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The Computation of Second-Order Mean and Double-Frequency Wave Loads on a Compliant TLP by HOBEM

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ABSTRACT

In this paper, the second-order mean and double-frequency wave loads on the ISSC TLP in regular waves are investigated. The second-order wave loads on the compliant (massless-spring-supported) TLP are compared with those on the stationary TLP in order to see the effect of body motions. A higher-order boundary element method (HOBEM) with free-surface Green function is used for the computation of the first- and second-order hydrodynamic loading. In particular, the capability of HOBEM in calculating the second spatial derivatives of the first-order potential on the body surface is demonstrated. The numerical results for the stationary ISSC TLP are compared with Matsui et al's (1992) experimental results, and reasonably good agreement is observed.

INTRODUCTION

Most of deepwater compliant offshore platforms such as tension-leg platforms (TLP) are designed so that their natural frequencies are away from typical wave frequencies in order to avoid unacceptably large wave-induced motions. As a result, second-order sum- and difference-frequency wave loads occurring close to the natural frequencies of those platforms often give greater contributions to high-frequency and low-frequency resonant responses. Therefore, in order to predict those resonant high- and low-frequency responses in a reliable manner, designers need to compute with reasonable accuracy the second-order sum- and difference-frequency wave loads as well as damping.

In monochromatic waves, the second-order force consists of two parts: mean and double-frequency excitations. The second-order mean forces can be obtained entirely from the first-order results, hence the relevant modules can straightforwardly be extended from the first-order diffraction/radiation programs. On the other hand, the second-order double-frequency forces need the computation of the second-order potential, which requires substantial human effort and computational time.

The second-order double-frequency wave loads on the full geometry of a stationary TLP were calculated in Kim (1991), Lee et al. (1991), and Molin and Chen (1990) using the constant panel method (CPM). Chau (1989) used a higher-order boundary element method to compute double-frequency forces on four columns of a stationary TLP. However, those previous studies were mostly limited to stationary TLPs, and only limited information is now available for the second-order double-frequency wave excitation on freely floating or compliant TLPs. It is primarily due to the numerical difficulty associated with the computation of the second spatial derivatives of the first-order potential on the boundary surface by CPM. Those terms appear both in the inhomogeneous free and body surface conditions. An alternative equation that contains only the first spatial derivatives may be derived through the use of Stokes theorem. However, the validity of this alternative formulation needs to be carefully tested for the complicated, multiply connected geometry containing sharp corners and edges such as a TLP.

In this paper, the second-order mean and double-frequency wave forces on stationary and compliant TLPs are calculated using HOBEM. For double-frequency forces, the second spatial derivatives of the first-order velocity potential are needed on the body and free surfaces, and they were calculated fairly accurately by HOBEM without using Stokes theorem. Thus the original body- and free-surface forcing functions are used in our second-order computation. The numerical results of the original formula are compared with those of modified formulas. Our numerical results are validated through convergence test and comparison with the results of Kim and Yue (1989, 1990) for a couple of simple geometries. For further verification, the computed double-frequency excitations on the stationary ISSC TLP are compared with the experimental results of Matsui et al. (1992).

Finally, the second-order mean and double-frequency wave loads on the actual compliant TLP are compared with those on the stationary TLP in order to see the effect of TLP motions. The relative importance of constituent components is also discussed to give insight into the development of approximation methods. In our motion computation, the dynamic effects of the tendon on hull responses are neglected (uncoupled analysis), and the tendon is simply replaced by a massless spring. This assumption is certainly not justifiable for a deepwater TLP, for which appreciable inertia and damping effects from the tendons are expected. In such a case, the dynamic analysis program that treats TLP as an integrated system needs to be developed.

PROBLEM FORMULATION

We consider the first- and second-order interaction of a plane monochromatic incident wave with three-dimensional bodies. For analysis, Cartesian coordinates with the (x,y)-plane in the quiescent free surface and z positive upward are used. Assuming ideal fluid and weak nonlinearity, we express the total velocity potential Φ as a sum of first- and second-order potentials: $\Phi = \varepsilon\Phi^{(1)} + \varepsilon^2\Phi^{(2)}$. At each order, the velocity potentials are decomposed into incident, diffraction, and radiation potentials; $\Phi^{(i)} = \Phi_I^{(i)} + \Phi_D^{(i)} + \Phi_R^{(i)}$, $i = 1, 2$. In the presence of a regular wave of frequency ω, we can write the velocity potential Φ and force **F** in the form:

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KEY WORDS: Second order, mean, double frequency, wave load, compliant TLP, higher-order boundary element, second spatial derivatives.