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Dynamic Behavior of Submerged Tension-Moored Structure with Pressurized Air-Chamber and Wave Transformation

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INTRODUCTION

The major advantage of the floating structure with a pressurized air-chamber lies in the easy control of the natural frequency of the structure just by adjusting the air pressure in the air-chamber without change of the mooring system and geometrical shape of the structure (Iwata et al., 1988). The theoretical model is newly developed by using the linear Dividing Region Method, which considers the air compression in the air-chamber. Laboratory experiments were conducted to examine the validity of the theoretical model.

THEORETICAL MODEL

The analytical situation for the submerged tension-moored floating structure with a pressurized air-chamber is shown in Fig. 1. The fluid region is divided into 6 parts by the water depth and the structural boundary conditions. Assumptions employed are: (1) incompressible fluid, (2) irrotational wave motion, (3) linear wave theory, (4) small harmonic motions of floating body, and (5) Hook's law in the mooring lines. The Laplace equation and boundary conditions in each fluid region are given:

$$\nabla^2 \Phi_j(x,z;t) = 0,\ \Phi(x,z;t) = \phi(x,z)e^{i\sigma t};\ j = I \sim VI \tag{1}$$

$$\frac{\partial \phi_j}{\partial z} = \frac{\sigma^2}{g}\phi_j,\quad \text{at } z = 0;\ j = I,V,VI \tag{2}$$

$$\frac{I}{\rho g}\frac{\partial P_a}{\partial t} + \frac{\partial \phi_j}{\partial z}e^{i\sigma t} = \frac{\sigma^2}{g}\phi_j e^{i\sigma t},\quad \text{at } z = -q_4 h;\ j = III \tag{3}$$

(water surface boundary condition in the air-chamber)

$$\frac{\partial \phi_j}{\partial z} = 0,\quad \text{at } z = -h;\ j = I \sim V \tag{4}$$

$$\frac{\partial \phi_j}{\partial z} = i\sigma(\beta + \omega x),\quad \text{at } z = -q_1 h;\ j = II,IV \text{ and } z = -q_3 h;\ j = VI \tag{5}$$

(body surface boundary condition)

in which, ϕ is the velocity potential, σ the angular frequency, i the imaginary unit, g the gravitational acceleration, ρ the fluid density, t time, P_a the air pressure in the chamber, j the region number, and β and ω the complex amplitudes of heaving and rolling motions, respectively. The air pressure P_a in the air-chamber in region III is formulated with Eq. 6, based on the adiabatic change of air in the air-chamber.

$$P_a = \overline{P}_0 + P_0 e^{i\sigma t},\quad P_0 = -\gamma \overline{P}_0(\beta - \eta_0)/\overline{V}_0;\quad \gamma = 1.4 \tag{6}$$

in which, $\overline{P}_0$ is the initial air pressure, η_0 the mean water level and $\overline{V}_0$ the initial air volume per unit width in the air-chamber.

The motion equations of the floating structure are given:

$$M\alpha\sigma^2 e^{i\sigma t} = \int_s i\rho\sigma\phi_j e^{i\sigma t} n_x ds + R_x \quad \text{(swaying motion)} \tag{7}$$

$$M\beta\sigma^2 e^{i\sigma t} = \int_s i\rho\sigma\phi_j e^{i\sigma t} n_z ds + R_z \quad \text{(heaving motion)} \tag{8}$$

and

$$I\omega\sigma^2 e^{i\sigma t} = \int_s i\rho\sigma\phi_j e^{i\sigma t}(s - \bar{z}_0)ds + M_R + M_r \quad \text{(rolling motion)} \tag{9}$$

in which, M and I are the mass and the inertia moment of the floating structure, respectively, n_x and n_z the directional cosines to the x- and z-axes, respectively, s the coordinate of the structure surface, M_r the restoring moment, R_x and R_z the resistance forces of the mooring lines to the swaying and heaving motions, respectively, and M_R the resistance moment of the mooring lines to the rolling motion.

The velocity potentials in the six fluid regions, the body motions, and the air pressure in the chamber can be solved with Eqs. 1–9, employing the matching conditions of the water pressure and the horizontal velocity at the interface of two adjacent fluid regions and the contacted surface between fluid and structure.

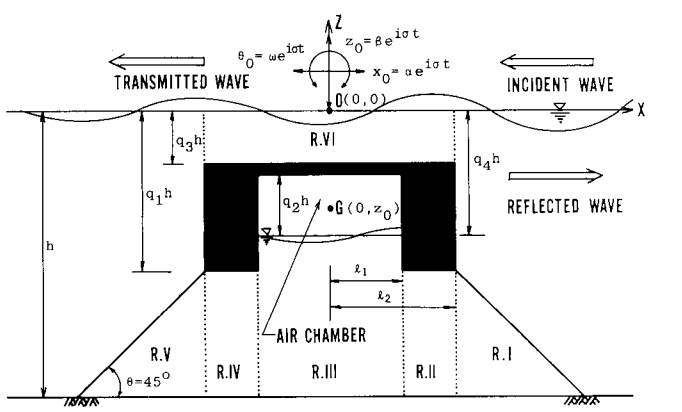

Fig. 1 Definition sketch

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