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New Launching Concept for Free-Fall Lifeboats and Validation by Model Experiments and Numerical Simulations

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Abstract

A new concept for launching free-fall lifeboats, proposed by Yokohama National University is described in this paper. It has been pointed out that, using the conventional single-skid free-fall system, the potential for dangerous lifeboat motions (in which the lifeboat moves backward or jerks on the surface after entering the water) increases with the fall height of the lifeboat. One of the principal causes of this undesirable motion is vertical rotation of the lifeboat during its restricted fall at the edge of the launching skid. Thus a new "double-skid" launching concept is proposed to effectively eliminate the rotation of the lifeboat at the skid end and to enable the lifeboat to move smoothly after entering the water. In order to evaluate the performance of the proposed method, a series of model experiments and numerical simulations is carried out in which two lifeboat models with overall lengths of 1 meter and 6 meters are used. The effects of design parameters such as skid angle and skid height are investigated, and an example of the implementation of this new system at the stern of a large merchant ship is illustrated.
Keywords: launching, double-skid system, lifeboat, experiment

1 Introduction

When a free-fall lifeboat passes the edge of a launching skid, rotational motion is produced by the effect of the gravity force and the reaction force from the launching skid. This rotation continues while the lifeboat falls in the air freely after leaving the skid. Therefore, if the falling distance is large, the attitude of the lifeboat at the time it hits the water tends to be perpendicular to the water surface. When such impact occurs, the lifeboat may move backward towards the mother ship after flotation or jerk violently on the water surface in an extreme case(Ogawa and Tasaki 1996, Arai and Khondoker 1997). To solve this problem of unfavorable boat motion, the authors propose a new double-skid launching concept. In the double-skid system, two sets of supports are installed at each side of the lifeboat at fore and aft of the hull (i.e., four rollers or short guide-rails; see Figure 1). Also, the rails of each skid are installed on two levels, in order to make the four supports run an equal distance on the rails and enable them to be released simultaneously from each skid. The rotational motion of the lifeboat at the skid end is removed completely with this system. Thus, the lifeboat falls in the air without rotation, and the water entry angle, which is equal to the skid angle, can be optimized easily. As a result, a drastic stabilization of the motion of the lifeboat after it enters the water can be expected. The basic concept of this system and a feasibility experiment using a small lifeboat model with overall length of $0.2m$ have already been reported(Arai and Okazaki 1998). In this paper,the results of detailed model experiments using $1m$ and $6m$ model lifeboats and the corresponding analytical research results arc shown. The performance comparison between the double-skid system and the conventional, single-skid system is presented. And the results of studies on the design parameters of the launching system, such as skid angle and skid size, are shown, as is a design example in which the double-skid system is installed at the stern of a large merchant ship.

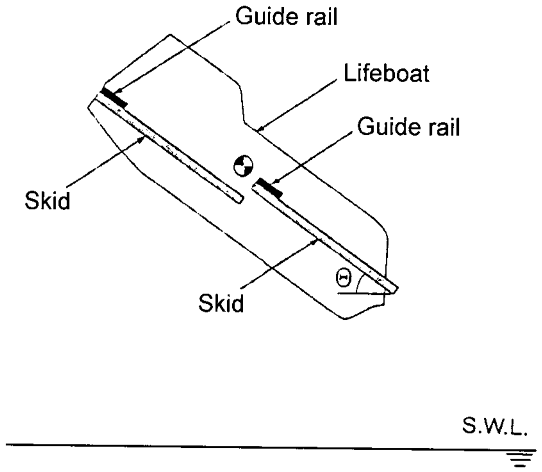

Figure 1: Double-skid launching system

2 Performance validation of double-skid system by model experiments and numerical simulations

2.1 Model experiments

In this paper, the results of model experiments using two lifeboat models designed by the SR232 committee of the Japan Ship Research Association are shown. In the committee's cooperative research project, an indoor model experiment using a small lifeboat model and a large-scale model experiment at the wharf of a shipyard were carried out in order to examine the launching performance of the free-fall lifeboat. The principal particulars of the model lifeboat and the prototype lifeboat are presented in Table 1. In the small-scale model experiment,the motion of the lifeboat and acceleration during its water entry were measured using a wooden rigid body model with an overall length of $L = 1m$. In the large-scale model experiment, the functional confirmation of various pieces of skid-related equipment, such as the releasing mechanism, and of the strength of the hull structure was mainly examined using the $L = 6m$ model lifeboat made of GFRP.

Table 1: Principal dimensions of the lifeboat models

	L=1m model	L=6m model	Full scale
Length(m)	1.000	6.000	8000
Breadth(m)	0.325	1.950	2.600
Depth at midship(m)	0.294	1.763	2.350
Draught(m)	abt. 0.074	0.345	0.460
KG(m)	0.167	0.776	1.052
Midship G(m): aft+	0.039	0.075	0.232
Radius of gyration	0.277	1.450	-
Displacement(kg)	15.77	2,320	5,500
Capacity: No. of persons	-	-	30
	1/8	3/4	1

2.2 Small model experiment

(1) Test equipment and model boat

The small-scale model experiments were carried out in the model test basin of Akishima Laboratories (Mitsui Zosen), Inc. The launching equipment installed in the test basin is shown in Figure 2. Both the double-skid and conventional single-skid launching facilities are prepared, and the performance of both systems was examined. In this study, the fall-height of the lifeboat is defined as the distance between the supporting apparatus at the aft end of the lifeboat at the instant of release and the undisturbed water surface(see Figure 2). The test conditions were the combination of the fall height (i.e., 1.5m, 2.0m, 2.5m), skid angle (i.e., 30^o, 40^o, 50^o) and sliding distance, (i.e., 0.5m to 1.3m). The definition of the sliding distance in this paper is the distance that the midship of the lifeboat slides on the skid rail. For example, the sliding distance is 0.5 the boat's length (i.e., 0.5m in the case of $L = 1m$ model boat) for both launching systems if the slide begins from the condition that the fore end of the boat coincides with the lower edge of the skid rail. At each side of the model boat, a long guide rail is installed from bow to stern, as is a short one just in front of the midship of the boat. With this system, tests for both launching methods can be carried out with a single model boat. Accelerometers were installed in the model boat at bow (symbol B), midship (symbol M), and stem (symbol S), as shown in Figure 3 and acceleration in longitudinal or axial direction (symbol a) and acceleration in vertical or normal direction (symbol n) were measured. In addition, a mast was installed at the midship to measure the motion of the model boat. Motion measurements of the lifeboat were carried out by using a video camera to obtain the momentary position and attitude of the model boat. Trial-and-error was needed to find a suitable location of targets for motion measurement, since water film is generated when the boat touches the water surface, the targets were sometimes hidden in the film, and the tracking of the targets was interrupted. After some trials, the arrangement of the two targets as shown in Figure 3 was found to be suitable. (Arrangement of the targets on the T-shaped mast was unsuitable for the reasons mentioned above.) Although the hull of the model boat was built with a light material (i.e., paulownia, whose specific gravity is 0.28), it became a little heavy in order to ensure the strength of the hull as a rigid body model. Therefore, the similarity law with the prototype is not perfectly satisfied in terms of draft, KG, etc. (see Table 1).

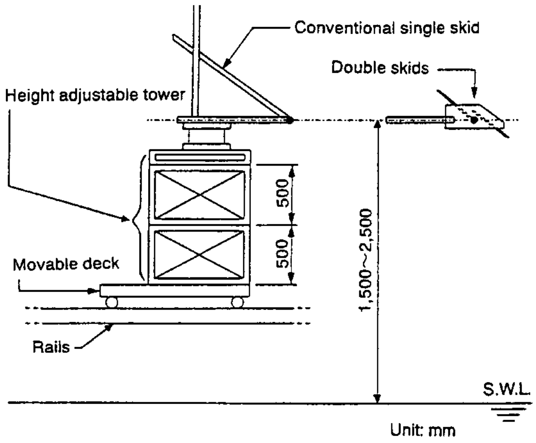

Figure 2: Test facilities for L=1m model

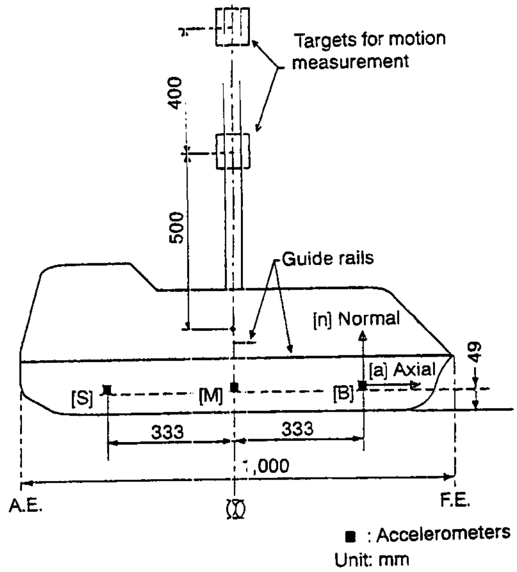

Figure 3: L=1m lifeboat model

(2) Comparison between measured and computed results

Motion and acceleration measured in a model experiment using the conventional single-skid system were compared with corresponding numerical simulations and arc shown in Figures 4 and 5. Conditions of the model experiment arc: fall height 1.5m, sliding distance 0.5m, and skid angle 4O degrees. The symbols in Figure 5 show the mounting positions of the accelerometers together with the direction of the acceleration(see Figure 3). The results of the model experiments and numerical simulations using the double-skid system under the same condition are shown in Figures 6 and 7. As shown in Figure 4, when the single-skid system is used, a dangerous boat motion occurs in which the lifeboat moves backward towards the mother ship after flotation. On the other hand, as is clearly shown in Figure 6, the boat launched from the double-skid has a favorable advance velocity towards a far and safe place. In spite of widely changing experimental and numerical conditions in fall height, skid angle, and sliding distance,the lifeboat motion remained similar to Figures 4 and 6. That is to say the lifeboat moves backward or stops at the position of flotation if the lifeboat is launched from the conventional single-skid system. On the other hand, the lifeboat advances smoothly if it is launched from the double-skid system. The reason such a different boat motion is generated is thought to be as follows. When the conventional single-skid system is used, the lifeboat holds a nose-down motion during free-fall, and the water entry angle tends to be close to a right angle, therefore the boat loses its advancing velocity easily and moves backward by a strong buoyancy force during flotation. This tendency is especially remarkable in Our model boat, since it has an extremely full bow shape. On the other hand, when the boat is launched from the double-skid system, the bow rises up at the water surface because of the smaller water entry angle and a stronger bow-slamming force. The boat does not submerge deeply in the water, and it is pushed in a forward direction by the bottom-slamming at the stern which follows. Of course, even if the conventional single-skid system is used, it is possible to create a safe boat motion if the boat has an appropriate hull form; however, it can be said that the proposed double-skid system is a generally effective method to provide a safe evacuation motion to free-fall lifeboats. It should be noted, however, that slightly greater upward acceleration to the lifeboat is generated by the double-skid system compared to the conventional one (see Figures 5 and 7). Furthermore, patterns of the acceleration histories between the two systems are different since the water entry motion of a boat differs in these two systems. Upward acceleration at the stern (Sn) by the double-skid system becomes greater in magnitude. Further examination is considered to be necessary in developing an actual lifeboat suitable for the new system, since there are some other important design parameters, such as hull forms and weight distributions, that influence water-entry motion and acceleration. It was proven that the calculation method in ref.(Arai et al 1995) is effective to evaluate the water-entry behaviors of free-fall lifeboats irrespective of the launching method, as shown in Figures 4 through 7.

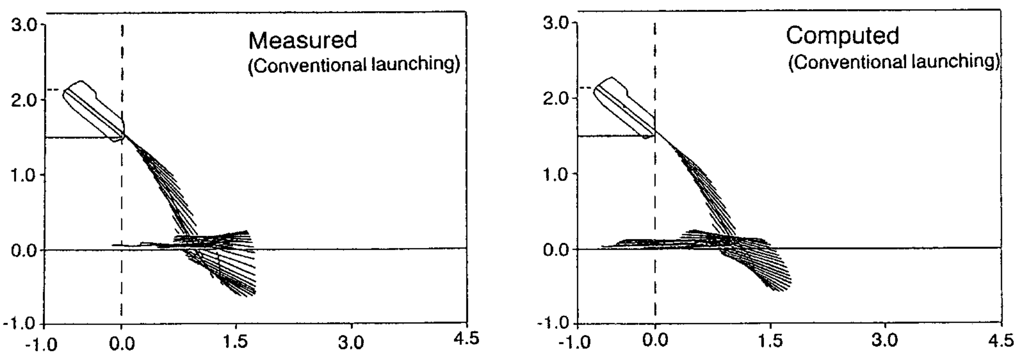

Figure 4: Measured and computed lifeboat motion(conventional single-skid method)

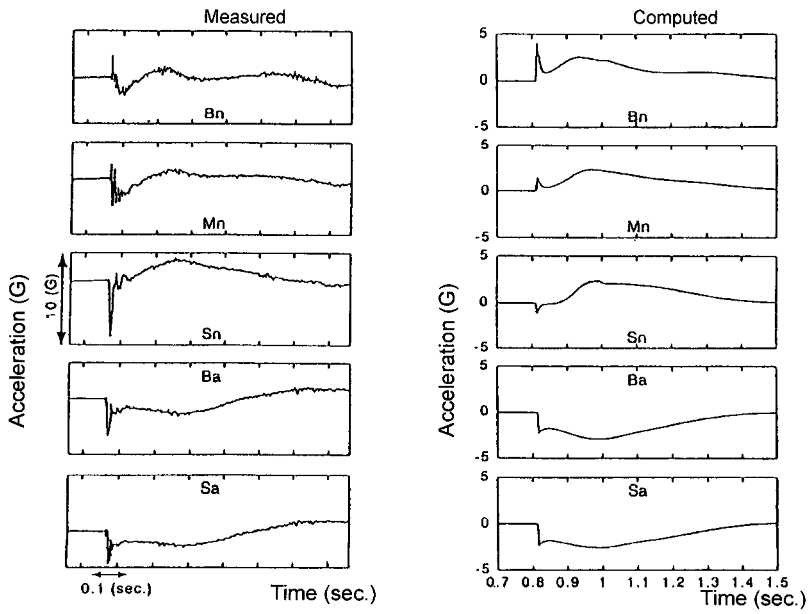

Figure 5: Measured and computed acceleration histories(conventional single-skid method)

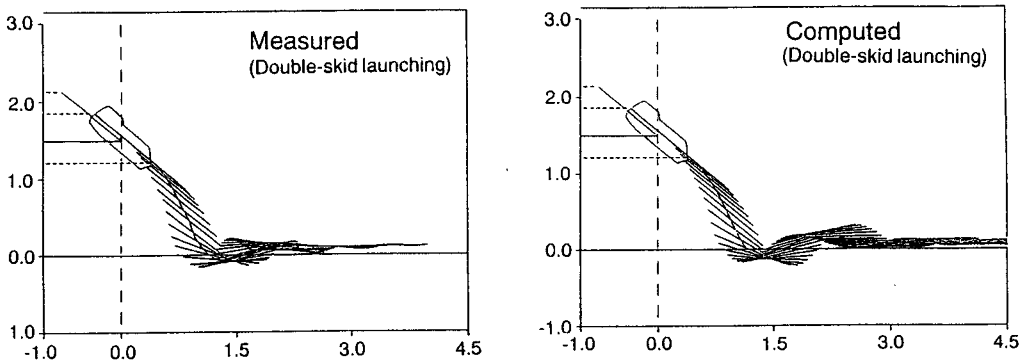

Figure 6: Measured and computed lifeboat motion(double-skid method)

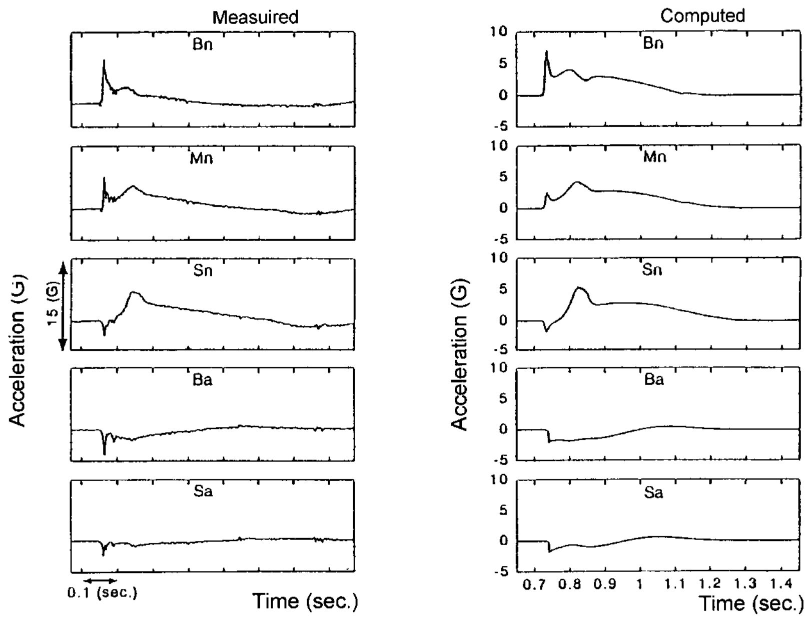

Figure 7: Measured and computed acceleration histories(double-skid method)

(3) Effects of manufacturing accuracy etc., of the skid system on launching performance

Error in the manufacture of skid rails or damage to the lifeboat's guide rail may seriously affect the launching performance of the free-fall lifeboat. For example, if the lifeboat rotates sideways, serious danger for the occupants can be anticipated. Especially,this kind of problem is apparent in the case of the escape from a mother ship that is laterally tilted (i.e., in a heeled condition). Therefore,a launching experiment was carried out in a condition where the support material at the front-left side of the lifeboat detached from the skid rail earlier than other supports. For this purpose, the length of the left-front rail of the double-skid was shortened by $20mm$ from the standard state. In the double-skid system, since most of the weight of the boat is imposed on the two front supports just before the boat leaves the skid, it is anticipated that the detachment of one of the front supports is most serious. Also, for another artificial condition, a model experiment was done in which the width of the rails of the front and rear skids was extended by $5mm$. (In the normal condition,the width of the rails was set to be $+3mm$ overall width of the boat.) As was mentioned earlier, evacuation from the mother ship in heeled condition seemed to be an especially severe situation, and model experiments were performed in which the skid listed 20 degrees starboard. This condition corresponds to the SOLAS requirement(SOLAS 1974) that the lifeboat should be launched safely in the 20-degree list of the mother vessel. Analysis of the experimental results of boat motion showed that there was no significant difference between the result of the normal case and those additional cases, i.e., the case in which one of four rails was shortened and the case in which the interval between the right and left rails was widened. If we convert those artificial deviations from the standard state into an actual scale, we would have $160mm$ for the skid rail length and $40mm$ for the interval between the left and right rails. These values are considered to be excessive as a manufacturing error of the skid rails or as damage to the support materials of a lifeboat. Therefore, it was confirmed that the double-skid system is sufficiently robust to accommodate usual manufacturing errors and other variances.

2.3 Large model experiment

(1) Motion of lifeboat

The large model experiment was carried out at a wharf of the Innoshima factory of the Hitachi Zosen Corporation. The general arrangement of the test tower is shown in Figure 8. Figure 9 shows the parts of the rails of the double-skid system. The skid rail was made of polyamide resin in order to reduce the effect of friction as much as possible. Rollers were installed at the outer side of the rails to prevent the lateral displacement of the model boat when the tests were done in the heeled condition. Figure 10 shows a typical launching. The main feature of double-skid launching, i.e., the boat holds a constant angle to the still water surface during sliding and free-fall,is clearly shown in these snapshots.

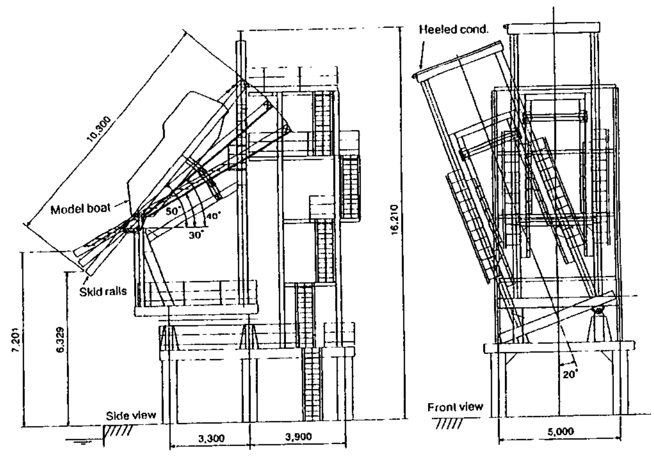

Figure 8: Test tower for L=$6m$ lifeboat model experiments

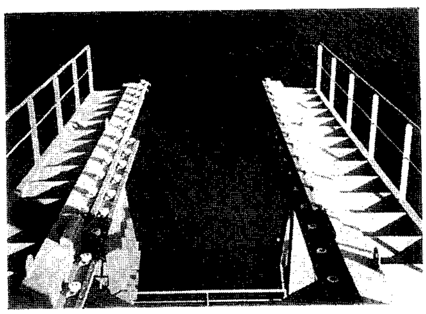

Figure 9: Launching rails of L=$6m$ model experiments

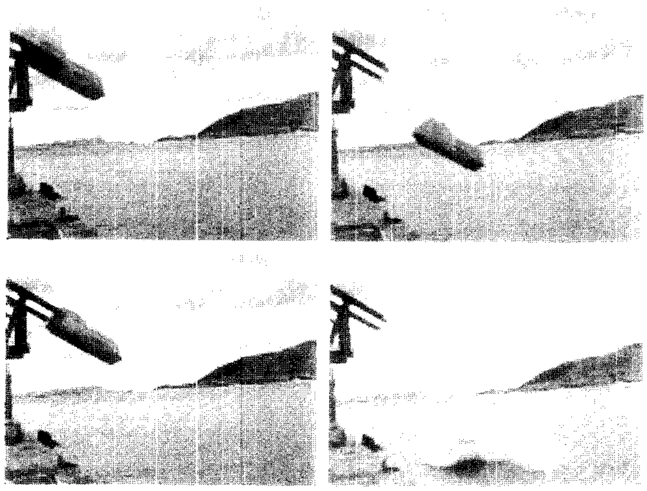

Figure 10: Motion of L=6m model launched from the double-skid

(2) Acceleration on the boat hull

The measured acceleration histories, with conditions of skid angle of 40 degrees, sliding distance of $0.5L$ (L=overall length of the boat),and fall height of $8.58m$ is shown in Figure 11. The boat was launched from the double-skid, which was not laterally tilted. Measured accelerations by this model experiment consisted of two components: rigid-body motion of the lifeboat and elastic deformation of the hull structure. Although accelerometers were installed at comparatively rigid structural members in the boat, the effect of the above-mentioned dynamic response of the elastic structure in acceleration time histories is clearly observed. On the other hand, in the numerical simulation used in this research, the hull is assumed to be completely rigid. Therefore, it is not possible to directly compare the measured and the numerical results. However, for reference, the results of the numerical simulation that was carried out with the same launching condition as with the above mentioned model experiment are shown in Figure 12. Figure 11 and Figure 12 seem to correspond well in tendency, if we take into account that the numerical simulation was done with the rigid body assumption.

3 Design example of the double-skid launching system

3.1 Difference from the conventional system and specific items to be studied

Most conventional single-skid systems are designed with skid rail length between 1.0 and $1.5L$ and a skid angle (Θ) between 30 and 35 degrees. Considering the severe space limitations on this kind of device in maritime usage, the dimensions of the double-skid system should be almost equivalent to the conventional skids. On the other hand, the skid angle of the double-skid system can differ from that of conventional skids because of differences in water-entry mechanisms.In the double-skid system, the effective skid angle can be wider in range from the viewpoint of the ability to give a necessary advancing velocity to a lifeboat after its water entry(Arai and Okazaki 1998). However, if the skid angle is too large, embarkation onto the lifeboat becomes difficult,

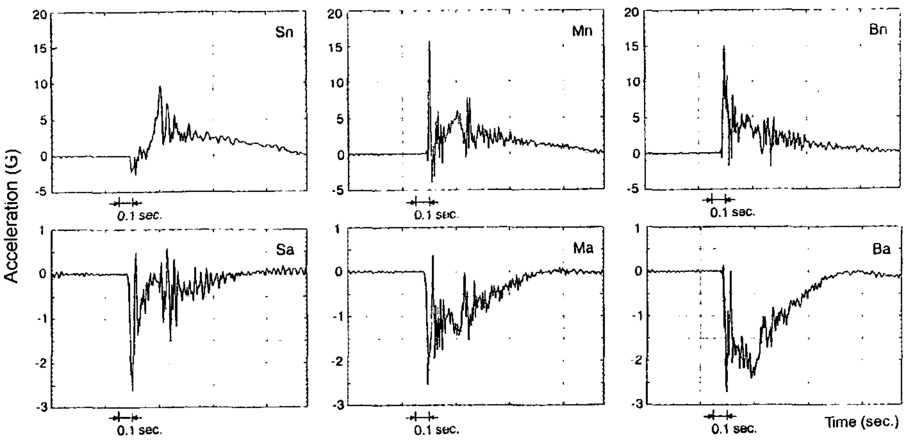

Figure 11: Measured acceleration histories(L=6m GFRP model)

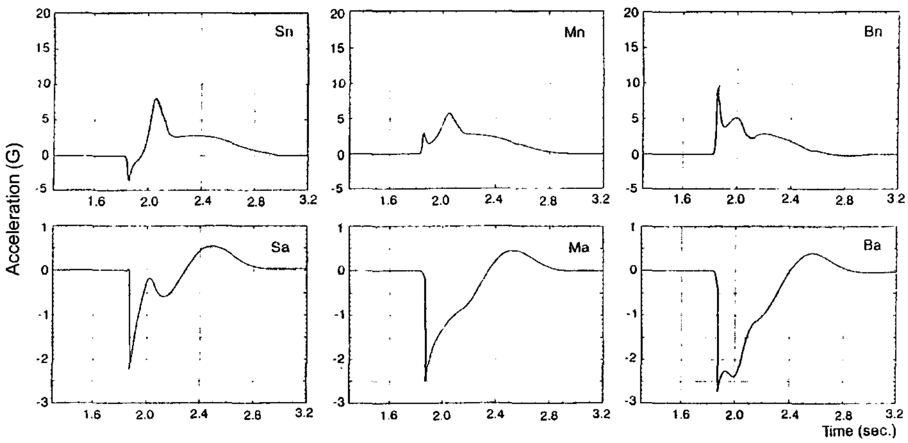

Figure 12: Computed acceleration histories(L=6m model, rigid body computation)

and if the skid angle is too small excessive impact acceleration will be exerted at the bottom of the lifeboat. When these conditions are considered, the practical design range of the skid angle is automatically determined. From the viewpoint of the motion of the lifeboat and impact acceleration during water entry, it seems reasonable to give the lifeboat a water-entry angle of around 45 degrees, which is also an optimum water-entry angle of a lifeboat by a conventional single-skid launching system(Hirota and Masabayashi 1995). That is to say, considering a balance between the convenience of embarkation onto the boat and water-entry performance, a skid angle of 40 to 45 degrees is practical.

One of the important items to be taken into account in designing the double-skid system is that the free-fall of the lifeboat starts earlier with this system than it does with a conventional one. In the conventional system, the free-fall starts at the fore end of the skid system, and the fore end usually coincides with the aft end of the mother ship. On the other hand, in the double-skid system the free-fall starts at the edge of the rear skid rail. Therefore, careful attention should be given to the interaction between the lifeboat and the deck of the mother vessel. Skid angle and skid rail length

are to be examined from this viewpoint.
In this chapter, an example of the double-skid system for a lifeboat of $L = 8m$ is designed considering the discussion given above. In addition, SOLAS(1974) requires that the lifeboat be embarkable safely while the mother vessel is listing to 10 degrees (i.e., trimmed condition). Therefore, the effect of the list of the mother vessel is also considered in the discussion shown in this chapter.

3.2 Results of investigation

The definitions of the basic parameters used in this study are shown in Figure 13. Here, the lower-aft end of the lifeboat is defined as point P, and the aft endpoint of the upper deck of the mother ship is defined as point Q. Skid may be designed so that the trajectory of point P passes over point Q during launching, since the lifeboat holds a fixed angle through the launching. The height of the front end of the skid rail from the deck of the mother ship is expressed as H_c in this paper and it will be called the necessary "clearance". Furthermore, the length of the part in which the front part of the skid rail is protruding from the rear rail is defined as L_f (corresponding to the distance between the supports in the fore and aft of the lifeboat). The length between the lower surface of the fore support and point P in the normal direction of the axis of the lifeboat is defined as h; the distance the support slides on the skid rail is defined as l; the friction coefficient between the skid rail and the support of the lifeboat is defined as μ; and the trim angle of the mother vessel is defined as ϕ (where $\phi > 0$ for trim by bow condition).
Using these parameters, we obtained the expression by which we can evaluate, the trajectory of

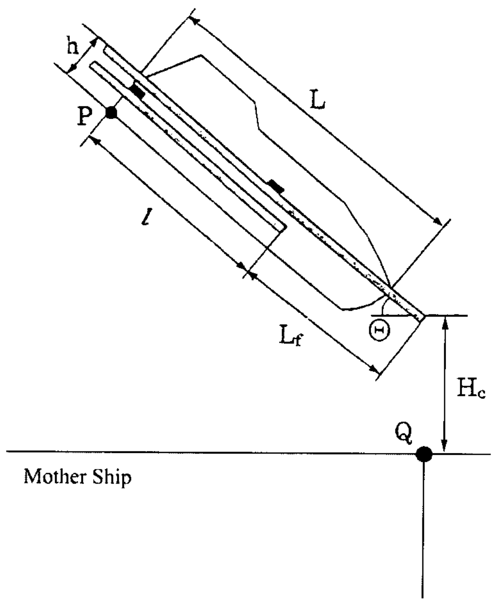

Figure 13: Definitions of design parameters

point P and the necessary clearance (see Appendix 1). Figure 14 shows the relationship between the skid angle and the clearance required. Where $\frac{l}{L} = 0.5$, $\frac{L_f}{L} = 0.5$, $\frac{h}{L} = 0.175, \mu = 0.02$ are used as calculation conditions. The calculation result for $\phi = 10$ degrees in this figure indicates

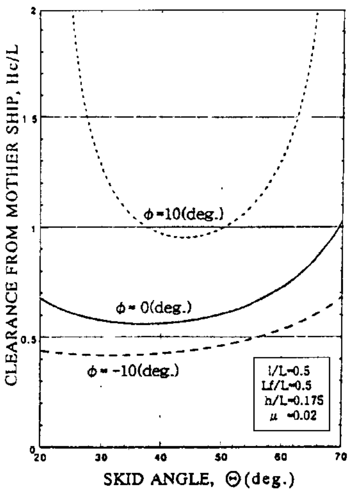

Figure 14: Clearance vs. skid angle

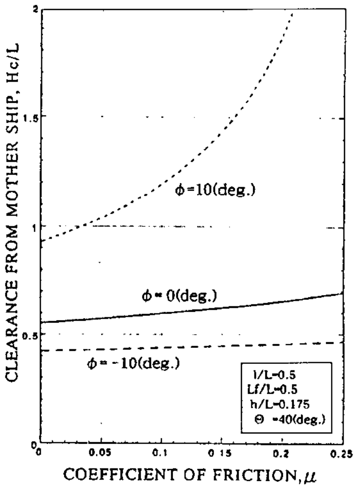

Figure 15: Clearance vs. friction coefficient

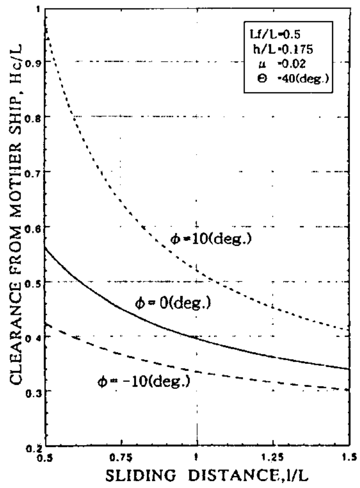

Figure 16: Clearance vs. sliding distance

that the necessary clearance remarkably increases with the effect of the list of the mother ship (i.e., trim by bow condition). There is an optimum value of about 43 degrees in the case of $\phi = 10$ degrees. This value is very close to the desirable angle from the viewpoint of the motion of the lifeboat after water entry (i.e., 45 degrees as mentioned in Chapter 3.1). This coincidence is favorable in designing the evacuation system. Figure 15 shows the effect of the frictional coefficient on the clearance. From this figure, it can be understood that the effect of the frictional coefficient is notable in the case of $\phi = 10$ degrees. In this paper discussion will be done assuming that the frictional coefficient is kept small (about $\mu = 0.02$), and therefore the effect of the frictional coefficient is not remarkable. However, it should be noted in the design stage of the free-fall lifeboat that, the effect of friction on the clearance is rather large if the frictional coefficient becomes large. Next, Figure 16 shows the relationship between the clearance and the sliding distance of the lifeboat on the skid rail. In the case of $\frac{L_f}{L} = 0.5$, if we choose $\frac{l}{L} \leq 1$, we can design a double-skid launching system to satisfy the condition that the skid rail length be less than 1.5 boat length, which is equivalent to the conventional single skid launching system. The necessary clearance for this design combination can be obtained from Figure 16.

3.3 Design example

A design example of the double-skid launching system is shown in Figure 17. Here, a lifeboat with overall length $L = 8.0m$ and a capacity of 30 occupants (see Table 1) are assumed as a target lifeboat to be installed. If we set the height of the front support $h = 1.4m$, skid angle $\Theta = 40$ degrees, frictional coefficient $\mu = 0.02$, sliding distance $l = 6.0m$, and clearance $H_c = 5.2m$, it is possible to design a system in which embarkation to the lifeboat can be done from the fourth deck, where the height of each deck is assumed to be $2.65m$.

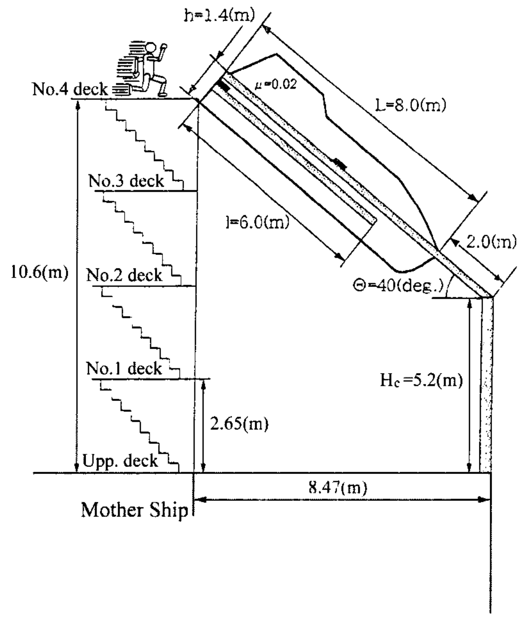

Figure 17: Design example of a double-skid system

4 Conclusions

In this study, model experiments and numerical simulations were carried out in order to evaluate the double-skid launching system which the authors have proposed. The system was devised to improve the water-entry motion of free-fall lifeboats. Features of the new system and some basic design items were studied. Performance comparisons between this new system and the conventional single-skid system were also carried out. The main results obtained are summarized as follows.

1) The proposed double-skid system is very effective as a means for improving the water-entry motion of the free-fall lifeboats. It can be applied to any free-fall lifeboat irrespective of hull form; however, it is especially effective for lifeboats that have blunt hull forms, since these have difficuly in gaining advance speed after water entry when released by the conventional single-skid system.

2) It was confirmed from small-scale and large-scale model experiments that there is no problem in launching the lifeboat from a listed mother ship.

3) In the double-skid launching system, there is a problem with the free-fall starting when the lifeboat is still above the deck of the mother ship. Special attention is to be paid to the launching of the lifeboat in the trim by bow condition of the mother ship.

4) A design example was shown in this paper in which the double-skid system is installed at the stern end of a large merchant ship.

Acknowledgement

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SOLAS 1974 Consolidated text of the Annex to the 1974 SOLAS Convention and the 1978 Protocol relating to the 1974 SOLAS Convention incorporating up to and including the 1991 Amendments, Chapter III, Regulation 44-6

Appendix

Necessary clearance on the deck of a mother ship

(1) Without considering the trim of the mother ship

In this paper, the origin of the coordinate system $O - xz$ is taken at the position of point P when the lifeboat finished the sliding and departed from the skid (see Figure A1). The trajectory of point P is then expressed ad :

$$z = \frac{x^2}{4l(\sin\Theta - \mu\cos\Theta)\cos^2\Theta} - x\tan\Theta. \quad \text{(A1)}$$

Where μ is the friction coefficient between the guide-rails of the lifeboat and skid rails. Defining $a(= L_f\cos\Theta + h\sin\Theta)$to be the horizontal distance between point O and point Q, and "z_a" to be the z coordinate at $x = a$, the necessary clearance H_c becomes:

$$\begin{aligned} H_c >&|z_a| - (L_f\sin\Theta - h\cos\Theta) \\ =& \frac{a^2}{4l(\sin\Theta - \mu\cos\Theta)\cos^2\Theta} + a\tan\Theta - (L_f\sin\Theta - h\cos\Theta). \end{aligned} \quad \text{(A2)}$$

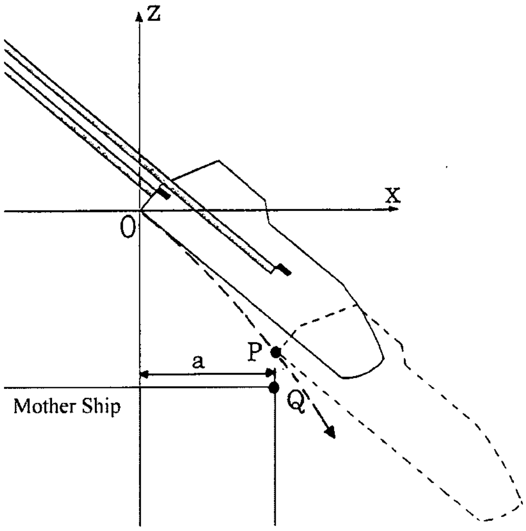

Figure 18: The trajectory of point P

(2) Considering the trim of the mother ship

Consider the trim in bow condition of the mother ship, i.e., the stern edge(point Q) of the mother ship raises, and the trim angle becomes ϕ. In this case, it can be considered that the parameter Θ in (A1) becomes $(\Theta - \phi)$. The equation that express the trajectory of point P can be expressed as :

$$z = -\frac{x^2}{4l\{\sin(\Theta-\phi) - \mu\cos(\Theta-\phi)\}\cos^2(\Theta-\phi)} - x\tan(\Theta-\phi). \tag{A3}$$

Next, define the new coordinate system $O - x'y'$ which is rotated with angle ϕ from the coordinate system $O - xz$ in Figure A1, and express (A3) by using x' and z'. then solve the simultaneous equations with

$$x' = a. \tag{A4}$$

Thus, the position is determined where point P crosses over point Q. When we describe the z' coordinate, where $x' = a$, to be z'_a, the necessary clearance becomes:

$$\begin{aligned} H_c > & |z'_a| - (L_f \sin\Theta - h\cos\Theta) \\ = & \frac{\cos\phi - 2aC_1\cos\phi\sin\phi - C_2\sin\phi - \sqrt{(\cos\phi - C_2\sin\phi)^2 - 4aC_1\sin\phi}}{2C_1\sin^2\phi} \\ & - (L_f\sin\Theta - h\cos\Theta). \end{aligned} \tag{A5}$$

Where:

$$C_1 = \frac{1}{4l\{\sin(\Theta-\phi) - \mu\cos(\Theta-\phi)\}\cos^2(\Theta-\phi)}, \tag{A6}$$

$$C_1 = \tan(\Theta - \phi). \tag{A7}$$

Equation (A5) holds good irrespective of the sign of ϕ. However, $\phi > 0$(the trim by bow condition of the mother ship) becomes a more severe design condition in general.