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Wave-induced Local Steady Forces on a Column-supported Very Large Floating Structure

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ABSTRACT

An accurate numerical calculation method is presented for the wave-induced steady forces and moments on each of the columns supporting a very large floating structure. The method is based on the direct integration of the pressure over the wetted surface of each column. First-order quantities needed in computing the pressure are determined by applying a higher-order boundary element method combined with the wave-interaction theory, taking into account the hydrodynamic interactions exactly within the linearized potential theory. The effects of motions of a structure are incorporated consistently up to the second-order in the wave amplitude. Experiments in head waves are also conducted using 64 truncated vertical cylinders arranged in a periodic array of 4 rows and 16 columns. Steady wave forces are measured at 6 different positions among 64 cylinders, and they are all in good agreement with computed results. Some characteristics in the variation tendency of the local steady forces are summarized.

INTRODUCTION

A column-supported structure has been considered a possible type of very large floating structure (VLFS). This structure consists of a large number of floating columns which support a thin upper deck. By comparison with an alternative pontoon type which has been studied recently by many researchers (e.g. Kashiwagi, 1999, for a review), it is said that the column-supported type is advantageous in small motions in waves, because incident waves will transmit through a gap between columns.

However, this recognition may not be true. For instance, according to Maniar and Newman (1997), near-trapped modes among many cylinders occur at some critical frequencies and exert large wave forces on each cylinder of the array. Their study is based on a simple geometry, where a large number of bottom-mounted circular cylinders are periodically placed along a single straight line. Hence no information is given on the near trapped-wave phenomena in a realistic array of columns and on the second-order wave drift force.

Recently, Kashiwagi (2000) presented a calculation method for the drift forces in the horizontal plane and the drift yaw moment on the basis of the momentum conservation principle. This method (referred to as the far-field method hereafter) is effective, because all necessary integrations over a control surface located far from the structure are analytically performed using Graf's addition theorem and the Wronskian formulae for Bessel functions and the orthogonality of trigonometric functions to integrals in the circumferential direction. However, this method gives only the total force and moment acting on the structure.

Meanwhile, the steady drift forces can also be computed by integrating the pressure over the wetted surface of a structure and taking time average over a period. (Hereafter this method will be referred to as the pressure-integration method or the near-field method.) This pressure-integration method enables us to evaluate the local forces on each column, which is very useful in the analysis of structural strength and in the design of mooring systems. This paper is concerned with this pressure-integration method.

The wave drift force is a second-order steady force with respect to the wave amplitude, which can be obtained from quadratic products of first-order quantities. In this paper, the boundary-value problems for the first-order velocity potentials are solved using the Kagemoto and Yue wave-interaction theory (1986) combined with a higher-order boundary element method (HOBEM). Thus, hydrodynamic interactions among many columns are taken into account exactly in the framework of the potential theory. The resulting hydrodynamic forces and wave-induced motions of a structure are computed, with which the effects of body motions on the local steady forces are properly evaluated. In the pressure-integration method, spatial derivatives of the velocity potential and the wave elevation at the waterline must be computed. This is successfully performed with the 9-point isoparametric representation for the surface geometry and velocity potential. The validity and numerical accuracy of the present method are confirmed by comparing the sum of local steady forces with the drift force computed by the far-field method.

Experiments are also carried out using 64 identical circular cylinders with a horizontal base, arranged in a periodic array with 4 rows and 16 columns. Results of the steady wave forces measured at 6 selected positions are compared with corresponding numerical results. Good agreement is found between computed and measured results. Some characteristics of the local steady forces are noted, which are markedly different depending on the position of the cylinder in the array.

FORMULATION AND SECOND-ORDER FORCES

We consider the interactions of plane, regular incident waves with a VLFS. As shown in Fig. 1, the structure considered here

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KEY WORDS: Drift force and moment, hydrodynamic interactions, pressure-integration method, trapped mode.