Air Pressure Scale Effects During Damage Model Tests

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Abstract The Stability in Waves committee of the 27th ITTC has investigated the significance of scale effects in air pressure on flooding model tests under atmospheric conditions. For this purpose, the committee classified the flooding cases into the trapped air case and vented air case and investigated the flooding process for a simple geometry, using the state equation of air and orifice equation. As a result, the committee concluded that the scale effect is large for the case of trapped air and small vent area. For the other cases, the effect is small and can therefore be neglected in the model test of a damaged ship. In addition, the committee proposed some directions that can be used to reduce the scale effect of air pressure.

Keywords Scale effect of air · Damage model test · Depressurised wave basin

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1 Introduction

One of the tasks of the committee on Stability in Waves of 27th ITTC is to investigate the scale effect of air pressure on damage model test and update the ITTC Recommended Procedure 7.5-02-07-04.2 "Model Tests on Damage Stability in Waves" [1, 2]. The guideline provides the test procedure for carrying out model tests on a damaged ship in irregular waves to determine the probability of capsizing or the significant wave height that will cause the model to capsize in a fixed time period. If there is a compartment of the model, which is not vented, and this compartment has a large effect on the model test, the scale effect of air pressure arises. However, most tests on damaged ship models are carried out in atmospheric conditions, and the model test in vacuum condition is very limited, there is only one facility suitable for the damage model test among many ITTC member facilities [3]. Ypma [4] reported the comparisons of the model test in atmospheric and vacuum conditions, including the difficulties of model test in the latter.

The effect of air compression on the cross-flooding process was taken into account in Refs. [5, 6]. Peters et al. [7] carried out rigorous calculations with air-flow to find the design alternatives of cross-flooding duct, and Ruponen et al. [8] calculated cross-flooding time with complex duct. Besides cross-flooding, Palazzi and deKat [9] studied the air flow/compression effects by model experiments; Ruponen et al. [10] provided the results of full-scale experiments with various air pipes. Most researchers knew there is a scale effect on the air compression, but the study on these air scale effects has not published yet.

The Stability in Waves committee has investigated the significance of scale effects in air pressure on flooding model tests under atmospheric conditions. For this purpose, the committee classified the flooding cases into the trapped air case and vented air case and investigated the flooding process for a simple geometry using the state equation of air and orifice equation.

In the case of trapped air, the scale effect of air is significant regardless of the damage size. In the case of vented air, the scale effect of air is dependent of the size of vent area. The ratio of the vent area to the damage area plays an important role in the flooding process. When this ratio is large, i.e. a large vent area (the ratio is greater than circa 0.1), the scale effect turns out to be small. For the small vent area, the scale effect is large during the initial stage, and as time passes the scale effect becomes small. In order to reflect the damage model test procedure, in which the model is initially set in equilibrium condition, the effects of assuming the air compression process to be isothermal or adiabatic were investigated after setting the inner air pressure to be equal to the outside water pressure at the position of damage opening in calm water. The scale effect is small in this case for both isothermal and adiabatic process.

As a result, the committee concluded that the scale effect is large for the case of trapped air and small vent area. For the other cases, the effect is small and can therefore be neglected in the model test of a damaged ship. In addition, the committee proposed some directions that can be used to reduce the scale effect of air pressure.

2 Model Test and Scale Factor

Damage model test is carried out under the Froude hypothesis. If the Froude number is set to be the same in full scale and model test, there is a dynamic similitude in both. The Froude number,

$$F_n = \frac{V}{\sqrt{gL}} \tag{1}$$

is the ratio of inertia force and gravitational force. Let the scale factor λ be the ratio of ship length to model length. Then the physical quantities follow the scale rules below.

$$\frac{L_s}{L_m} = \lambda,\ \frac{V_s}{V_m} = \sqrt{\lambda},\ \frac{t_s}{t_m} = \sqrt{\lambda},\ \frac{\omega_s}{\omega_m} = \frac{1}{\sqrt{\lambda}},\ \frac{p_s}{p_m} = \lambda, \tag{2}$$

where L is length, V velocity, t time, ω frequency, p pressure, and the subscript 's' means full scale ship and 'm' means model scale. In order to follow the scale rule, the pressure head of the model and the atmospheric pressure should be reduced to the ratio of 1/λ.

The water flow through an opening is usually represented by the orifice equation

$$q = C_D \rho_w A \sqrt{2(g\Delta h + \Delta p_a/\rho_w)}, \tag{3}$$

where C_D is the discharge coefficient of opening, ρ_w the density of water, A the area of opening, Δh the difference of water pressure head, p_a the difference of air pressure in and out. Using water with the same density and gravity, the flow rate obeys the scale rule provided that the air pressure, namely, it follows the scale rule of 1/λ.

The model scale pressure should be 1/λ in order to maintain dynamic similitude. That is, if the model is small, then the pressure of the air should be reduced proportionally. This is possible only in a depressurised tank facility. Most model basins can only test in atmospheric air conditions, not scaled air pressure. Figure 1 reveals conceptually the difference in pressure head between the scaled air pressure model test and atmospheric model test.

3 Scale Effects in Air Pressure

There are some cases in which the flooding of a ship is affected by the air pressure inside the vessel. The main contribution of air pressure takes place in trapped air cases and in vented air cases with small vent area (the area ratio of vent to damage is less than approximately 0.1). In a model test of a damaged ship, if the air pressure is maintained at atmospheric pressure, then scale effects in air pressure occur.

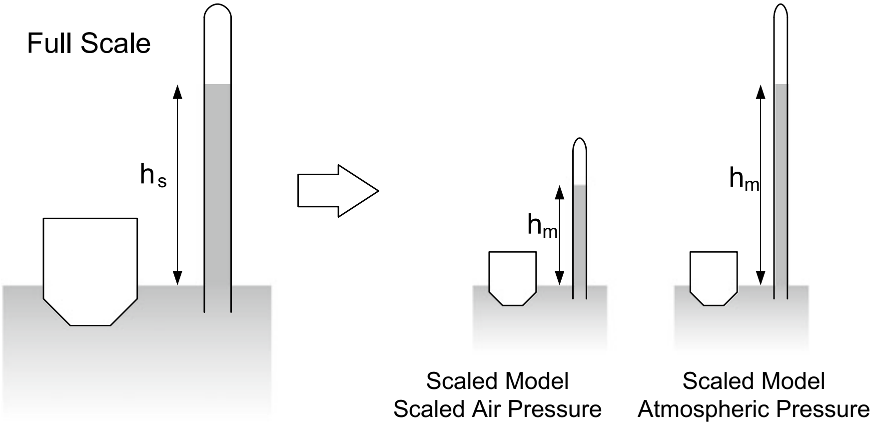

Fig. 1 Concept of scaled model test

For the trapped air case, the pressure of the model in atmospheric conditions is higher than in scaled pressure. Therefore, the flooding to that compartment is restricted as shown in the Fig. 2.

For the vented air case, the air will be compressed and the internal pressure increases. The pressure in atmospheric conditions is higher than in scaled air pressure, so the flooding speed will be slower than in scaled air pressure. Therefore, the following situation will occur, Fig. 3.

We can simulate the above situation by using the state equation of air.

$$PV^{\gamma} = const., \tag{4}$$

where P is absolute pressure of the air, V is the volume under consideration, and γ is the ratio of specific heat, in the case of air it is 1.0 for an isothermal process and 7/5 for an adiabatic process. The flow through an opening can be estimated by the orifice equation.

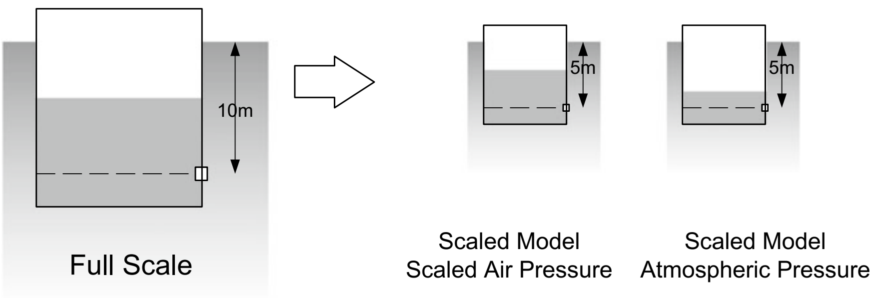

Fig. 2 Flooding in trapped air case

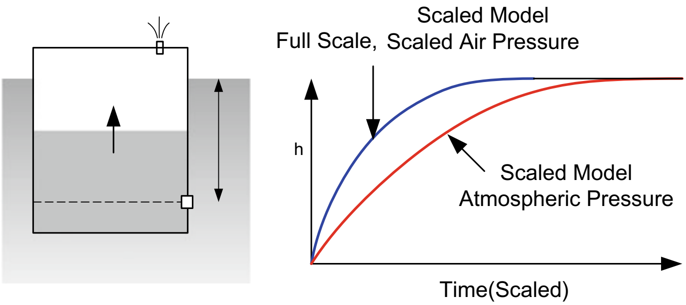

Fig. 3 Flooding in vented air case

Figures 4, 5 and 6 show the water height behaviour along with scaled time in the case of trapped air case for small opening and large opening in the compartment bottom.

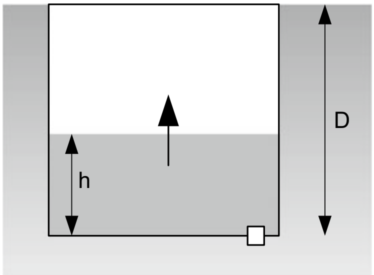

Fig. 4 Schematic drawing for flooding in non-vented air case

The above two figures are exactly the same except for the time scale. This time scale difference comes from the opening area ratio. As one over the scale ratio becomes small, the final water height reduces also. In this case, the scale effect of air pressure is significant regardless of damage size.

For the vented case, Figs. 7, 8, 9 and 10 show the density ratio of air and water height during the flooding process.

The ratio of the vent area to the damage area plays an important role in the flooding process. When this ratio is large (tentatively over 0.1), i.e. a large vent area, the scale effect turns out to be small. For the small vent area, the scale effect is large during the initial stage, and as time passes the scale effect becomes small.

In order to reflect the damage model test procedure in which the model is initially set in equilibrium condition, the effects of assuming the air compression process to be isothermal or adiabatic can be simulated after setting the inner air pressure to be equal to the outside water pressure at the position of damage opening. For this purpose, the pressure of the compartment is set to the outside water pressure initially

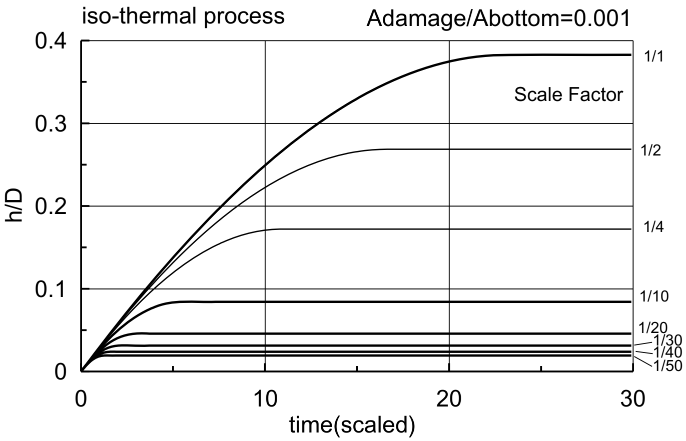

Fig. 5 Flooding in non-vented air case for a small opening

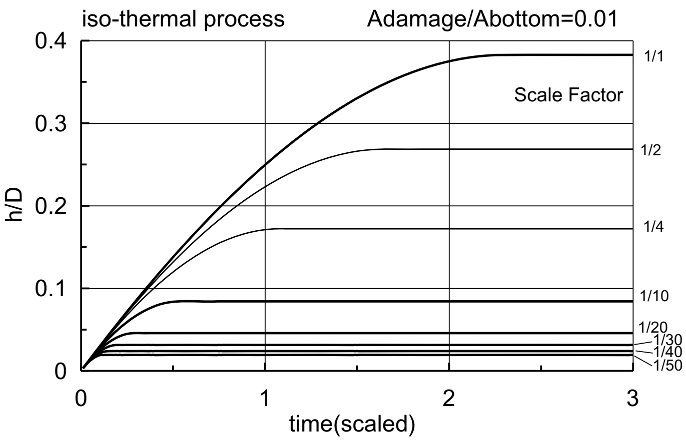

Fig. 6 Flooding in non-vented air case for a large opening

for the vented case. Figures 11 and 12 show the flooding process of the isothermal and adiabatic processes, respectively.

If the flooding speed is slow, the air compression process will be isothermal and if the speed is high the adiabatic process can be applied. When a damaged ship with a large damage opening floats in waves, the flooding due to waves and ship motion is relatively fast, so an adiabatic process takes place in the air compression process. Figures 11 and 12 show that the scale effect is not large.

In line with the above discussion, it can be concluded that the scale effect is large for the case of trapped air and small vent area. For the other cases, the effect is small and can, therefore, be neglected in model tests of a damaged ship.

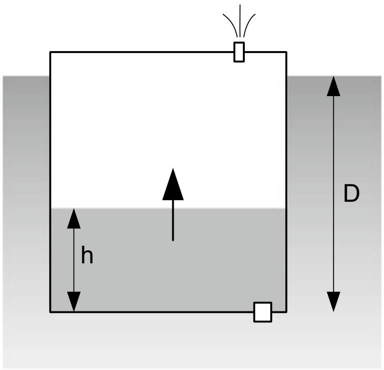

Fig. 7 Schematic drawing for flooding in vented air case

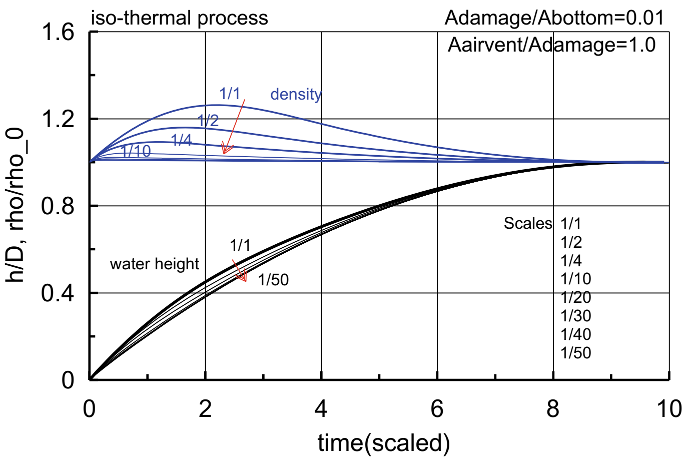

Fig. 8 Flooding in vented air case for a large air vent area

In atmospheric conditions, it is possible to use alternative methods to reduce the scale effect of the air pressure. For the case of a small vent area, the vent opening can be enlarged to an appropriate size in order to reflect the inflow and outflow of the full scale situation. For the case of trapped air, a simple solution would be to attach a balloon to the compartment in order to lessen the scale effect of air pressure and to obtain realistic flooding results in the test condition.

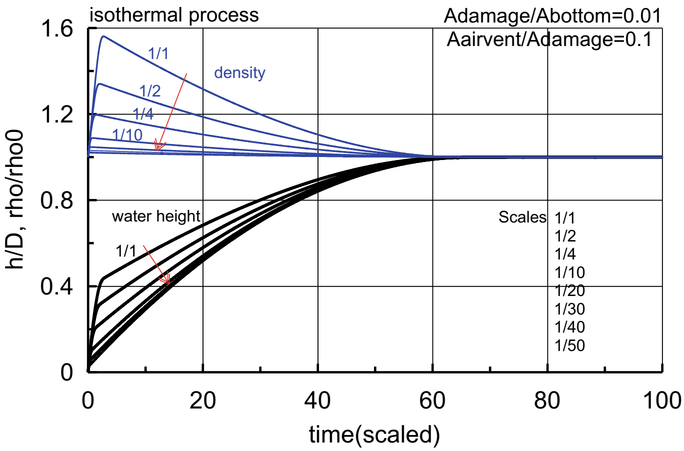

Fig. 9 Flooding in vented air case for a medium air vent area

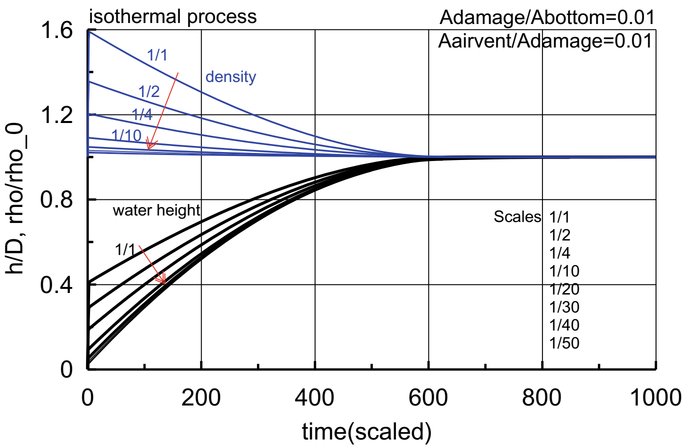

Fig. 10 Flooding in vented air case for a small air vent area

4 Conclusions

In summary, if the damage opening is large and the compartment is well vented the scale effect of air pressure will be small and model tests in atmospheric conditions are suitable. The scale effect will be large in the trapped air case and small vent area case. In that situation, if precise and accurate test results are required, the use of pressure regulation values on the compartments to control the internal pressure or model tests in a depressurised model basin are necessary. As a minimum, in the case of model tests in atmospheric conditions, modifications are recommended to reduce scale effects.

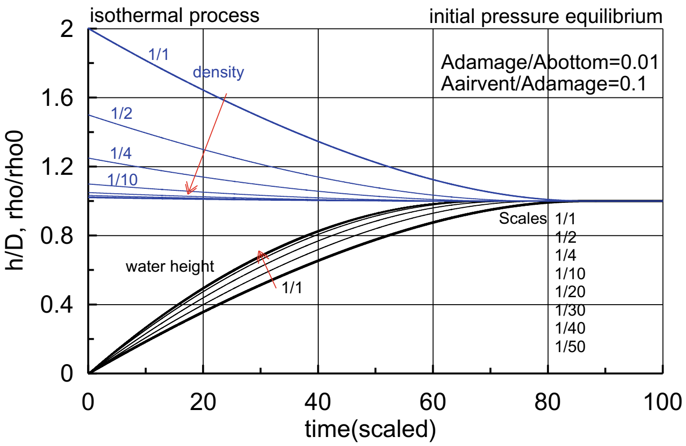

Fig. 11 Flooding for the isothermal process; when the air pressure was initially balanced

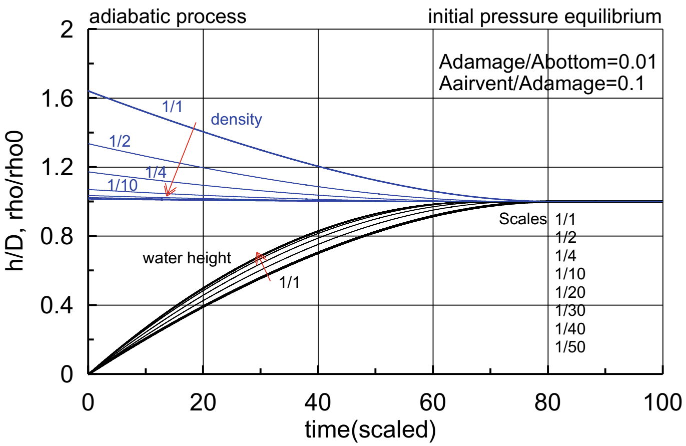

Fig. 12 Flooding for the adiabatic process; when the air pressure was initially balanced

The model test guideline for damage stability experiments (ITTC 7.5-02-07-04.2) was updated to reflect the above discussion.

Acknowledgements The aim of this paper is to introduce the work of ITTC Stability in Waves committee on the damage model test. A large part of this material comes from the report of ITTC with some rearrangements.

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