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Roll Motion of Ro-Ro Passenger Ship with Flooded Vehicle Deck

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This paper tries to confirm the effectiveness of an estimation method of roll motion on a Ro-Ro passenger ship with a flooded vehicle deck. A time domain simulation of roll motion expressed by the 2-dimensional lump mass concept was applied to the Ro-Ro passenger ship with no water ingress, but with a flooded vehicle deck. Measurements of the motion of the ship with different amounts of water on deck were carried out in regular beam waves in order to compare with calculated results. The trend of the calculated results on roll amplitude generally represents the experimental results.

INTRODUCTION

After the disaster of the Ro-Ro passenger ship *Estonia* in the Baltic Sea in 1994, the safety of damaged Ro-Ro passenger ships has been discussed at the International Maritime Organization (IMO). Because Ro-Ro passenger ships have large, flat vehicle decks with no watertight bulkheads, large amounts of water can enter the decks through damage holes causing the ship to lose stability. To prevent such kinds of disasters, it is necessary to assess the static and dynamic effect of the water on deck for ensuring the stability of such kinds of ships.

Many experimental investigations of the Ro-Ro passenger ships with a hole from damage and a flooded deck have been conducted (Ishida et al., 1996; Hamano et al., 1997; Haraguchi et al., 1998; Vassalos et al., 2000; and others). It is, however, difficult to capture all dangerous conditions of a flooded ship deck using limited sample ships and experimental conditions. Although calculation methods on ship motion have been presented to predict the capsize of the ships (Dillingham et al., 1986; Zaraphonitis et al., 1997; Hasegawa et al., 2000; Papanikolaou et al., 2000), there are many uncertain points of applicability and detail.

To exactly estimate ship motion with a deck flooded with water entered from damaged holes, it is necessary to deal with 2 subjects: (1) to estimate the amount of water coming from damaged holes, and (2) to estimate ship motion with flooded vehicle decks, which means to calculate the dynamic influence of the water on deck. In past investigations, both subjects were treated at the same time. To be clear about the problems of the estimation method of the Ro-Ro passenger ships with flooded decks, each subject must be treated separately.

In this paper, the calculation method of roll motion for the sample Ro-Ro passenger ship with the flooded vehicle deck is presented from the viewpoint of subject (2). The 2-dimensional lump mass concept for the flooded deck used by Ishida et al. (1996) and Murashige et al. (1997, 1998) that is applied to the flooded box is used for the Ro-Ro passenger ship in the calculation. The calculated results are compared with the experimental ones. The trend of the calculated results on the roll amplitude sufficiently represents the experimental results.

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KEY WORDS: Ro-Ro passenger ship, *Estonia*, estimation method, roll motion, flooded vehicle deck, model experiment, damage stability.

MATHEMATICAL MODEL OF ROLL MOTION ON RO-RO SHIP WITH FLOODED DECK

The Ro-Ro passenger ship is assumed to have a large, flat vehicle deck flooded with water and no forward speed in beam waves. In this case, it is assumed that the ship rolling and water moving effects are main components of ship motion. The equation of 2 degrees of freedom for ship rolling and water moving is used in the calculation, neglecting the effect of sway and heave motion.

Fig. 1 defines the coordinate system of the ship and water. The ship breadth, draft and height of the free-board are denoted by B, d_s, f_r. When the ship is upright, the water of width b_w and depth d_w is on the vehicle deck. Each position of the center of gravity, buoyancy of the ship and the water is respectively designated G_s, G_w and B_s. Using the suffixes G_w the horizontal and vertical position x_{G_W}, y_{G_W} of the gravity center of the water is defined from the origin, that is, the G_w position when the ship is upright, while the roll angle of the ship and the water surface slope are defined as ϕ and χ. The vehicle deck is one compartment without partitions such as a central casing, and the center of gravity of the water G_w transfers 2-dimensionally in the midship section on the vehicle deck, not moving with respect to the longitudinal direction of the ship.

The kinetic energy K, potential energy P and dissipation energy D of the ship and water can be expressed with ϕ and χ in the

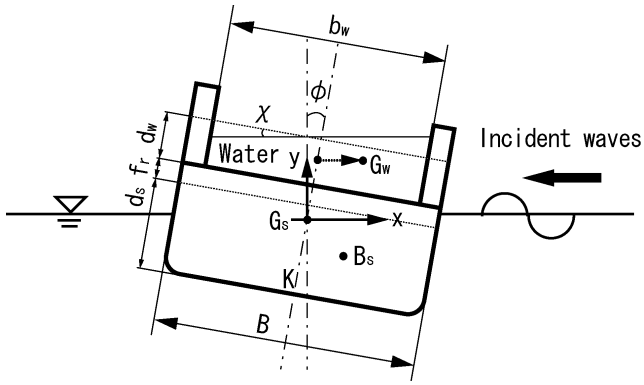

Fig. 1 Coordinate system on Ro-Ro passenger ship with flooded deck