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The investigation of launching parameters on the motion pattern of freefall lifeboat using FSI analysis

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Abstract

The freefall lifeboats have been designed to be fast and reliable evacuation system. Once the occupants have gone onboard, the lifeboat is simply sliding from a skid before the freefall. Some second after the water impact, the propulsion system can be started and the lifeboat can sail away from parent vessel. During the launching process, trajectories of freefall lifeboats can be divided into such categories, depending on the headway and advance speed after water entry and surfacing of the lifeboats. The aim of the paper is investigating the influence of the launching parameters such as, sliding distance, angle of skid and the falling height on the motion pattern of the freefall lifeboats by using Fluid Structure Interaction (FSI) analysis. The fluid structure interaction analysis is simulated using penalty coupling algorithm. The fluid is treated on a fixed mesh using a Single Material Arbitrary Lagrangian Eulerian formulation and the lifeboat structure on a rigid shell element mesh using a Lagrangian formulation. The results of the numerical simulations provide the magnitude of launching parameters for safely launching of the freefall lifeboat.

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Keywords: Freefall Lifeboat; Motion Pattern; Launching Parameters

1. Introduction

The performance of the freefall lifeboats is affected by initial launching parameters, such as, length of the launch rail, angle of the launch skid and freefall height. These parameters interact to influence some factors such as: the

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behavior of the lifeboat at the time of water impact, the acceleration forces experienced by the occupants, and headway made by the lifeboat immediately after the water entry, [1]. On the other hand, the trends of the offshore structures design recently show the increment on the height of the platform. Thus it is necessary to investigate the effects of these parameters on the performance of the freefall lifeboat for the safety of the occupants during the freefall launching. The results of the numerical simulations provide the values of launching parameters for the safely launching of the freefall lifeboat.

Since the freefall lifeboat will be applied on the evacuation system of offshore environment. This study was made to predict the motion and attitude of the lifeboat during water entry and surfacing. The motion was categorized with respect to the forward velocity and headway of the lifeboat at first phase of surfacing. Numerical study using FSI analysis was carried out to evaluate the effects of the launching parameters on the motion characteristics. Moreover, a suitable range of skid angle was determined for the freefall lifeboat based on zero forward velocity at surfacing corresponding to different sliding distance and drop heights. The LS-DYNA FSI technique was applied to estimate the influence launching parameters to the motion pattern behavior of the freefall lifeboat.

2. FSI Analysis Technique of LS-DYNA code

In FSI problems, fluid is usually represented by solving Navier–Stokes equations with an Eulerian or ALE formulation. FSI can be simulated using a fluid-structure coupling algorithm, such that fluid is treated on a fixed or moving mesh using an Eulerian or ALE formulation and the structure on a rigid or deformable mesh using a Lagrangian formulation. Since ALE approach is based on the arbitrary movement of a reference domain as a third one in addition to the common material and spatial ones, it controls the mesh geometry independently from material geometry, [2] [3] [4].

The coupling algorithm computes the coupling forces at the fluid–structure interface. These forces are added to the fluid and structure nodal forces, where fluid and structure is solved using an explicit finite element formulation. The Euler–Lagrange coupling algorithm uses a penalty coupling similar to penalty contact in Lagrangian analyses, as shown in Figs. 1, [3].

(a) (b)

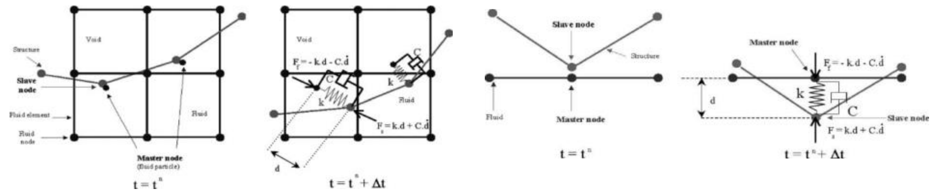

Fig. 1. (a) sketch of penalty coupling algorithm; (b) sketch of penalty contact algorithm, [3]

In FSI problems with interface between different materials such as fluid and air, the distortion of the Lagrangian mesh makes many re-meshing steps for the continued calculation. Eulerian formulation can be used to create easily an undistorted mesh for the fluid domain. However, this approach requires settling two problems, such as the interface tracking and the advection phase. To solve these problems, an explicit finite element method for the Lagrangian phase and a finite volume method for the advection one are used, [2] [3] [4].

There are two approaches to implement the ALE equations. Firstly, the solution of the fully coupled equations for computational fluid mechanics handling a single material in an element and reference of an operator split for each time step into two phases with the first Lagrangian phase and secondly, the advection phase. Contrary to the Lagrangian phase, in the second advection phase, transport of mass, internal energy and momentum across cell boundaries are computed; this may be thought of as remapping the displaced mesh at the Lagrangian phase back to its original or arbitrary position element. The VOF method is attractive for solving a broad range of non-linear problems in fluid and solid mechanics, because it allows arbitrary large deformations and enables free surfaces to evolve, [2] [3] [4].

3. Simulation model

The freefall lifeboat launching was simulated by ALE3D option of LS-DYNA. The outer surface of the lifeboat model was made using rigid shell elements to minimize the computational time. The number of elements that used was 5224 elements, as shown in Fig. 2. Among the three contact options, such as kinematic constraint method, penalty method and distributed parameter method, the second one was adopted for contact between the lifeboat and skid.

The second model is the fluid model. For impacts of objects into the water, an Euler mesh representing air must be modeled on top of the water to allow the water to form the wave that occurs in an impact. Since the air is assumed to have only a little influence on our simulation, it can be modeled as a void. The dimensions of the water and void block are 26.5 x 58.97 x 4 m and 26.5 x 58.97 x 21.8 m respectively. Fine mesh, 0.3 × 0.3 × 0.3m of fluid element was used around at the free surface with mesh size increment of bias 20% along the vertical direction.

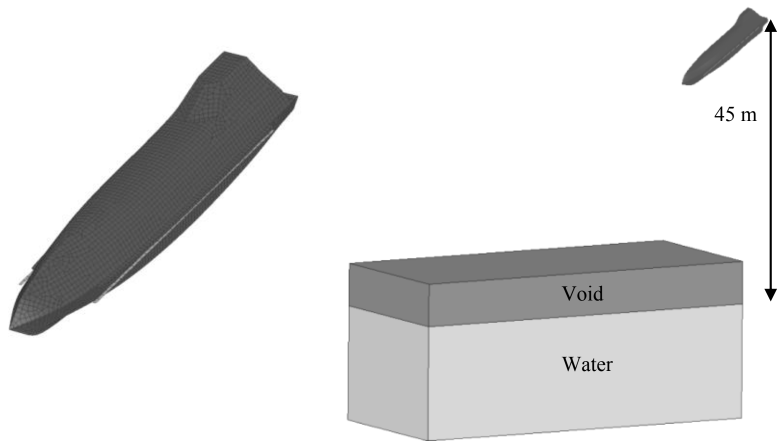

Fig. 2. Simulation model of freefall lifeboat launching

There are several commands and options for the fluid modeling and coupling algorithm using FSI analysis technique of LS-DYNA code in addition to the structural modeling and contact option. For fluid modeling, 3D fluid element is usually considered; ELFORM 12 has been chosen to create the single material ALE formulation in SECTION_SOLID command.

For the fluid material description, MAT_NULL command and Equation of State (EOS) have to be defined, [5]. Since this study is not concerned with tracking the propagation of energy and pressure in water and air, EOS_LINEAR_POLYNOMIAL card was used for defining the equation state of water, the properties of EOS linear polynomial of fluid model are shown in Table 1, [6].

Several parameters are very sensitive to the coupling between the fluid and structure in CONSTRAINED_LAGRANGE_IN_SOLID command. Coupling leakage and penalty force, etc., are affected by the penalty factor, number of quadrature coupling points on a Lagrangian segment and the mesh size ratio between the structure and fluid. Following this conditions the default setting was used for the penalty factor and number of quadrature coupling points. Additionally, continuum treatment and advection method might be selected in CONTROL_ALE command.

The boundary condition of fluid model and constraint condition of structure are also important to the acceleration responses of freefall lifeboat water entry on to the water. The following assumptions were considered as follows:

- Only gravitational external load was applied to the whole system using a load curve for the gravitational acceleration time history
- Top, side and bottom boundaries of the fluid were fixed to the normal directions and were set free to the outer directions.
- Initial velocity of lifeboat was set to zero

Table 1. EOS linear polynomial of fluid model

Item	Water
Density (kg/m3)	1025
C0 (Pa)	0
C1 (Pa)	2.036×10^{9}
C2 (Pa)	8.432×10^{9}
C3 (Pa)	8.014×10^{9}
C4	0.4934
C5	1.3937
C6	0
E0 (Pa)	3.8442×10^{6}
V0	1

4. Results and discussion

4.1. Motion Pattern of Freefall Lifeboat

A numerical study has been carried out to investigate the motion of freefall lifeboat for different initial conditions of falling. Launching parameters such as falling angle, fall height, skid length and launch rail length abaft the center of gravity have been varied and correspondingly different type of trajectories for lifeboats have been obtained for these varying launching parameters. These trajectories of freefall lifeboat are different from each other. The motions of freefall lifeboat can be divided into four categories depending upon the headway and advance speed after water entry and surfacing of the lifeboat, Fig.3., [7] [8], The categories are described below.

- **Motion pattern – I**: after water entry and surfacing, the lifeboat will have a positive headway and significant forward speed. It will move sufficient distance from the parent vessel within a very short period, since the advance speed of the boat is high enough after water entry and surfacing. Obviously, this is the most desirable type of motion for the freefall lifeboat.
- **Motion pattern – II**: after water entry and surfacing, the lifeboat will have a positive head way and will proceed some distance from the parent vessel with an up and down movement. In this case, the advance speed of the boat is positive but not significantly large. This category of motion is also acceptable but there remains a risk of the boat coming back towards the danger location in the presence of a high wind and head sea wave situation.
- **Motion pattern –III**: after water entry and surfacing, the lifeboat may have a positive headway but a backward velocity will make the boat move back to the danger location. This motion type is dangerous and will cause severe damage to the system evacuation and injury to the occupants.
- **Motion pattern – IV**: this is the most erratic type of lifeboat motion wherein the boat will move back almost exactly in the reverse direction as it first hits the water surface. However, the boat will again fall into the water and make a forward or backward movement. If the boat moves forward, there is no possibility to go back to danger location or damage the system. However, the double impact will be happened during this category

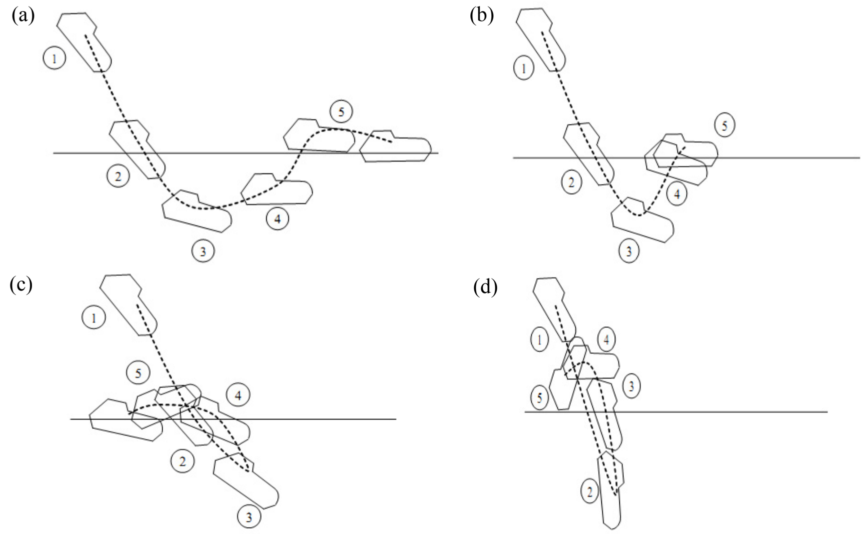

Fig. 3. Motion pattern of freefall lifeboat: (a) motion pattern I; (b) motion pattern II; (c) motion pattern III; (d) motion pattern IV.

a. *The Effects of Launching Parameters on Motion Pattern*

The performances assessment of the freefall lifeboat has been done by using numerical investigations with the LS-DYNA FSI Technique. A number of numerical investigations were carried out to find the combination of the effective skid length (sliding distance, L_{go}) and drop height (H), see Fig. 4, for determining the motion pattern of the freefall lifeboat. The water condition has been assumed as calm (no wave or current) condition.

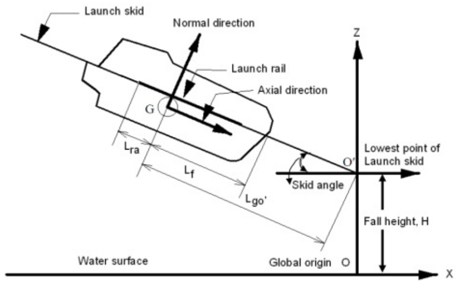

Fig. 4. The definition of variable in freefall lifeboat launching

Based on the numerical result, the relationship between launching parameters drop height (H), sliding distance (L_{go}) and resulting motion patterns of type I, II, III and IV of the freefall lifeboat is described in Fig 5. In the Fig. 5. (a), it can be shown that the motion pattern of the freefall lifeboat for a falling height of 40 m, the sliding distance is 7.36 m; the falling angle is 35 degrees is the motion pattern-I. It means that the motion pattern of the freefall lifeboat is acceptable motion pattern.

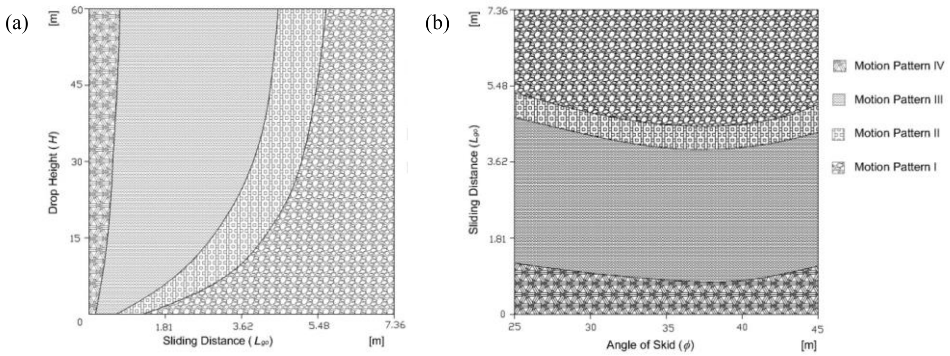

Fig. 5. (a) Relationship of sliding distance, drop height and motion pattern of the freefall lifeboat (skid angle = 35^0); (b) Relationship of skid angle, sliding distance and motion pattern of the freefall lifeboat (drop height = 40 m)

It is also observed that if the sliding distance is increased, the axial velocity of the lifeboat at the end of the sliding stage increase and the boat will have a better motion due to higher advance speed at first phase of water entry and surfacing. According to the simulation result the minimum sliding distance to have the motion pattern type I, for the drop height 40 meters is 5.48 m, Fig. 5. (b). The correlation between sliding distance and motion pattern is shown in table 2.

Table 2 Relation of sliding distance and motion pattern

Sliding Distance	Motion Pattern
< 1.81 m	IV
1.81 m to 3.63 m	III
3.63 m to 5.48 m	II
> 5.48 m	I

b. The Effects of Launching Parameters on Forward Velocity

The influence of the combination sliding distance and falling height to the some particular forward velocities on surfacing of the freefall lifeboat was investigated. Since the sliding distance has generate initial forward velocity before the water entry, it is important to know the combination of sliding distance and falling height that able to produce the safe forward velocity.

According to the launching condition, that the freefall lifeboat will be launch in the angle of skid is 35 degrees, the forward velocity performance was investigate with the relations of drop height and sliding distance. The result shows that a small increase in the sliding distance will increase the horizontal velocity in the case of fixed drop height.

In the case of a particular forward velocity, the increase in the sliding distance is very large for the range of falling heights consider. For an instance at skid angle 25 degrees, and 45 m drop height there will be negative velocity for a sliding distance 5.48m, whereas at 45 m drop height the required sliding distance for zero forward velocity is 7.31m. Based on these characteristics, the required sliding distance can be determined for a desired forward velocity with the maximum skid length that determined by the designer as a constraint with considering the space that available

Fig. 6 describes the relation between the angles of skid and drop heights that produce the positive forward velocity on the freefall lifeboat. Based on the graph, for a particular sliding distance, there is a maximum drop height that the freefall lifeboat able to produce the accepted forward velocity (positive velocity). In the case of 40 m drop height, angle of skid 35 degrees, the minimum sliding distance 5.48 m. By increasing the sliding distance became 10.97 m, the positive velocity area will be larger. It can be explained that the boat has improved their forward velocity performance and expand their drop height coverage by increase their sliding distance. If the sliding distance is reduced, the drop height coverage also will be reduced and the forward velocity will be decreased.

Based on the investigation the effects of the launching parameters such as: drop height, sliding distance and angle of skid on the performance of the freefall lifeboat (motion pattern and forward velocity), the free fall lifeboat should be installed in the following configuration: the drop height range is 35 m – 45 m, the angle of skid is 35 degrees and the minimum sliding distance is10.97 m.

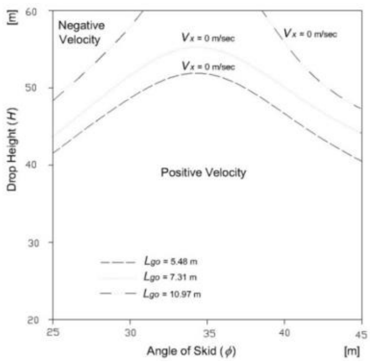

Fig. 6. Relationship of drop height, angle of skid and forward velocity of the freefall lifeboat

5. Conclusion

The motion pattern of the freefall lifeboat has been investigated using FSI analysis with respect to the launching parameters such as: sliding distance, drop height and angle of skid. According to the numerical results, the following conclusions can be made:

- The motion patterns of the freefall lifeboat have to be investigated, since inadequate motion pattern (Motion pattern II, motion pattern III, and motion pattern IV) may be happened during the launching and it have injury potential for the lifeboat occupants.
- The LS-DYNA FSI analysis using ALE formulation with penalty coupling algorithm is able to estimate the motion pattern behavior of freefall lifeboats due to the configurations of launching parameters.
- Although numerical investigations have shown the performances of the freefall lifeboat, the validation should be done by comparing the computational results with the experiment measurement.

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