EXPERIMENTAL STUDIES ON TRANSIENT MOTION AND TIME TO SINK OF A DAMAGED LARGE PASSENGER SHIP

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Abstract

Transient roll motions in the intermediate stages of flooding and time to the final condition due to flooding of a damaged large passenger ship are experimentally investigated. In the experiments, various arrangements in the damaged compartment are simulated, and the effects of arrangements on the transient roll motions in the intermediate stages are examined. The results show that multiple decks and arrangements on the decks in a damaged compartment play important roles in the transient roll motions and time to the final condition. Survivable probability of the damaged large passenger ship used in the present study is confirmed to be completely different from the assessed ones at the final condition in static assumption.

1. INTRODUCTION

Many large passenger ships carrying large number of passengers and crews onboard are widely operated for cruising. IMO started a task on LARGE PASSENGER SHIP SAFETY in 2001, and the SLF sub-committee decided to study the time to sink for all damage cases that are not survival. One of the characteristics of a large passenger ship is multiple decks and complicated arrangements on these decks in a compartment, like crew cabins, various workshops, machines, tanks and so on. When flooding occurs at such compartments, flooded water moves in complex manner and may affect on the safety of the ship.

For a pure car carrier (PCC), that has multiple decks in compartments too, the authors experimentally investigated the flooding process and pointed out the importance of transient roll motion in the intermediate stages of flooding [1] [2].

Riaan van't Veer et al. [3] simulated the transient motion of a Large Passenger Ship during flooding, and obtained the time to sink. Time to sink, or time to flood is also important for safe evacuation from a damaged ship. D.Vassalos et al. [4] [5] and A.Jasionowski et al. [6] studied the survival time of RoRo ship.

In the present study, transient behaviors of a model of a large passenger ship in the intermediate stages of flooding and time to the final condition of flooding are experimentally investigated.

2. MODEL

A large passenger ship with 292m length and 49m width is selected for the study, and a 1/185 scale model is used for experiments. The ship is not a real large passenger ship operating now, and has much wider beam. The principal particulars are shown in Table 1 and the body plan of the model is shown in Fig. 1. The model is made of GRP with thin hull skin, and divided into 13 compartments by 12 transverse bulkheads as shown in Fig.2. In the figure, CC denotes a crew cabin space, EG an engine room, v a void space and FWT a flesh water tank, respectively. In the experiments, flooding into Compartments 5, 6, 7 and 8 are treated. Each compartment under the bulkhead deck consists of three decks as shown in Fig. 3. The horizontal bulkhead deck is assumed to be watertight, and flooding through the bulkhead deck is not assumed. Flooded water in the upper two decks, DK 3 and DK 2 in Fig.3, flows down through only a staircase. In a crew cabin space, many cabins are arranged as shown in Fig.4. Doors of the cabins are not watertight, and water can enter the cabins through slight openings and spreads over the deck gradually. In the void space, there is nothing on the deck except a staircase in the present study. The super structure of the model is built as shown in Fig. 2, and no flooding above the bulkhead deck is assumed.

Table 1 Principal particulars of model and full-scale ship

	Model	Ship
Loa	1.580 m	292.3 m
Lpp	1.500 m	277.3 m
Beam	0.268 m	49.53 m
Depth	0.085 m	15.73 m
Draft	0.062 m	11.47 m
Displacement	13.5 kg	85,477 ton

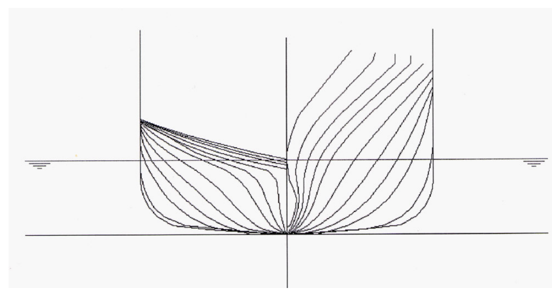


Fig. 1 Body plan of model

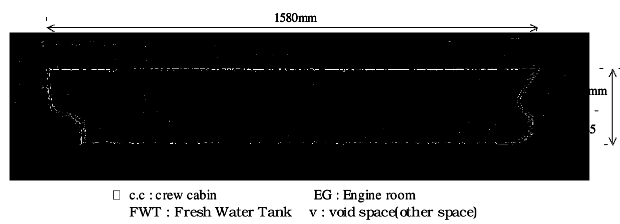


Fig. 2 Compartmentation and Internal deck arrangement of model

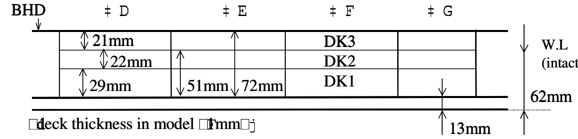


Fig. 3 Details of deck arrangement in compartments under the bulkhead deck

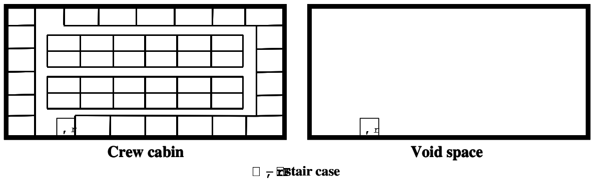


Fig. 4 Crew cabin (CC) and void space (V)

3. DAMAGE OPENINGS

In the experiments, flooding cases to one, two, three and four compartments are examined. The size, shape and location of the openings are changed as shown in Fig.5. The openings for three and four compartments are much longer raking damage than the maximum length defined in SOLAS.

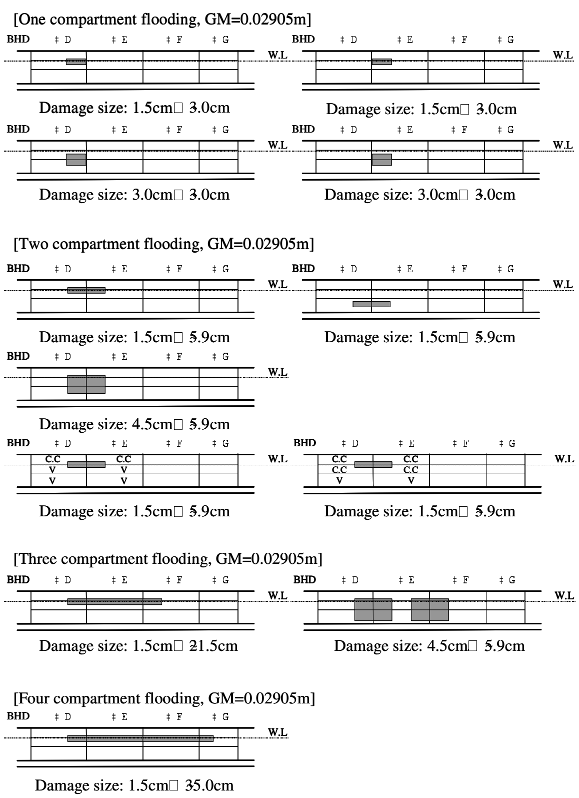


Fig. 5 Size, shape and location of damage openings in experiments

4. MEASUREMENTS

The model in intact condition floats in calm water, and the damage opening on the side hull is released by hand. Disturbances on attitude of the model which are given at releasing moment by hands are carefully minimized. Roll and heave motions are measured by potentio-meters during flooding duration (from start to finish of flooding).

5. EXPERIMENTAL RESULTS

5.1 One Compartment Flooding

Measurements for one compartment flooding are carried out for Compartments 5 and 6. In Compartment 5, only the upper deck is a crew cabin space and lower two decks are void spaces. In Compartment 6, however, upper two decks are crew cabin spaces, and the lowest deck is a void space. Two different damage openings are selected for the experiments. Measured heave and roll motions are shown in Fig. 6 (a)-(d). In the intermediate stages of flooding, the ship slightly heels to the damaged side, and then reaches upright condition in most cases. The maximum heel angles during the stages are 3-5 degrees. The experimental results show that it takes 400-700 seconds in full scale to reach fully flooded condition.

5.2 Two Compartment Flooding

For cases of two component flooding, the damage openings with the same length as the maximum one defined in SOLAS but different areas are located at the bulkhead between

Compartments 5 and 6. The measured behaviors of the model are shown in Fig. 7 (a)-(c). It should be noted that large roll motion to the damaged side appears as shown in Fig. 7 (a). The results for the same damage opening located in deeper location shown in Fig. 7 (b), however, roll motion in the intermediate stages is not large. These results suggest that the damage openings at shallow water depth cause larger roll motion in the stages. Fig. 7 (c) shows the result for a very large damage opening. Since water rushes into the three decks in the compartment simultaneously, the model sinks and heels rapidly. The maximum roll angle, however, is smaller than that for a smaller opening located at shallow water depth shown in Fig. 7 (a). It should be noted the time to fully flooding condition of the large opening is longer than those for smaller openings though the behavior of ship motion in first stage of intermediate stages of flooding is very quick. In Fig. 8, experimental results for different arrangements on the decks in the flooded compartment are shown. It is found that motions in the intermediate stages of flooding significantly depends on the arrangements on flooded decks.

5.3 Three Compartments Flooding

As three compartment flooding cases, a long raking damage opening and a huge damage opening are selected. The length of the damage openings is 40m in full scale. The measured results are shown in Figs. 9 (a)-(c) and 10 (a)-(c). GM values in intact condition are also changed in the experiments.

The results in Fig. 9 (a) show that roll motion in the intermediate stages for three compartments flooding is smaller than that for two compartments flooding, but continues longer comparing with two compartment flooding cases shown in Fig. 8 (a). As decreasing GM value, the maximum roll angle increases.

The results for a huge damage opening shown in Fig. 10 show completely different tendencies from the results for the raking damage cases described above. The model heels to undamaged side at first, then heels to damaged side or reaches upright condition immediately. The results may suggest that for such a large damage cases the behavior of the ship in the intermediate stages of flooding is not serious and does not affect on the final condition of flooding. This may be because that large roll motion in the intermediate stages for a LPS is caused by shallow accumulation of water on multiple decks but such shallow accumulation of water does not occur for a huge damage opening.

5.4 Four Compartments Flooding

Longer raking damage is assumed for the case of four compartments flooding. In the experiments, the length of the damage opening is 65m in full scale, and located on the third deck. GM values in intact condition are changed as the same manner as those for three compartments flooding in previous section.

The measured results shown in Fig. 11 demonstrate that behavior of the ship is different from that for three compartments flooding shown in Fig. 9. At the beginning, flooding rapidly progresses and the maximum heel angle reaches about 24 degrees as shown in the time history of the measured heel angles. This large heel appears in a moment, and returns to slow roll motion, which is similar to that for three components flooding shown in Fig. 9. The experiments show that it takes only 140-180 seconds to reach the first large heel, but takes more than 8000 seconds to final condition of flooding in full scale.

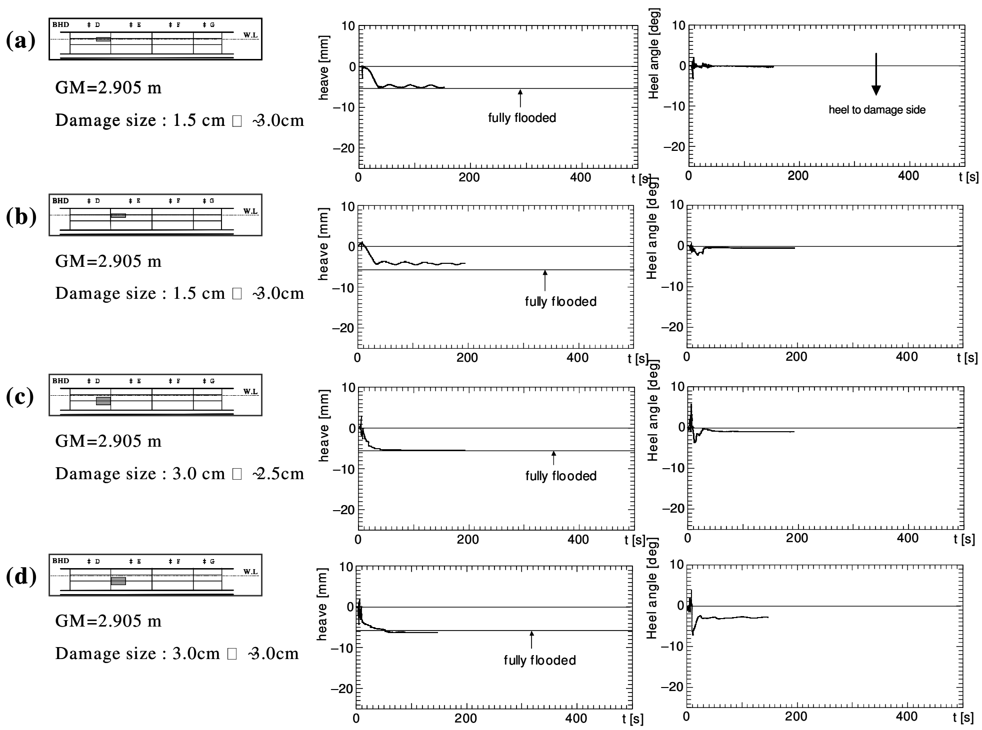


Fig. 6 Time histories of ship motion for one compartment flooding

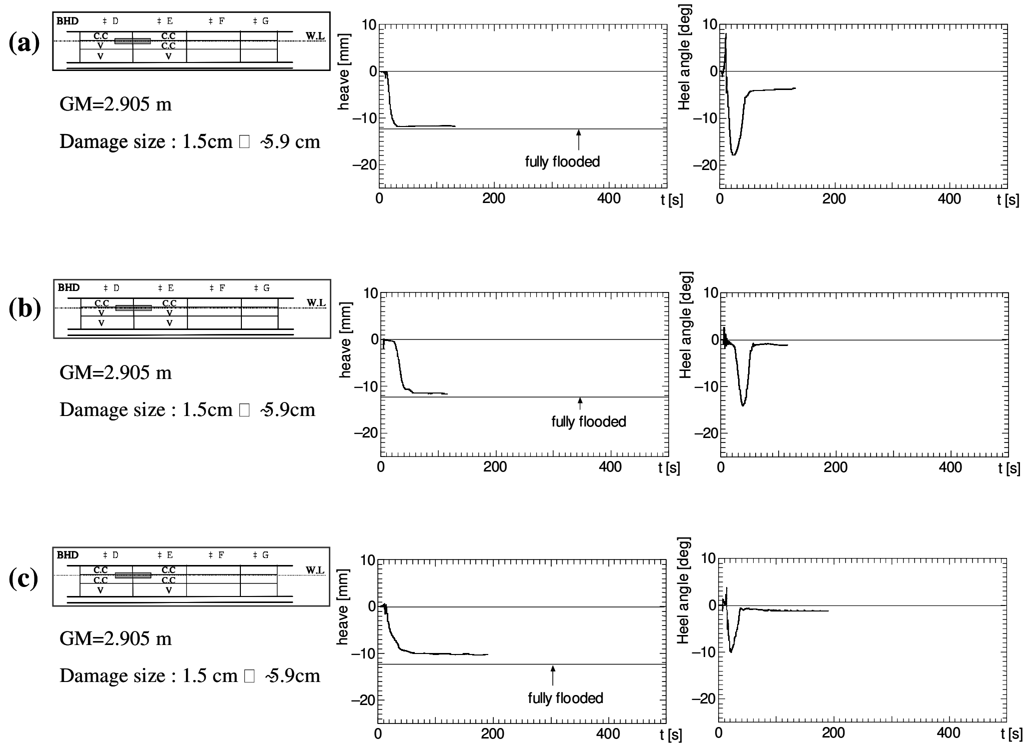


Fig. 7 Time histories of ship motion for two compartment flooding

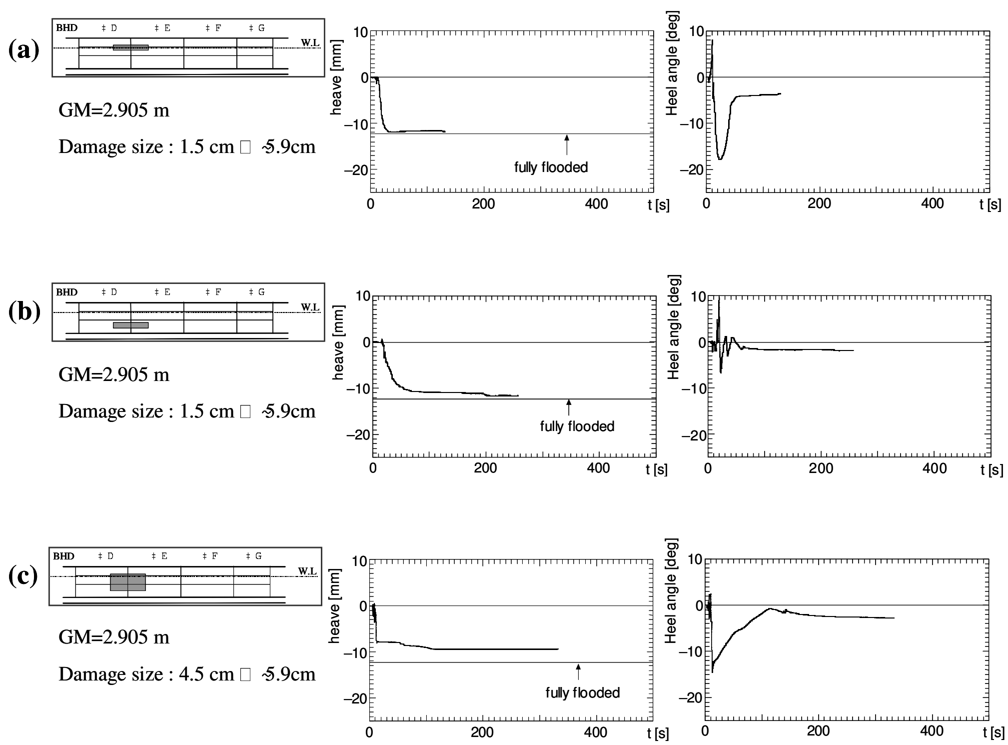


Fig. 8 Time histories of ship motion for different arrangements on decks

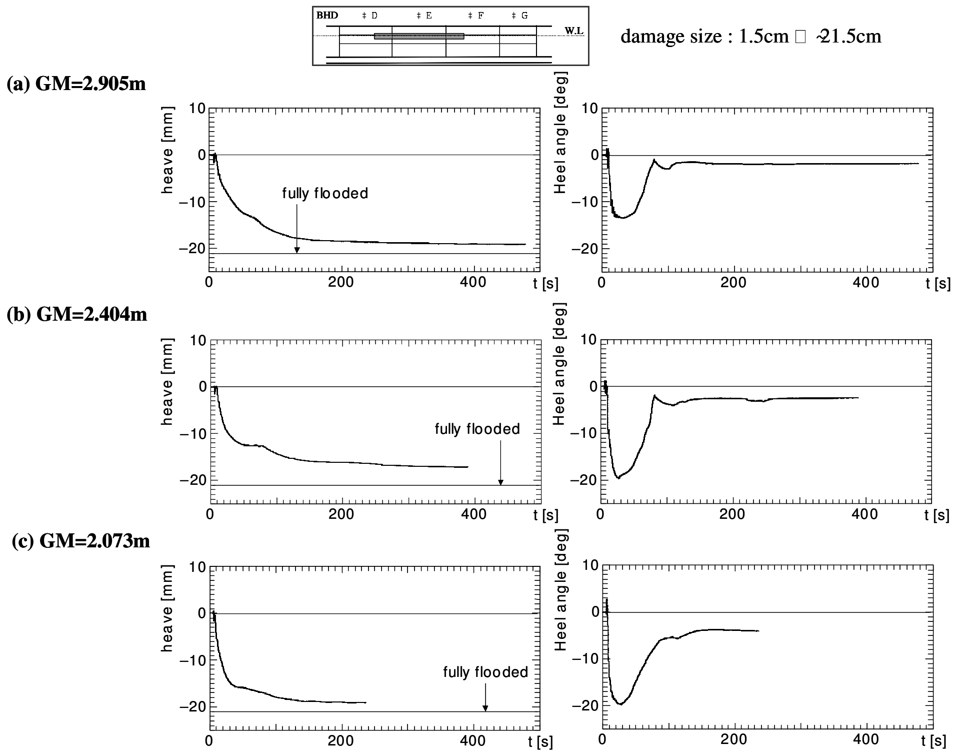


Fig. 9 Time histories of ship motion for three compartment flooding.

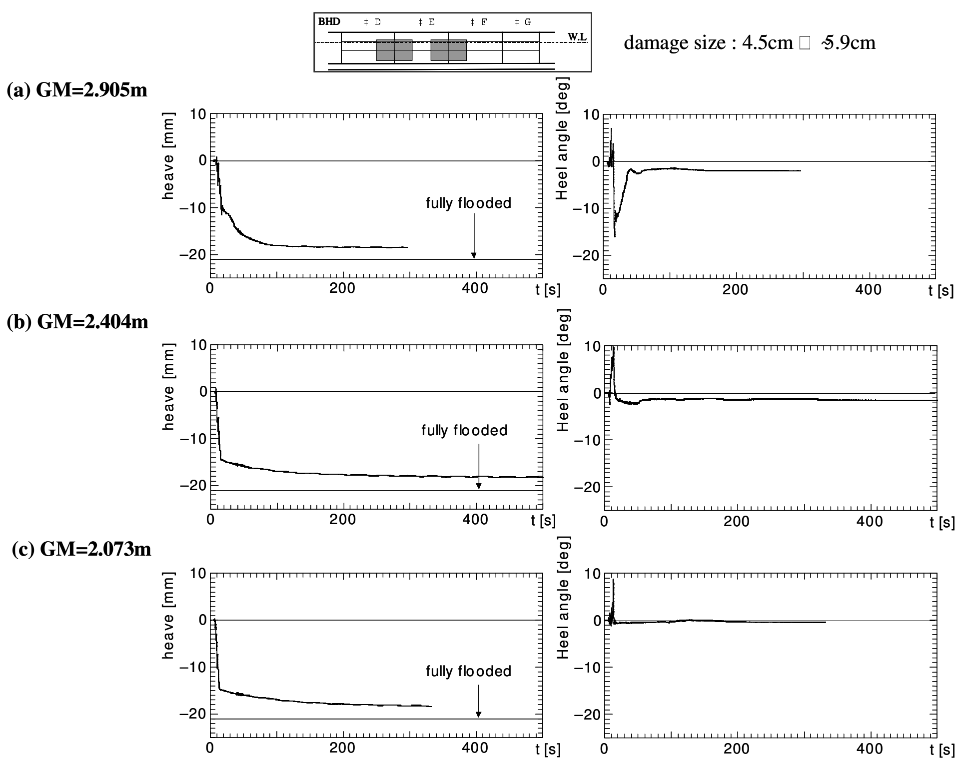


Fig. 10 Time histories of ship motion for three compartment flooding

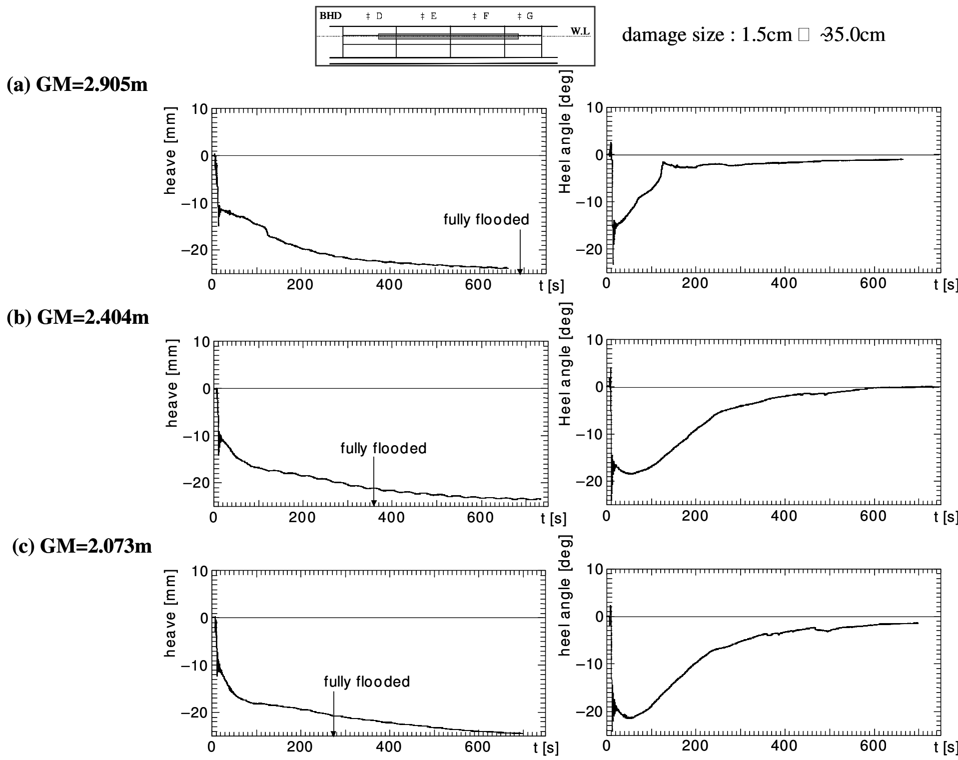
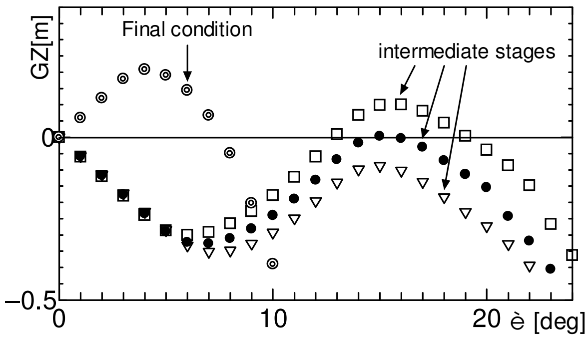


Fig. 11 Time histories of ship motion for four compartment flooding

6. GZ CURVES IN FINAL AND INTERMEDIATE CONDITIONS

The GZ curve is calculated for the final condition and the intermediate stages. For the intermediate stages, stability calculations are done on the assumption that various amount of water exist on the middle deck, Deck 2 in Fig3.

The calculated results are shown in Fig.12. For the final condition, the GZ curve is positive up to 7 degrees. This means that the ship can float in upright condition in the final stage of flooding. For 1000cm^3 of deck water volume in model scale, the ship heels at 13 degree, and from 13 to 19 degrees of heel angles the GZ value is positive. For 1125 cm^3 and 1250cm^3 of deck water volume, however, the GZ is negative in whole roll angle. These results suggest that water on the middle deck can cause capsizing of the ship during the intermediate stages of flooding although the ship is stable in the final condition after flooding.



*assumption of water on Deck2 in intermediate stages

	water value in model scale	water depth in full scall
◎	4830cm^3	
□	1000cm^3	1.80m
●	1125cm^3	2.03m
▽	1250cm^3	2.25m

Fig. 12 Calculated GZ curves for water on middle deck at final condition and in the intermediate stages of flooding

7. CONCLUSIONS

Flooding experiments for a model of a large passenger ship in calm water are carried out, and following conclusions are deduced.

1) Large and slow roll motion can appear in the intermediate stages of flooding for a damaged large passenger ship.
2) The maximum heel angle in the intermediate stages of flooding depends on size and location (mainly depth from water surface) of a damage opening. Raking damage located at shallow water depth may cause larger heel angle in the intermediate stages of flooding. Longer damages do not always cause larger heel angle.
3) Behavior of a LPS in the intermediate stages of flooding significantly depends on arrangements on flooded decks.

8. ACKNOWLEDGEMENTS

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