Model experiment of accumulating water in compartments of a damaged ship

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ABSTRACT

Water volume flooding into damaged compartments can be modeled by a simple mathematical model proposed by Vassalos. This model is validated by model experiments. In the model, the flooding coefficient is very important. In this paper, the coefficient is estimated in several damage scenarios.
Key ward: Ship, Capsize, Damaged compartment, Water on deck, Flooding coefficient.

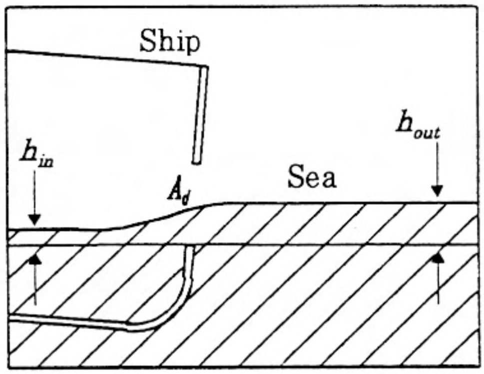
1.INTRODUCTION

It is well known that many people were killed by the capsize of Ro/Ro vessel ESTONIA at the Baltic Sea in 1994. The incident and the following measures including revision of SOLAS Convention are well summarized by Vassalos[1] and Watanabe[2]. Ro/Ro vessel has different characteristics with the other type ships. It is large undivided space on deck. The space is used for car carrying. Cars can move the space easily. However, when water enters on the deck of the ship, water on deck affects the behavior of ship seriously. It will make dangerous situation for stability of the ship. In this case, it is necessary to consider the water on deck dynamically, not statically. Consideration of the volume and the behavior of water on deck are important to determine the damaged ship's behavior. Vassalos *et al.*[3] have proposed a simple model to estimate water on deck and several researches[4] [5] were done also in Japan concerning to water on deck.

The purpose of this study is to estimate the water volume on deck for a damaged ship by the model experiments. If the water volume on deck is well modeled, it will be useful for the prediction of the ship motion by numerical simulation (*e.g.* [6]).

2.MODELING THE WATER INGRESS

Flooding into a damaged compartment is a complex phenomenon. There are still various difficulties to approach this problem theoretically. One of the ways to solve this phenomenon is CFD technique. However, the CFD technique is not yet completed to solve this sophisticated phenomenon. Vassalos *et al.*[3] has proposed a simplified method for this phenomenon.



h_{in} is water level inside the compartment.
h_{out} is water level outside the compartment.
A_d is area of opening.

Fig. 1 Water Ingress/Egress Main Parameters

According to this method, water ingress/egress depends on the water level inside and outside of the damaged compartment. The velocity is described by flowing equation, using the Bernoulli's equation, where the water velocity far from the ship is assumed as zero.

$$h_{out} + \frac{P_{air}}{\rho g} + 0 = h_{in} + \frac{P_{air}}{\rho g} + \frac{v^2}{2g} \tag{1}$$

$$\begin{aligned} h_{out} > h_{in} &: v = \sqrt{2g(h_{out} - h_{in})} \\ h_{in} > h_{out} &: v = -\sqrt{2g(h_{in} - h_{out})} \end{aligned} \tag{2}$$

The volume of flooding water can be estimated by calculating surface integral of the velocity of water at the opening area.

$$Mw(t) = K \int_{Damage} \mathrm{sign}(h_{out} - h_{in}) \sqrt{2g|h_{out} - h_{in}|} \mathrm{d}A \tag{3}$$

This model is simple and easy to use. In this model, all the difficult problems that influence the phenomena such as configuration of opening area, wave condition, etc. are concentrated into the flooding coefficient *K*.

3.EXPERIMENTAL APPARATUS AND CONDITION

The experiment was carried out in the towing tank (100×8×4m) of Osaka University[7] [8]. In this experiment, a 1/80 scale model of general Ro/Ro ship of North Europe and a box type model were used. This ship is more blunt than those operating in Japan. The model is set so as the opening is perpendicularly to wave crest by wire as shown in Fig. 2.

The body plan of this ship is shown in Fig. 3. Principle particulars of the ship and models are shown in Table 1. In the model, opening part can be set freely on its size, style and location on that model.

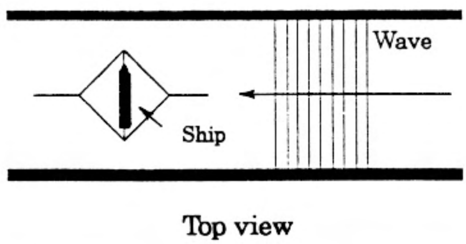


Fig. 2 Experiment setting

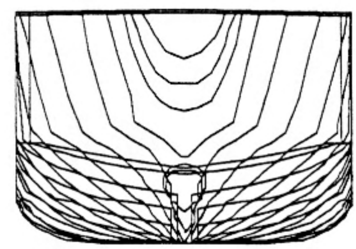


Fig. 3 Body Plan

Table 1 Principle particulars Scale of ship model 1/80

ITEMS	SHIP	MODEL	BOX TYPE
Length,Lpp	130.00m	1625.0mm	1825.0mm
Beam,B	25.5m	318.8mm	270.0mm
Depth to Bulkhead Deck(car deck),D	8.35m	104.4mm	
Depth to Upper Most Continuous Deck	17.10m	214.8mm	256.0mm
Draught,d	5.75m	71.9mm	66.0mm
Displacement,Δ	12000tonnes	22kg	32.52kg
Block Coefficient,Cb	0.612		

In this experiment, image processing was used to measure the inside and outside water level of the compartment. Five plastic floats were set in the compartment and a CCD camera was set in the next compartment to record the movement of those floats (Fig. 3).

When the water flows in, floats will have free movement (up and down) according to the water level at that time. In this way, inside water level can be measured by processing the image of every 1/10 second.

The outside relative water level (h_{out}) was measured using a ultrasonic wave height sensor, and to validate image processing system another ultrasonic wave height sensor was set to measure inside water level at the center line as shown in Fig. 5.

The result shows good coincidence between two measures. Besides, in the ultrasonic wave height sensor, sometimes it fails, because of large wave slope.

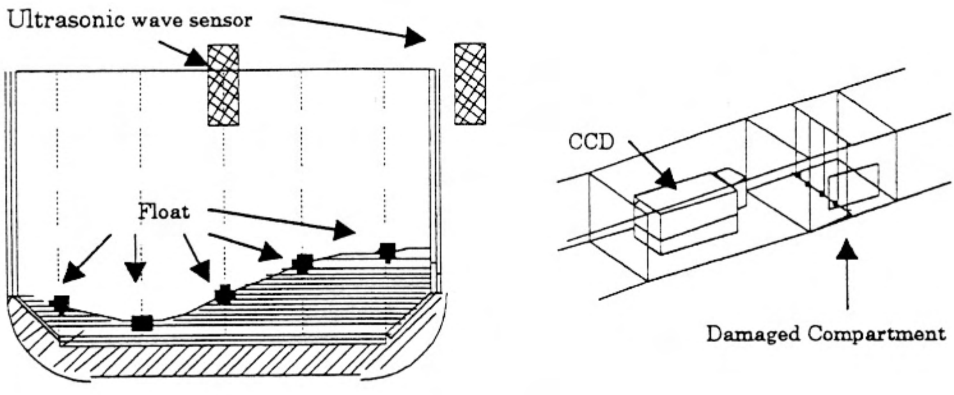


Fig. 4 measuring system

4..DAMAGE SCENARIOS AND TEST CONDITIONS

The damage scenarios and test conditions are shown in Tables 2 and 3. This ship model has five compartments from midship to stern (Nos.1 to 5). Damaged scenarios were symmetrical flooding of two adjacent compartments such as Nos.1 and 2, Nos.2 and 3, and so on. Four scenarios as shown in Table 2 were applied. Size of the opening area is 100mm× 50mm rectangle. Regular wave was used. The parameters of the waves are set as shown in Table 3.

Table 2 Damage scenarios

Scenario	Damaged compartment	Mark in Fig.11
I	1、2	■
II	2、3	●
III	3、4	○
IV	4、5	△

Table 3 Regular wave parameters

Wave length	Wave height	Wave height – length ratio
1m	0.033m	1/60
	0.066m	1/40
	0.100m	1/30
2m	0.025m	1/60
	0.050m	1/40
	0.075m	1/30
3m	0.017m	1/60
	0.033m	1/40
	0.050m	1/30

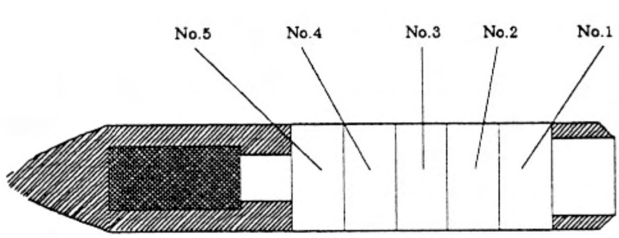


Fig. 5 Model Ship

5.RESULT OF EXPERIMENTS

The volume of water inside the compartment was estimated from the image processing analysis. At the same time, it was calculated based on eq.(3). In the equation, K was determined to minimize the difference between two values estimated and calculated. Some of the results were shown in Figs. 6 to 9. Two modes were observed. In the first mode (Figs. 6 and 8), at the beginning water filled in the damaged compartment gradually, then by increasing of heel, flooding in the damaged compartment increasing exponentially. In this case the model rolls with offset heel to the opening side. In the second mode (Figs. 7 and 9), water filled in the damaged compartment at the beginning and after a few minutes the model rolled to the other side and no more flooding didn't occur, because the opening is higher than outside water level. Comparing of the flooding coefficient K of two modes, the value in the former mode is larger than that of latter mode.

The values thus estimated were plotted in Fig. 10 versus wave length. In the figure, ▼ denotes experiment result with a box type model. In Fig. 11, the values were replotted versus wave height ratio for each wave length. In the figure, each mark denotes each damage scenario. From Figs. 10 and 11, it can be said the flooding coefficient K decreases as wave length increases. Comparing of h/λ=1/30 and 1/40 scenario, in most cases, the flooding coefficient K of h/λ=1/30 is smaller than that of h/λ=1/40. Damaged scenario does not affect flooding coefficient K significantly. Vassalos *et al.*[3] has proposed to use 0.7 as the flooding coefficient. The value is considered as the moderate value in Fig. 10.

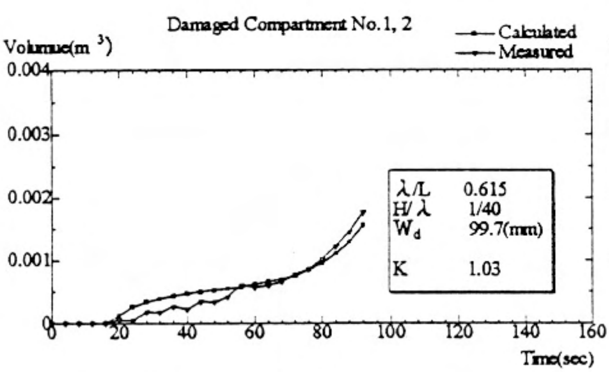


Fig. 6 Water Accumulating in Damaged Compartment

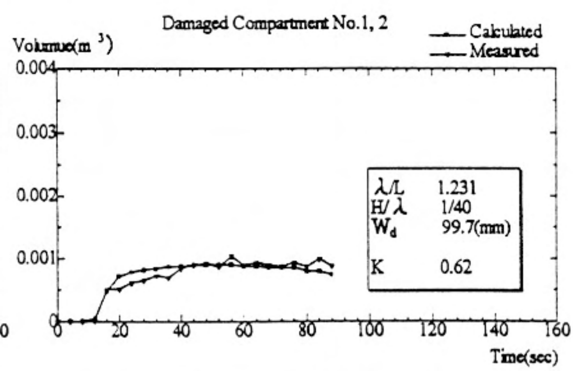


Fig.7 Water Accumulating in Damaged Compartment

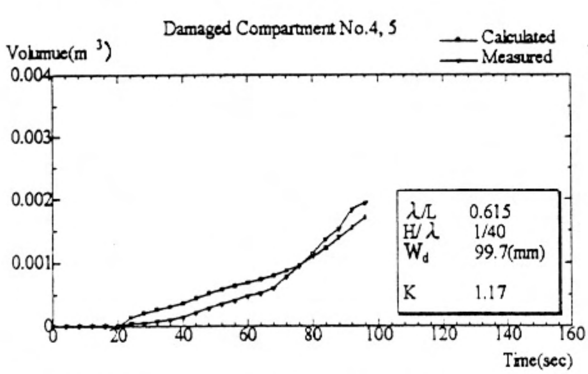


Fig. 8 Water Accumulating in Damaged Compartment

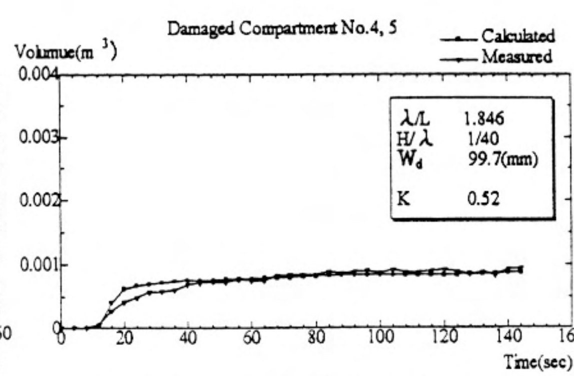


Fig. 9 Water Accumulating in Damaged Compartment

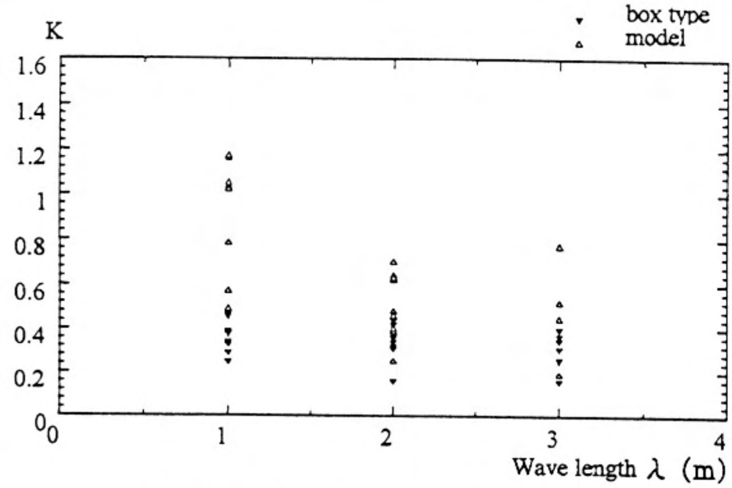


Fig.10 Flooding coefficient K versus Wave length

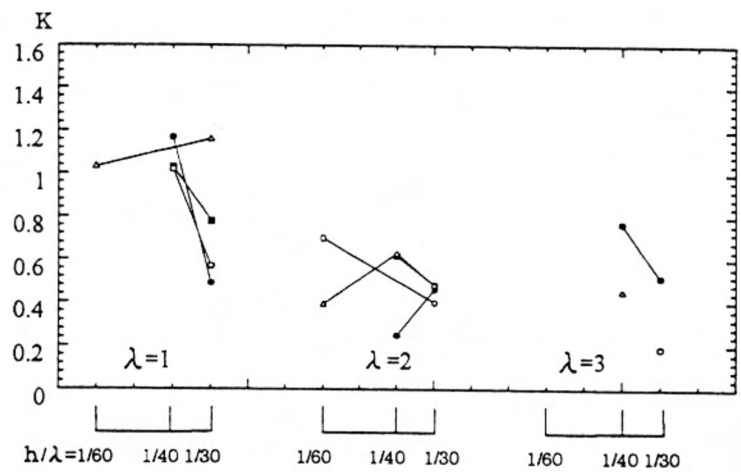


Fig.11 Flooding coefficient K versus wave length, Wave height ratio for each wave length

6.CONCLUSIONS

The conclusions can be summarized as follows.

1) The water volume in the damaged compartment can be roughly estimated by a simple model proposed by Vassalos *et al.*[3].

2) The flooding coefficient in the model may vary 0.3~1.2,depending on wave length, wave height ratio, damage scenario and so on. But significant parameter governing it can not be found.

3) Image processing can be successfully used to estimate water level in the damaged compartment in the experiment.

4) We can expect future experiments to improve water volume measurement.

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