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Second-Order Nonlinear Wave Force in Random Seas

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ABSTRACT

A Volterra-model method is used to create the time series of second-order nonlinear wave force by employing the frequency response function, which forms the Fourier transform pair with the impulse response function. The linear and quadratic frequency response functions for the wave forces are hydrodynamically computed using HOBEM. The convolutions of the impulse response functions with the given random wave and random wave*wave yield the nonlinear wave forces in the time domain. As an example, this method is applied for the simulation of nonlinear responses of a TLP in the long-crested seas.

KEY WORDS: nonlinear wave force, first- and second-order wave force, Volterra model, time domain simulation, Gaussian random wave

INTRODUCTION

This paper presents a practical method for the time-domain simulation of nonlinear wave forces on a floating structure in random seas.

Time histories of nonlinear wave forces are essential for the simulation of nonlinear responses of offshore structures. For instance, the slowly and rapidly varying dynamic responses of a Tension-Leg-Platform (TLP) are due to the above nonlinear hydrodynamic wave forces.

Conventional methods to generate the time series of wave elevation employ the given wave spectrum and linear superposition theory (random phase). These may lose natural randomness and groupness as discussed by Burcharth (1981) and Tucker *et al.* (1984). Besides, it needs enormously dense frequency resolution to produce a long Gaussian wave time series. To avoid the foregoing difficulty, frequency-disturbance method was introduced by Shinozuka and Jan (1972), but it failed to produce Gaussian waves. These disadvantages can be avoided if we use a linear filter with Gaussian random signals, where the linear filter is derived from the specified wave spectrum. The wave time series derived in this manner will have practically infinite repeating period with randomness and groupness resembling the natural waves. Zhao (1996) developed an authentic Volterra method recently.

Wiener (1958) studied the Volterra model technique. Dazzell (1974) used Volterra model experimentally to determine the frequency response functions for the added wave resistance of ship. Later, Dazzell and Kim (1979) calculated hydrodynamically the Linear and Quadratic Frequency Response Functions, LFRF and QFRF, to compare with the measured. The slow wave drift force of a ship was simulated in the time domain using Volterra model and the statistics of the forces by Kim and Boo (1990).

For the added resistance and drift forces, only the low frequency components are important, while for the TLP responses the low, wave and high frequency wave forces are all indispensable. The present work, different from Kim and Boo (1990), uses the filtering scheme for the random waves and the Volterra model for the wave forces on a TLP, in which the forces contain the difference (low), wave, and sum (high) frequency components. Moreover, a decomposition method is introduced for the radiation damping force in the dynamic simulation since this damping force is a term requiring special consideration.

Liu *et al.* (1991, 1995) applied a Higher-Order Boundary Element Method (HOBEM) for the hydrodynamic computation of floating offshore structures, which are employed in the present work.

The forces due to viscosity, wind and current are not discussed in this paper. The application of these forces in the TLP simulation can be found in the research by Zhao (1996).

GENERAL EXPRESSION OF WAVE AND POTENTIAL

It is convenient to express a wave field $\eta(x;\, t)$ and velocity potentials for the wave-exciting forces in the following forms.

$$\begin{aligned}\eta(x;\, t) &= \mathrm{Re}\{\sum_{j=1}^{\infty} \eta_{0j}(t) e^{ik_j \cdot x}\} \\ &= \mathrm{Re}\{\sum_{j=1}^{\infty} A_j e^{-i(\omega_j t - k_j \cdot x)}\} \\ &= \sum_{j=-\infty}^{\infty} \hat{A}_j e^{-i(\omega_j t - k_j \cdot x)}\end{aligned} \tag{1}$$

in which

$$A_j = |A_j| e^{-i\alpha_j} = 2\hat{A}_j \tag{2}$$

is the complex amplitude, α_j is the phase angle of a component wave at frequency ω_j, $A_{-j} = \overline{A}_j$ ($A_0 = 0$ for zero-mean waves),