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A Study of Parametric Roll Motions by Fully Nonlinear Numerical Wave Tank

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ABSTRACT

The parametric roll motion of a two-dimensional floating body is studied numerically, theoretically and experimentally. For the numerical study, a fully nonlinear numerical wave tank is used. This is a time-domain simulation program which solves simultaneous equations of ideal fluid motion and floating body motions. To satisfy the radiation condition at the tank ends, an artificial damping technique is applied. Using this numerical wave tank, motions of a floating body in regular waves are simulated and the critical wave height, which excites the parametric roll oscillation, is estimated. Theoretical estimation of these criteria is also given from the stability analysis of a coupled Mathieu-type equation of heave and roll motions. To validate these numerical and theoretical results, an experiment is performed. Comparison among numerical, theoretical and experimental results shows that the simulated motions agree well with the measured motions in both harmonic and parametric oscillations, and as a result, the criteria estimated by the numerical simulations agree with the measured criteria qualitatively and quantitatively, while the theoretical criteria agree qualitatively.

INTRODUCTION

Responses of floating bodies such as ships or ocean structures to incident waves are one of the main concerns 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. But the body motions are not always harmonic in the real ocean. When amplitude of wave and body motions are large in rough seas, nonlinear effects become dominant. Capsizing in the plunging breaker is the extreme example. Even if the amplitudes are small, nonlinearity due to body shape, mooring force, free water on the deck, etc. affect the body motions and chaotic or parametric motions may result. In this paper, the harmonic and parametric roll motions of a two-dimensional body are studied numerically, theoretically and experimentally.

Parametric roll motions arise from the time-dependent variation of the metacenter height of the body due to the relative heave motions to the free surface. If the body has a shape sensitive to parametric excitation, the roll angle diverges exponentially and results in capsizing. In particular, when the wave period is nearly equal to the half of the natural roll period, it is very easy to excite parametric motion even in a small-amplitude wave.

For the analysis of parametric roll motions, time-domain, fully nonlinear simulation can be a powerful tool. Time-domain, fully nonlinear simulation methods have been studied by many researchers in the past decade (Vinje and Brevig, 1981; Cointe et al., 1990; Tanizawa, 1990, 1995b; Kang and Gong, 1990; Van Daalen, 1993; Sen et al., 1989; Cao et al., 1994) and fully nonlinear numerical wave tanks have been developed. In this study, using the numerical wave tank (Tanizawa, 1996), the parametric motion together with the harmonic motion are simulated seamlessly in time domain, and the critical wave height, which excites the parametric motion, is estimated. For the validation of the numerical results, an experiment is performed.

Parametric oscillation is a classical problem and has been studied using Mathieu-type model equations in a number of fields of science. So, also in this paper, Mathieu-type simultaneous equations of heave and roll motions are composed and the criteria are estimated from the stability analysis of these model equations.

Through these studies, the applicability of the numerical wave basin to the parametric motions is discussed.

FULLY NONLINEAR NUMERICAL WAVE TANK

Mathematical Formulation

Motions of a floating body inside a 2-D wave basin are considered. As Fig. 1 shows, fluid domain Ω is bounded by free-surfaces S_f, a piston wavemaker S_p, bottom and rigid wall S_b, and a floating body S_s. Here, gravitational acceleration g, density of fluid ρ and width of floating body B are chosen as units to nondimensionalize the problem. A space-fixed Cartesian coordinate system o–xz is used with x coincident with the calm free surface and z positive upward. The fluid is assumed to be homogeneous, incom-

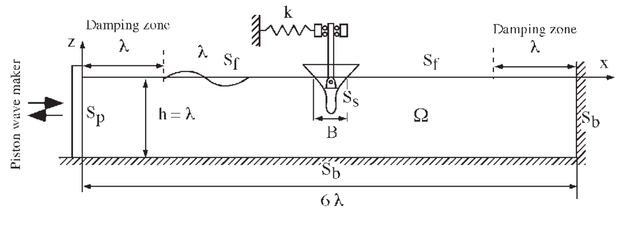

Fig. 1 Simulation with damping zones

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KEY WORDS: Parametric oscillation, numerical wave tank, fluid-body interaction, fully nonlinear simulation, acceleration potential, implicit body surface boundary condition.