An Application of Fully Nonlinear Numerical Wave Tank to the Study on Chaotic Roll Motions

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ABSTRACT

A numerical wave tank is applied to the study on chaotic roll motions of two-dimensional floating body. This numerical wave tank is constructed by time domain fully nonlinear simulation method based on potential theory. In this simulation method, boundary value problems both on the velocity potential $\phi$ and its time-derivative $\partial \phi/\partial t$ are solved. The coupling condition between wave and floating body is imposed as the implicit boundary condition of $\partial \phi/\partial t$ on wetted body surface. The radiation condition at the tank ends are satisfied by artificial damping technique. Using this numerical wave tank, chaotic motions of a two dimensional unstable floating body with small negative GM are simulated in time domain taking fully nonlinear fluid-body interaction into account. Simulated time history, phase plot and Poincaré section of roll motions are presented and the dependency of the motion to wave height is discussed.

KEY WORDS: Numerical wave tank, Fully nonlinear, Chaos, Roll motion, Negative GM, Parametric oscillation

INTRODUCTION

Responses of floating bodies such as ships or ocean structures to incident waves are one of the main concern in ocean engineering. The responses are usually treated as harmonic assuming small amplitude wave and body motions. Under the assumption, the frequency responses have been investigated by linear or perturbation theories. However, the body motions are not always harmonic in real ocean. When amplitude of wave and body motions are large in rough seas, nonlinear effects are dominant. Capsizing in a plunging breaker is an extreme example. Even if wave amplitudes are small, nonlinearities due to body shape, restoring force, mooring force, free water on the deck etc. affect to the body motions and parametric or chaotic motions may be resulted. In this paper, chaotic roll motions of two dimensional unstable floating body with small negative GM are investigated numerically.

For the analysis of chaotic roll motions, nonlinear ordinary differential equations of body motions are popularly used as model equations and hydrodynamic forces are taken into consideration as hydrodynamic coefficients. However, when roll motions are chaotic, we are not convinced to use hydrodynamic coefficients corresponding to the incident wave frequency. They are usually obtained by linear or weak nonlinear theories. In the study on such a highly nonlinear hydrodynamic phenomena, hydrodynamic coefficients, in other word hydrodynamic forces, should be treated as variables with respect to time.

The aim of this study is introducing a new technology to the field of nonlinear hydrodynamics and floating body dynamics. That is time domain fully nonlinear simulation. Time domain fully nonlinear simulation methods are studied by Vinje 21, Cointe 29, Tanizawa 5, 9, 10, Van Daalen 8, Sen 7, Cao 8, Francescutto 11 and others in the past decade and fully nonlinear numerical wave tanks have been developed. Using these numerical wave tanks, nonlinear interaction between body motions and fluid motions can be solved in time domain without assuming any periodicity.

In our previous study 13, we applied the numerical wave tank to the analysis of parametric roll motions of bow section body and showed the simulated harmonic and parametric motions, critical wave height of the parametric excitation, etc. are well agree with the experimental data. In this study, we apply the same numerical wave tank to the analysis of chaotic roll motions.

FULLY NONLINEAR NUMERICAL WAVE TANK

Mathematical formulation

Motions of a floating body inside a two-dimensional wave basin is considered. As Fig.1 shows, fluid domain is bounded by free-surfaces $S_r$, a piston wave maker $S_p$, bottom and rigid wall $S_b$ and a floating body $S_f$. Here, gravitational acceleration $g$, density of fluid $\rho$ and width of floating body $B$ are chosen as units to nondimensionalize the problem. An space-fixed Cartesian coordinate system $o-\mathbf{zz}$ is used with $\mathbf{z}$ coincident with the calm