Experimental and Numerical Studies on Roll Motion of a Damaged Large Passenger Ship in Intermediate Stages of Flooding

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ABSTRACT

Measurements of roll motion of a two-dimensional scale model of a damaged large passenger ship are carried out during flooding process. The experimental results demonstrate that large and slow roll motion sometimes appears in the intermediate stages of flooding. The appearance of the large roll motion significantly depends on location and size of damage opening. It is also confirmed that the simulated results are in fairly good agreement with experimental ones.

Keywords

large passenger ship, damage stability, roll motion, flooding simulation, intermediate stages of flooding

INTRODUCTION

In the previous paper, the authors pointed out on the basis of model tests that large and slow roll motion can appear in the intermediate stages of flooding for a damaged large passenger ship and the maximum roll angle depends on size and location of a damage opening (Ikeda 2003). The large roll is caused by shallow water accumulation on each deck of multiple decks in damaged compartments.

In the present study, measurements of ship motions from start of flooding to final condition after flooding are carried out for a two dimensional model. The model is modeled the mid-ship parallel body of the ship designed for studies on large passenger ship safety by US coast guard, MARIN and Fincanteri. Numerical simulations are also carried out to validate the accuracy of the calculation method.

The experimental results demonstrate that large and slow roll motion some times appears in the intermediate stages of flooding and a part of the bulkhead deck sink. In some cases the model used in the study can be capsized in the intermediate stages of flooding, even although she is safe in the final condition.

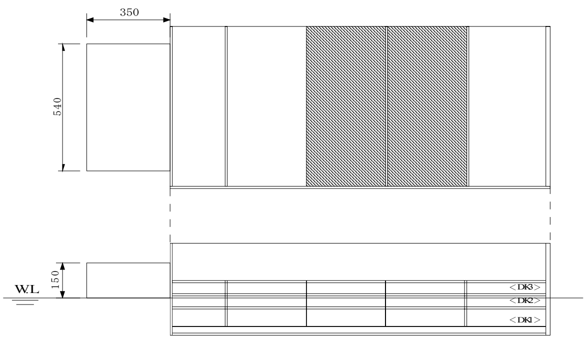


Fig. 1 Schematic view of 2-D model..

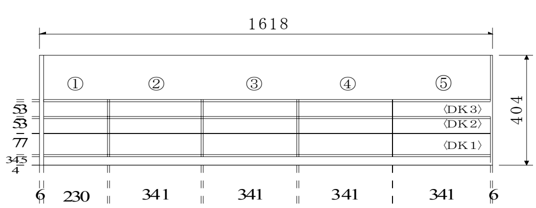
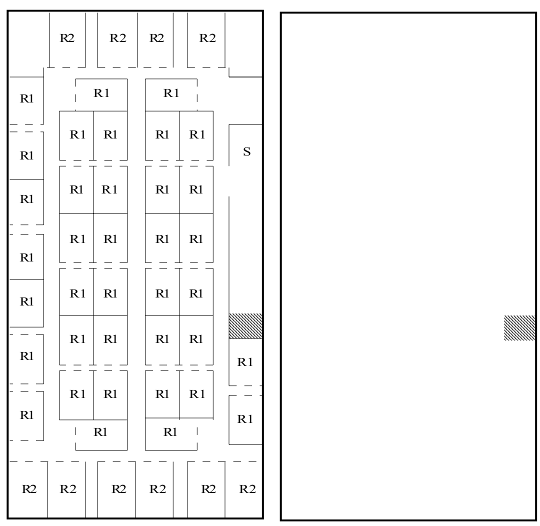


Fig. 2 Deck position and size



R1 : 66mm × 43mm R2 : 77mm × 48mm

S : 300mm × 43mm shaded : 32mm × 43mm

(a) Crew cabin (b) Void space

Fig. 3 Crew cabin and void space

MODEL

The model used in the experiment is a two-dimensional model of the parallel part of the mid-ship body of an un-building large passenger ship of 110,000GT designed by Fincanteri. The length, beam, draft and displacement of the model are 1.1618m, 0.728m, 0.168m and 194kg, respectively. The scale is 1/50. The model have a float to adjust the trim in flooded condition to that of the three dimensional ship. The model with a float is shown in Fig.1

The GM value is adjusted to the corresponding one of the original three-dimensional large passenger ship. The model has a watertight super-structure in above the bulkhead deck. In each compartment there are three decks as shown in Fig.2, which are used for crew accommodations or void space. Arrangements for crew cabins and void space on the decks are shown in Fig.3. All crew cabins are made with and without cabin doors, which are not watertight.

A damage opening, whose size is 210mm length and 20mm or 60mm heights, is located on the side-hull below the bulkhead deck. The size and location of the opening is systematically changed in the experiments.

BEHAVIOR OF THE SHIP

In calm water, the opening located on the side hull of the model is released, and the behavior of the model (roll and heave motions) is measured until end of flooding.

An example of time histories of measured roll of the model for two-compartment-damage is shown in Fig. 4. The result shows that the model rolls gradually, reaches a maximum angle, and returns to upright condition. In most cases with large roll motion in the intermediate stages of flooding, the maximum roll angles are around 17 degree. When a damage opening is located in lower position or large, such large roll motion does not appear.

The results of all experimental cases are tabulated in Table 1. The results demonstrate that large roll motion in the intermediate stages of flooding does not appear only when height of damage opening is low or middle. The initial heel angle also affects the roll motion, and large roll motion does not appear when the ship inclines to opposite direction (minus initial heel angle in the table) of damaged side.

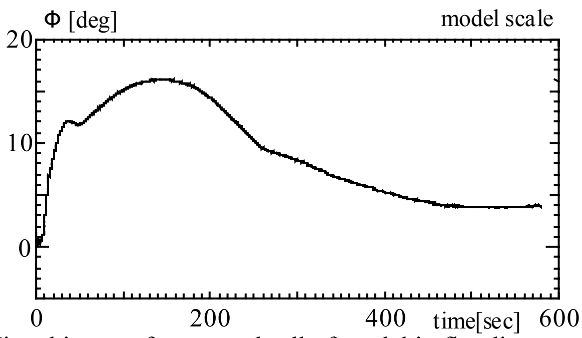


Fig. 4 Time history of measured roll of model in flooding experiments

MAXIMUM ROLL ANGLE

In most cases with large roll angle in the intermediate stages of flooding, the maximum roll angles are around 17 degrees as shown in Fig. 5. Fig. 6 shows the comparison between the calculated roll angle by static calculation and measured maximum roll angle. It should be noted that in the calculation the super-structure above the bulkhead deck is assumed to be intact. The results demonstrate that the angle of 17 degrees almost coincides with the calculated one, which is up to about 20 degrees as shown by the solid line in Fig. 6 at the worst case of accumulation of water on each deck of three decks in the compartments. This means that shallow water accumulated on each deck create the almost largest roll moment, respectively.

The time to the maximum roll angle from rest is shown in Fig.7. The results show that the roll motion reaches the maximum angle in 100-150seconds in model scale, or 13-18 minutes in full scale. The results also show that the time to maximum roll angle decreases with increasing size of damage opening.

Table 1 Experimental conditions and appearance of large roll in the intermediate stages of flooding

case	the opening size/ height	internal subdivision on DK2	initial heel	large roll motion	maximum roll angle [deg]	time to maximum roll angle [sec.]
1	small/ low	c.c.(without doors) – v	0 deg.	×	—	—
2	small/ middle	c.c.(without doors) – v	0 deg.	×	—	—
3	small/ middle	v – c.c.(without doors)	0 deg.	×	—	—
4	small/ middle	v – v	0 deg.	×	—	—
5	small/ high	c.c.(without doors) – v	0 deg.	×	—	—
6	small/ high	c.c.(with doors) – v	0 deg.	○	15.5, 16.2, 16.9	130.4, 150.8,146.5
7	large/ high	c.c.(with doors) – v	0 deg.	○	16.5	126.9
8	large/ high	c.c.(with doors) – v	2 deg.	○	17.5	108.0
9	large/ high	c.c.(with doors) – v	-2 deg.	×	—	—
10	large/ high	v – v	0 deg.	×	—	—
11	large/ high	v – v	2 deg.	○	17.1, 16.9	35.6, 23.2
12	large/ high	v – v	-2 deg.	×	—	—
13	very large	c.c.(with doors) – v	0 deg.	×	—	—

Opening size : small : 210mm × 20mm large : 210mm × 60mm very large : 210mm × 105mm
location : low : 100mm middle : 158mm high(small) : 172.5mm high(large) : 162.5mm
very large : 142.5mm (Center of opening from baseline)

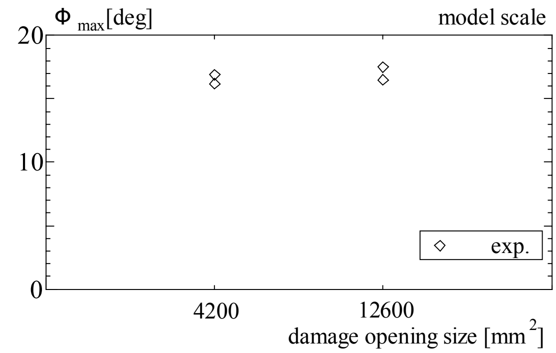


Fig. 5 The maximum roll angle in the intermediate

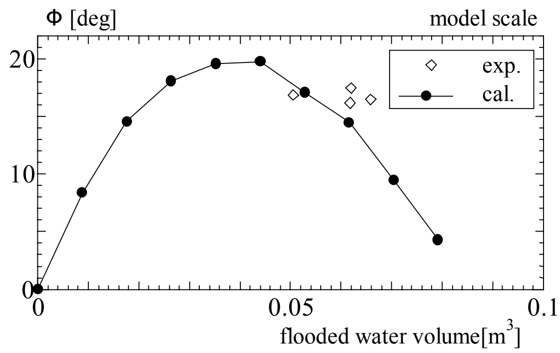


Fig. 6 The comparison between the calculated roll angle by static calculation and measured maximum roll angle

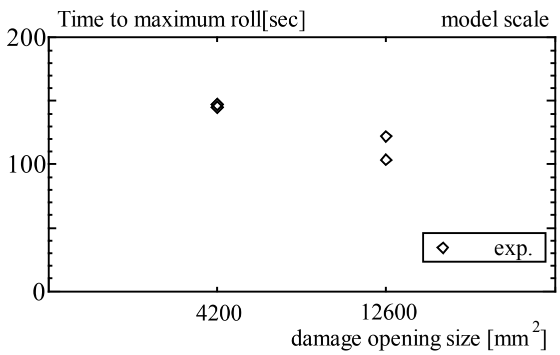


Fig. 7 Time to maximum roll angle in intermediate stages of flooding

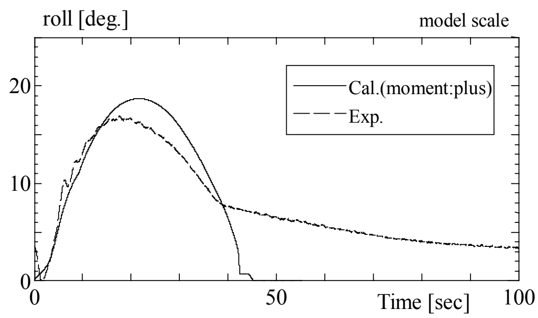


Fig. 8 Simulated and experimental results of roll motion for Case 11.

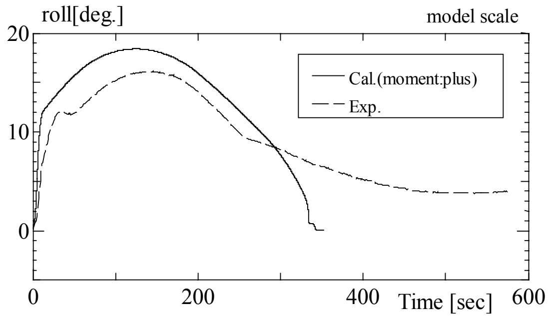


Fig. 9 Simulated and experimental results of roll motion for Case 6.

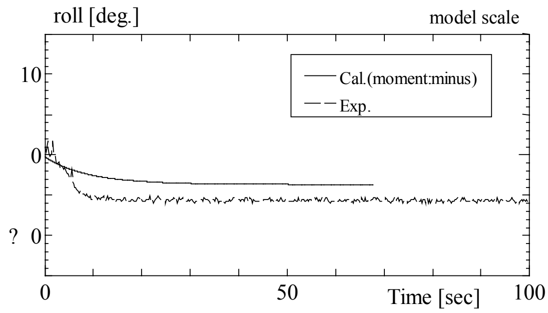


Fig.10 Simulated and experimental results of roll motion for Case 2.

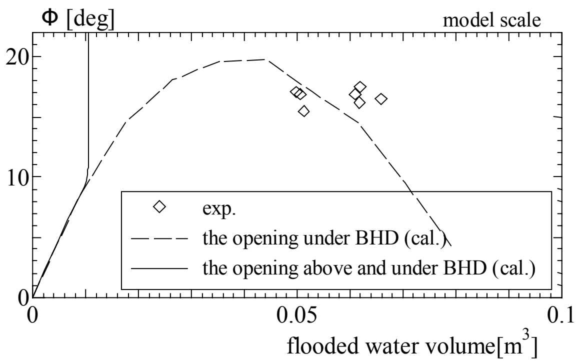


Fig. 11 Calculated roll angles for the opening under BHD and above BHD.

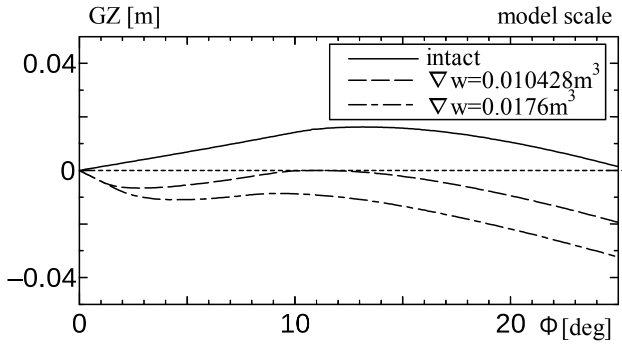


Fig. 12 GZ curve of model for water on each decks

FLOODING SIMULATION

Simulations of flooding into the model are carried out. The simulation program for a PC was developed in National Maritime Safety Agency. Flooding flow velocity through damage openings and holes on a wall to an adjacent compartment or to upper/lower decks is calculated by the Bernoulli equation with a modification factor. In the present simulation, the modification factor is assumed to be 0.8.

Simulated results for Case 11, 6 and 2 are shown in Figs. 8-10 with experimental results. The simulated results are in fairly good agreement with the experimental ones.

CAPSIZING IN THE INTERMEDIATE STAGES

A capsizing was observed for the model for which the damage opening extended to sidewall of the superstructure above the bulkhead deck. In the case, there is no transverse watertight wall to restrain flooded water over the bulkhead deck. Figs. 11 and 12 shows calculated GZ curves and obtained roll angle for various volumes of water on each deck. The results suggest the ship can capsize in the intermediate stages of flooding if damage opening extending to above the unrestrained bulkhead deck.

Since the designed ship has some partial watertight walls on the bulkhead deck, such a capsize could not occur in reality. It should be noted, however, that it may be important to guarantee not to spread flooded water widely on the bulkhead deck.

CONCLUSIONS

Following conclusions are obtained.

1) Large and slow roll motion sometimes occurs for a damaged large passenger ship in the intermediate stages of flooding.
2) The large roll motion appears only when not so large damage opening is located in high.

3) The roll amplitude can be approximately predicted by a static calculation.
4) The simulation method used in the present study can predict the roll angle in the intermediate stages of flooding with enough accuracy.

ACKNOWLEDGEMENT

The present study was carried out in the fiscal years of 2003 and 2004 as a part of the RR-S2 research panel of the Shipbuilding Research Association of Japan funded by the Nippon Foundation, to whom the authors express their gratitude.

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