Twice Expansion Analysis Method in Time-Domain for Wave-body Interaction

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ABSTRACT

Significant drift phenomenon of platform with mooring system is often observed in deep sea. It would be incorrect if the traditional perturbation expansion method was adopted to investigate the wave-body interaction directly. In order to solve the problem, a twice expansion method in time-domain is proposed here. The analysis method is applied for forced motion of truncated cylinder and couple motion of a Spar platform in bichromatic waves. The numerical results show the correctness of the theory and the necessity of the present method.

KEY WORDS: Second-order time-domain method; Twice expansion; Hydrodynamic force; Drift motion

INTRODUCTION

Deep water structures are usually positioned in sea by mooring lines, which perform strong nonlinearity. The structure system usually has a very low natural frequency, and can be inspired larger reciprocating drift motion by nonlinear wave force at low frequency.

To deal with the problem due to mooring nonlinearity, Sarkar and Eatock Taylor (1998, 2001) proposed a two-scale perturbation method to investigate the interactions of nonlinear mooring stiffness and wave hydrodynamics, and established a frequency domain method for this problem. Ormberg and Larsen (1998), Garrett (2005) carried out the coupled analysis of floater motion and mooring dynamics. These papers put more weight on the mooring system rather than the hydrodynamic parts, in which first and second-order wave force was also evaluated by frequency-domain method. Low and Langley (2005, 2006, 2007) published a series articles, pointing that there exist two kinds of coupled analysis. One referred to the coupling between vessel and moorings, while the other was between the wave frequency and the low frequency. In their latter research, a combination method of frequency domain and time-domain was adopted to solve the coupled analysis.

The nonlinear problem is more widely studied in the time domain, and coupling analysis must be carried out for wave interaction with floater and mooring system. As the total time domain coupling analysis is complex and tremendous, hydrodynamic load is often computed by a perturbation expansion method (Yang et al, 2012), or by Cummins method based on the frequency domain perturbation expansion (Kim et al, 2013).

However, in deep water the floater may oscillate with an amplitude larger than wave lengths. At this condition, the traditional perturbation expansion is obviously not correct. The most obvious disadvantages of the present perturbation method are that the phase change of the wave load due to body motion and the change of the encountering frequency of incident waves are unable to be considered. To solve those problems, a time domain twice expansion method is proposed in this study. The displacement of floater motion is divided into two parts: one is a large amplitude motion with low frequency, and an oscillation about the low frequency motion at higher frequency. The large amplitude motion at low frequency is obtained by numerical filtering of body response matching with the progress of simulation. This position is called as the instantaneous mean position. The smaller amplitude motion about the mean position is computed by perturbation expansion method. Thus, it can be guaranteed the perturbation expansion factor is always smaller.

The numerical filtering is implemented by a wavelet transform method in this study, and a HOBEM is applied to calculate the wave field at each time step. At each time step, the overall body and free surface meshes vary with the low frequency movement, but the relative location of the computational grids is invariant. Recursive interpolation is used to get the physical values of those nodes inside the free surface mesh, and Taylor series expansions is used for the boundary nodes after the body and the meshes have translated to a new position. At the new position, computation is similar with that for body moving in a steady current.

DEFINITION OF COORDINATE SYSTEMS AND DECOMPOSITION OF BODY MOTION

To describe the motion of a floating body, three coordinate systems (Fig. 1) are defined. The first one is an earth-fixed coordinate system \( Oxyz \) at the initial equilibrium position of the body, the second one is an instantaneous mean coordinate system \( \hat{O}xyz \) translating horizontal with the body at low frequency and the third one is a body-fixed coordinate system \( \hat{O}'x'y'z' \). The origins of the coordinate systems \( Oxyz \) and \( \hat{O}xyz \) are at the still water surface, and the \( z \) and the \( \hat{z} \) axes measure vertically upward.