant frequencies, but the latter shows physically unreasonable negative damping results at resonant frequencies.

In all of the cited works except for Eatock Taylor's and Hung's work, the body is assumed to be placed on the centerline of a tank and assumed to be of simple configuration such as a vertical circular cylinder. In principle, these limitations can be removed, if the interaction theory developed by Kagemoto and Yue (1985) is applied to the case of an infinite number of bodies. However, numerical results based on such idea have not been reported. It should be also emphasized that almost all the existing theories treating a vertical cylindrical body in a towing tank are described in cylindrical coordinates. Thus they include the infinite series of Bessel functions corresponding to an infinite number of image bodies: Efficient and accurate evaluation of this infinite series must be performed with caution.

In this paper, a three-dimensional (3-D) integral-equation method is applied to the problem of tank-wall effects. The integral-equation method offers, in principle, no restrictions on the geometry of the body. However, complications may exist in the derivation, and then in an efficient evaluation of the Green function satisfying the zero-flux condition on tank walls. In the present work, satisfaction of the zero-flux condition is achieved by considering an infinite number of image singularities, and then a closed-form expression for the resultant infinite series is analytically obtained; thus, unlike the existing studies, there is no need to worry about the convergence of the infinite series and its efficient and accurate evaluation.

A floating structure comprising four vertical circular cylinders with horizontal base is considered a simple model of offshore structures; it is situated midway between two parallel tank walls and is responding to the incident wave. Computational results are presented of added-mass and damping coefficients, wave-exciting force and moment, motion amplitude, and second-order drift force. Compact formulas for calculating damping coefficient, wave-exciting force, and drift force are derived from the principle of energy and momentum conservations. It is analytically shown that the formulas reduce to the 2-D and 3-D results in the open sea in the low- and high-frequency limits, respectively.

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KEY WORDS: Integral-equation method, tank-wall effect, offshore structure, added-mass and damping, wave-exciting force, drift force.