EFFECTS OF TRANSIENT MOTION IN INTERMEDIATE STAGES OF FLOODING ON THE FINAL CONDITION OF A DAMAGED PCC

Yoshiho IKEDA and **Tomoko KAMO**, Osaka Prefecture University, Gakuen-cho, Sakai, Osaka, 599-8531 Japan, ikeda@marine.osakafu-u.ac.jp

SUMMARY

Flooding experiments of a 5000unit pure car carrier are carried out. The experimental results demonstrate that transient motions in intermediate stages of flooding significantly affect the final condition of a damaged and flooded ship. It is revealed that fully flooded condition on the basis of static consideration seldom appears at the final stage

1. INTRODUCTION

Survivability of a ship damaged and flooded by collision is usually evaluated in the ship conditions in the final stage of flooding where water surfaces in the damaged compartment and outside of the ship coincides each other. The damage stability regulations in SOLAS were also deduced on the basis of such a static concept. However, it has been revealed by one of the authors [1][2] that ship conditions in the final stage of flooding do not always coincide to those calculated on the basis of a static assumption. For example, even for flooding into a symmetrical compartment, the final condition is not always in upright. Sometimes such a damaged ship heels in the final stage since the damage opening goes up above water surface and flooding stops in intermediate stages. These facts suggest that the effects of transient motion in intermediate stages of flooding on the final condition should be carefully taken into account for a damaged and flooded ship.

In the present study the effects of transient behaviors of a damaged Pure Car Carrier (PCC) in intermediate stages of flooding on the final conditions are experimentally investigated.

2. EXPERIMENTAL SETUP

A 1/120 scale model of a PCC built by a Japanese shipbuilder is used for the experiments. The principal particulars of the model are shown in Table 1. The general arrangement and the mid-ship section of her are shown in Figs.1 and 2. In the experiments the compartment A is assumed to be a damaged one. The model floats in six-degree of freedom in calm water, the damage opening located on the side of the compartment is released, and ship motions, roll, heave and pitch, are measured until the final stage of flooding. Size and location of lower edge of openings are systematically changed as shown in Fig.3 in order to know the effects of them on transient motions and final results. In the compartment A, four car decks without watertight are modeled. On the decks, many small holes of 0.8mm diameter are made to simulate down-flow through these decks.

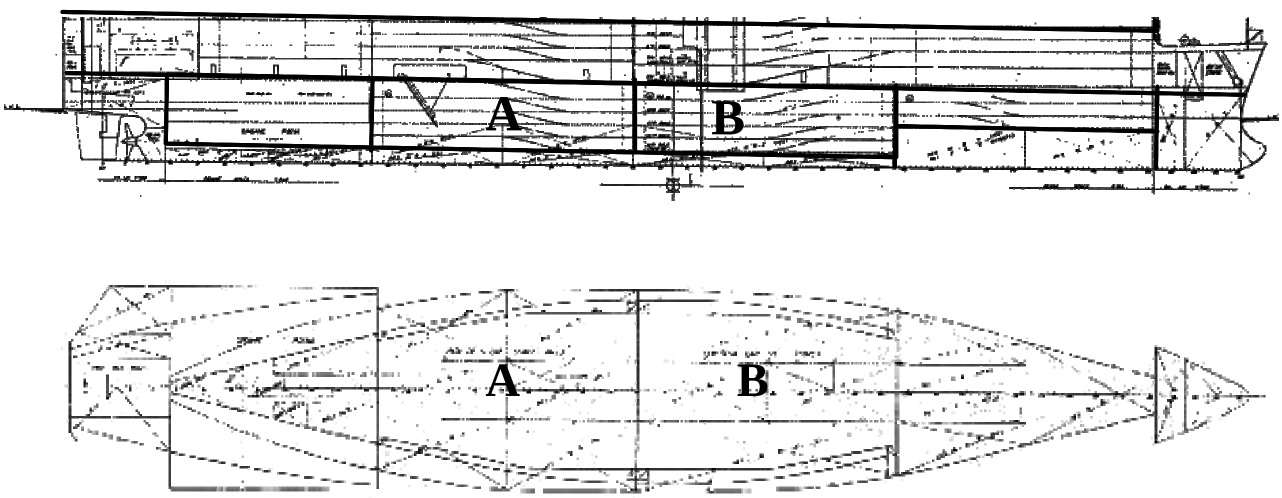


Fig 1. General arrangement of PCC

Table 1 Principal particulars of ship and model

	Ship	Model
Loa	190m	1580mm
Lpp	180m	1500mm
Beam	32.2m	268mm
Depth	13.05m	109mm
Draft	8.925m	74mm
Disp.	29129ton	16.9kg

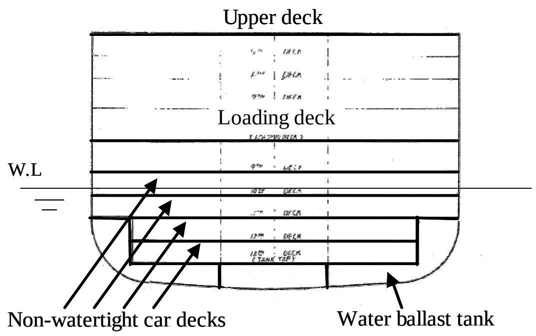


Fig.2 Mid-ship section of PCC

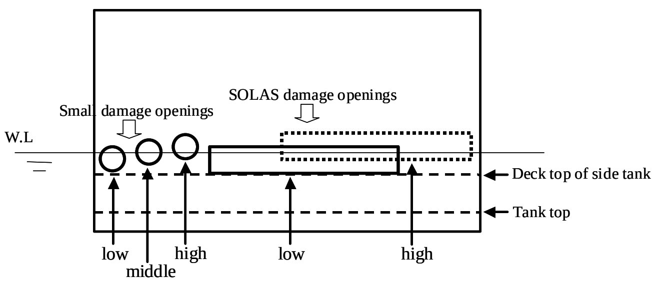


Fig .3 Size and location of damage openings

3. RESULTS AND DISCUSSIONS

The experimental results in the case of a small damage opening are shown in Figs.4 and 5. Flooding in these cases is slow, and the ship motions seem to be almost static. In intermediate stages of flooding, the ship heels to damage side, and gradually recovers to upright position. Flooding continues up to the final condition, where water surface inside and outside coincides each other. This means the damaged compartment is almost fully flooded. It should be noted however that permeability in final stage does not reach 100% but about 70% as shown later in Table 2.

Figs. 6 and 7 show the experimental results in the case of maximum damage length determined in SOLAS. Longitudinal length of the damage opening is 70mm, vertical height of it is 10mm, and the depth the lower edge of the opening from water surface at start of flooding is changed by 2mm and 8mm. As soon as the opening is released, water rushes into the compartment, and the ship heels to the opposite side of the damage opening. Then the opening comes up above water surface, and flooding stops. In the final stage, the ship heels at certain angle, and the amount of flooded water in the damaged compartment is limited. The same conclusion is obtained in the experiments for smaller damage opening of half size of the SOLAS damage opening as shown in Figs. 8 and 9. These experimental results demonstrate that ship motions in intermediate stages of flooding sometimes change the final result.

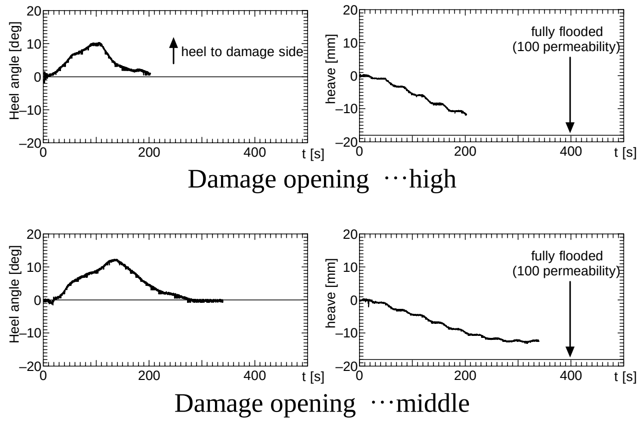


Fig.4 Time histories of ship motions in case of small damage opening with car decks in compartment (GM=23.5mm)

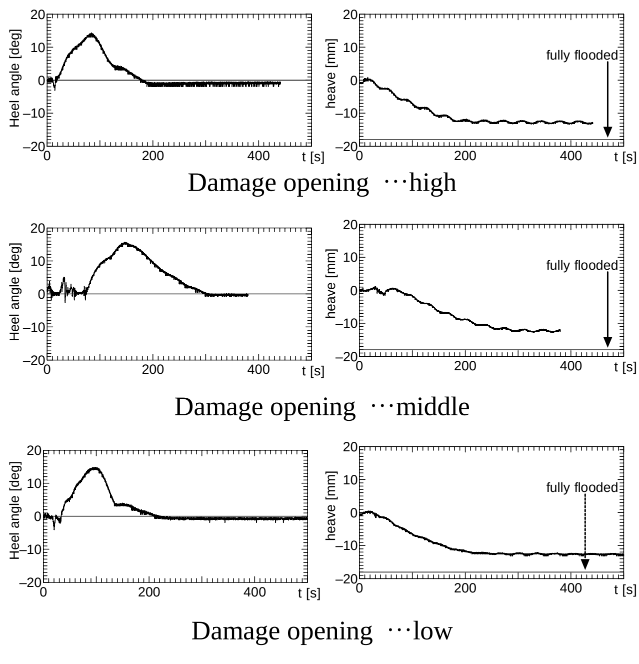
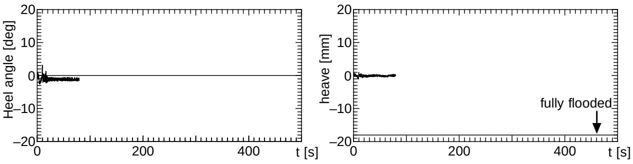
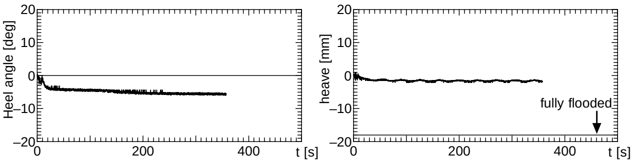


Fig.5 Time histories of ship motions in case of small damage opening with car decks in compartment (GM=14.0mm)

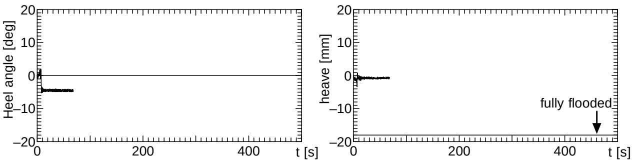


Damage opening …high

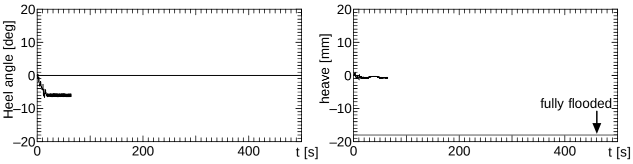


Damage opening …low

Fig.6 Time histories of ship motions in case of SOLAS damage opening with car decks in compartment (GM=23.5mm)

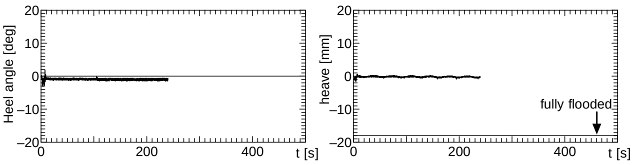


Damage opening …high

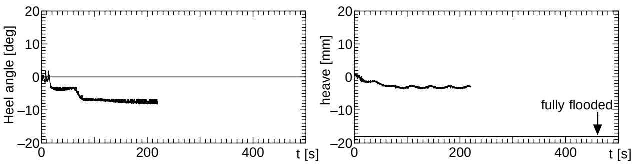


Damage opening …low

Fig.7 Time histories of ship motions in case of SOLAS damage opening with car decks in compartment (GM=14.0mm)

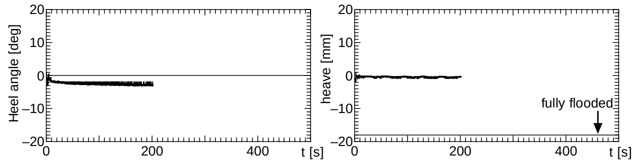


Damage opening …high

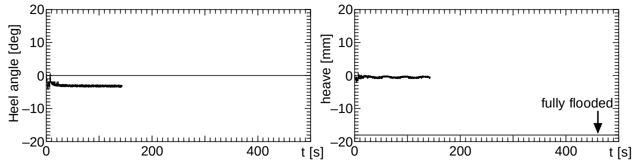


Damage opening …low

Fig.8 Time histories of ship motions in case of half size damage opening of SOLAS's one with car decks in compartment (GM=23.5mm)



Damage opening …high



Damage opening …low

Fig.9 Time histories of ship motions in case of half size damage opening of SOLAS's one with car decks in compartment (GM=14.0mm)

When the ship has initial heel angle to the opposite side of the damage opening, flooding always stops in intermediate stages of flooding. Fig.10 shows the experimental results for 1.5 degree of initial heel to the side. On the contrary, when the ship has opposite initial heel of the same degree, the opening has been kept underwater, and flooding reaches to almost 50～70% of permeability as shown in Fig.11. These results demonstrate that initial heel angle is also a very important factor to determine the final condition of a damaged ship. It seems to be realistic that a struck ship has a heel angle to the opposite side of damaged opening because the head of the forecastle of a striking ship collides with a struck ship first and this makes the struck ship heel to the opposite side as shown in Fig.12.

All the results are tabulated in Table 2. In the table, final heel angle, permeability of the compartment (=volume of flooded water/volume of compartment), final outside water surface location from the horizontal loading deck are shown. It should be noted the permeability is lower than 100% in all cases. This is because some air is trapped in the compartment. When the ship heels at the final stage, air is usually trapped at ceiling of the compartment. When the ship sinks in nearly upright condition, air is trapped in lower car deck spaces even though the decks are non-watertight. In the experiments, the maximum permeability is only about 70% for a SOLAS damage opening and for a small damage opening. In many cases, the loading deck edge in damaged side is located above water surface. This fact suggests that the upper horizontal compartment can work as buoyancy even when the side plate of the upper compartment is broken by collision in such cases.

In order to know the effects of non-watertight car decks in a damaged compartment, some experiments for the compartment B without any non-watertight car decks are carried out. The experimental results are shown in Table 3. The results are completely different from those mentioned before. In most of cases, the final conditions are in nearly upright or slightly heeled conditions. This facts suggest that the deck arrangements in a compartment affects ship motions in intermediate stages of flooding and change the final condition of her.

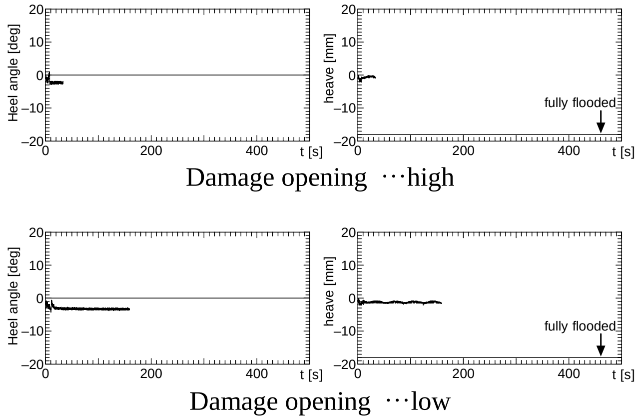


Fig.10 Time histories of ship motions for 1.5 degree of initial heel to the opposite side of damage opening in case of maximum damage opening with car decks in compartment (GM=23.5mm)

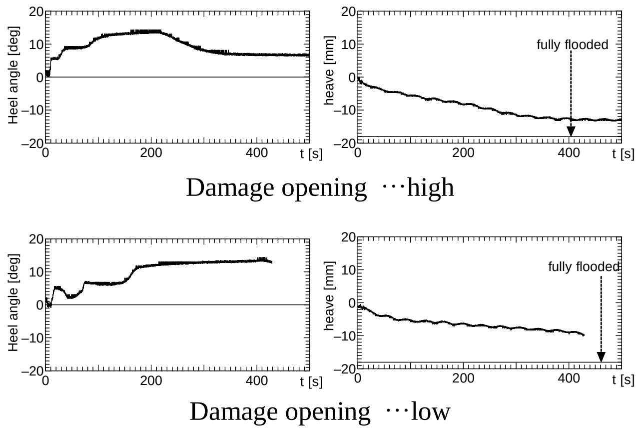


Fig.11 Time histories of ship motions for 1.5 degree of initial heel to the same side of damage opening in case of maximum damage opening with car decks in compartment (GM=23.5mm)

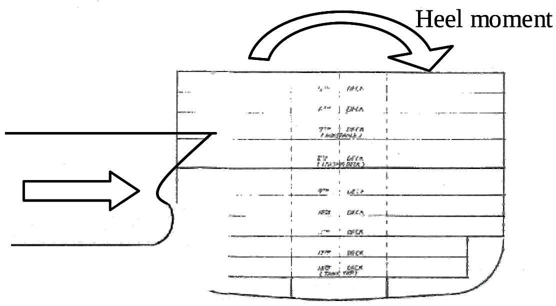


Fig.12 Behavior of a struck ship just after collision

4. CONCLUSIONS

Following conclusions can be deduced from the present experimental study on a damaged PCC.

1) In the case of small damage opening, flooding is almost static, and the final condition is in upright but the permeability is limited to be about 70%. When a ship has small initial heel to the opposite side of a damage opening, flooding stops in intermediate stages, and the final permeability is very small.
2) In the case of SOLAS maximum damage opening and its half size one, flooding stops at intermediate stages of flooding because the damage opening comes up above water surface.
3) Flooding is heavier if there is no non-watertight car decks in a damaged compartment. This fact suggests that such decks in a compartment take an important role to reduce flooding in a damage compartment of a damaged PCC.

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5. REFERENCES

[1] Ikeda Y., Ma Y., ‘ An Experimental Study on Large Roll Motion in Intermediate Stage of Flooding due to Sudden Ingress Water’, Proc. of 7th International Conference on Stability of Ships and Ocean Vehicles, pp.270-285, Tasmania, 2000

[2] Ma Y., Katayama T., Ikeda Y., ‘A Study on Stability of Damaged Ships in Intermediate Stage of Flooding’, Jour. of Kansai Soc. N. A., Japan, No.234, pp.179-186, 2000 (in Japanese)

Table 2 All results of experiments with car decks in compartment

		opening size	small			half of SOLAS(medium)			SOLAS(large)		
GM	initial heel	opening height	heel	P	FWL	heel	P	FWL	heel	P	FWL
2.82m	-1.5 deg	high	-2.0 deg	6.7%	28.1mm				-2.0 deg	2.8%	28.8mm
		middle	-4.0 deg	8.3%	23.1mm						
		low	-5.0 deg	5.6%	21.2mm				-3.5 deg	8.3%	24.3mm
	0 deg	high	0 deg	69.4%	21.5mm	-1.0 deg	2.8%	31.2mm	-1.0 deg	0.6%	31.6mm
		middle	0 deg	69.4%	21.5mm						
		low				-8.0 deg	16.7%	12.2mm	-5.5 deg	8.3%	19.6mm
	1.5 deg	high							6.5 deg	69.4%	6.2mm
		middle									
		low							13.0 deg	50.0%	-5.9mm
1.68m	-1.5 deg	high	1.0 deg	69.4%	19.2mm						
		middle	-4.0 deg	8.3%	23.1mm						
		low	-5.0 deg	5.6%	21.3mm						
	0 deg	high	1.0 deg	69.4%	19.2mm	-3.0 deg	2.8%	26.5mm	-4.5 deg	5.6%	22.5mm
		middle	0 deg	69.4%	21.5mm						
		low	0 deg	69.4%	21.5mm	-3.0 deg	2.8%	26.mm	-6.0 deg	2.8%	19.4mm
	1.5 deg	high							-3.0 deg	18.8%	25.5mm
		middle									
		low							-5.0 deg	11.1%	20.3mm

・・・Damage opening is below water surface at final stage
・・・Damage opening is above water surface at final stage
P ・・・permeability
FWL・・・final water line from horizontal loading deck
(+; Water line is below the deck)

Table 3 All results of experiments without car decks in compartment

		opening size	small			half of SOLAS(medium)			SOLAS(large)		
GM	initial heel	opening height	heel	P	FWL	heel	P	FWL	heel	P	FWL
2.82m	-1.5 deg	high							-2.0 deg	10.0%	27.8mm
		middle	-4.0 deg	85.0%	7.12mm						
		low	-4.0 deg	85.0%	7.12mm				-4.5 deg	85.0%	6.5mm
	0 deg	high	3.5 deg	85.0%	8.8mm				-1.0 deg	5.0%	29.7mm
		middle	3.5 deg	85.0%	8.8mm						
		low	3.5 deg	85.0%	8.8mm				-2.0 deg	85.0%	12.3mm
	1.5 deg	high									
		middle									
		low									
1.68m	-1.5 deg	high							-4.5 deg	10.0%	21.5mm
		middle	5.5 deg	85.0%	4.1mm						
		low	5.5 deg	85.0%	4.1mm						
	0 deg	high	6.0 deg	80.0%	3.9mm				5.5 deg	85.0%	3.6mm
		middle	6.0 deg	80.0%	3.9mm						
		low	7.0 deg	80.0%	1.5mm				-7.0 deg	50.0%	7.5mm
	1.5 deg	high									
		middle									
		low									

・・・Damage opening is below water surface at final stage
・・・Damage opening is above water surface at final stage
P ・・・permeability
FWL・・・final water line from horizontal loading deck
(+; Water line is below the deck)