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THE DEVELOPMENT OF NEW TYPE FREE-FALL LIFEBOAT USING FLUID STRUCTURE INTERACTION ANALYSIS

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Key words: acceleration response, fluid structure interaction analysis, occupants safety, freefall lifeboat.

ABSTRACT

Freefall lifeboats provide a safe alternative to conventional lifeboats for emergency evacuation from ships and offshore platforms. The international regulations require that a lifeboat for free-fall launching should be able to give protection against impact accelerations when it is launched with its full occupants and equipment from at least the maximum designed height.

Since the height of offshore structure to the water surface is significantly high, during the water entry phase the acceleration response of the free-fall lifeboat might cause an injury to the occupants. The special hull form design should be applied to reduce the acceleration. The aim of the research is to develop a new type freefall lifeboat for the evacuation system on offshore platform. The new hull form design is proposed and investigated, especially on the acceleration response due to slamming load. The Fluid Structure Interaction (FSI) analysis with the penalty coupling method is used for estimating the acceleration response. The numerical results were compared with the requirements of the IMO regulations.

I. INTRODUCTION

Marine evacuation systems are mandatory requirements to support activities on the ship and offshore platform. The development of marine evacuation system should consider the usability/functionality and habitability to give the long survival period under more severe environmental condition, (Taber et al., 2011). Formerly, the most common lifesaving equipment is the conventional lifeboat. However, many life threatening accidents have occurred with this type of lifeboats during launch into water. This risk has substantially reduced due to the use of free-fall lifeboats recently.

The freefall lifeboats have been designed to be fast and reliable evacuation system. Once the occupants have been gone onboard, the lifeboat is simply sliding from a skid before the free-fall. Some seconds after the water impact, the propulsion system can be started and the lifeboat can sail away from hazard location. Although the free-fall lifeboat has offered a safe alternative to conventional lifeboat, however the injury potential of the occupants was appeared because of acceleration response induced by the slamming load. Regulations for the protection against the impact acceleration were imposed by the International Maritime Organization (IMO) and national regulatory agencies.

Since the height of offshore structure to the water surface is significantly high, the acceleration response would become the main factor on the development of new type hull form of free-fall lifeboat. The particular hull form design should be applied to reduce acceleration response, such as: FF1200 from Schat Harding Company, and torpedo type from Noreq Company. The aim of this paper is to develop an alternative new type hull form of free-fall lifeboat for evacuation system on the offshore platform. The application of the deep V shaped (chine type) as the free-fall lifeboat hull form was investigated for the proposed design. The acceleration response of proposed design was evaluated by the numerical simulation using FSI analysis Technique with penalty coupling method of LS-DYNA code.

II. FSI ANALYSIS FOR ESTIMATION OF ACCELERATION RESPONSE OF FREE-FALL LIFEBOAT

The impact of the boat with the water was formulated on the mathematical equations by using theories of hydrodynamics, (Newman et al., 1989; Boef W. J. C., 1992 a; Boef W. J. C., 1992 b; Arai et al., 1995). The water entry problem of the free-fall lifeboat could be treated as FSI problems, such as slamming and sloshing. These FSI problems could be conveniently simulated using Arbitrary Lagrangian Eulerian (ALE) formultion and Euler-Lagrange coupling algorithm. Volume

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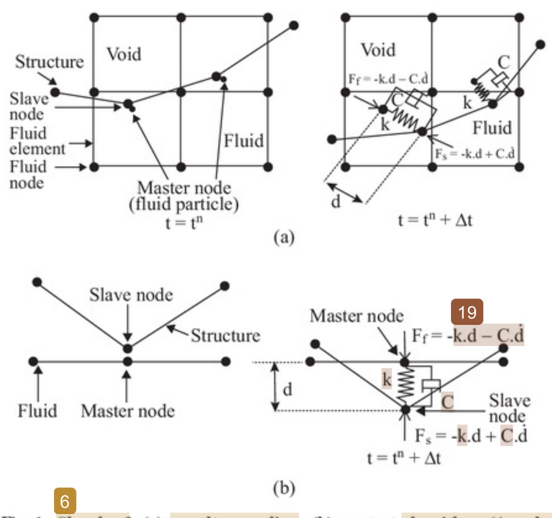


Fig. 1. Sketch of: (a) penalty coupling; (b) contact algorithm, (Aquelet et al. 2006)

of Fluid (VOF) that able to solve a broad range of nonlinear free surface problems is adopted for solving the formulations. The coupling algorithm is more suitable for the coupling between Euler element and Lagrange element on the complex structure problem, since the fluid grid is able to overlap with the structure mesh, (Aquelet et al., 2006).

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 independent from material geometry, (Souli et al., 2000).

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 are solved using an explicit finite element formulation. The Euler-Lagrange coupling algorithm uses a penalty coupling similar to penalty contact in Lagrangian analyses, see Fig. 1.

The large deformation of the fluid elements caused the Lagrangian formulation has to be solved by creating many remeshing steps to continue the calculation step. Eulerian formulation can be used to create easily an undistorted mesh for the fluid domain. However, surfaces and boundary conditions are difficult to track using this approach. To solve these problems, an explicit finite element method is used for the Lagrangian phase and a finite volume method for the advection problem, (Souli et al., 2000; Aquelet et al., 2003; Aquelet et al., 2006).

There are two approaches to implement the ALE equations. The first way solves the fully coupled equations, but this is only able to handle a single material in an element. The other way is using an operator split for each time step which uses two phases with the first Lagrangian phase and the second 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 operator split was used for the ALE formulation on the free-fall lifeboat simulation.

III. HULL FORM DEVELOPMENT

The new type of lifeboat was proposed by applying the deep V shape and the chine type hull form. The hulls with the steep dead rise angle able to slice through waves as they enter the water, and not pound along on top of the waves. The other advantage of the deep V shape is the capability to have a superior riding on the rough conditions. By the kinds of characteristics, the deep V shape would be adopted to reduce the effect of the slamming load on the acceleration responses.

The main variables that influence the performance of impact response motion are the angle of inclination of the under surfaces (α) and the impact velocity (V_0), (Karman, 1929). Since the impact velocity has been determined by launch height, the Karman formula has shown that the angle of section was the main parameter on the development of new hull form. Based on the condition the development was made through the variations of dead rise angle by the purposed to minimize the acceleration response.

$$P_{max} = \frac{\rho V_0^2}{2} \pi \, Cotg \, \alpha \qquad (1)$$

Where,

P_{max} = The impact pressure,
$\frac{\rho V_0^2}{2}$ = Dynamics pressure
$\pi \, Cotg \, \alpha$ = Theoretical factor of increase
V_0 = Impact velocity
ρ = The seawater density
α = the angle of inclination of the under surfaces

Since the existing hull form design of free-fall lifeboat has many kind shapes type, the first step is classifying and selecting the hull form type and develops the new type of hull form. Furthermore, finite element model of each type of lifeboat hull form was created and evaluated by the numerical analysis. If the proposed hull form has the higher impact acceleration than the existing one, then the modification of deadrise angle of the proposed hull form was made. Since the

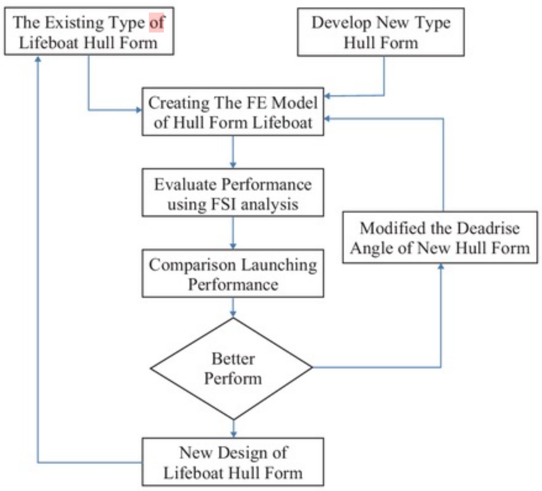
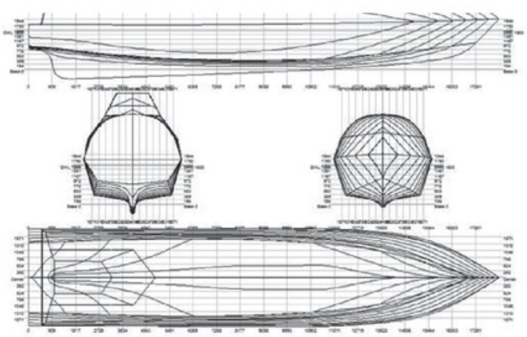


Fig. 2. Flowchart of development methodology.



Principal Dimension:		
Length	:	18.17 m
Breadth	:	3.70 m
Draught	:	1.50 m
Height over all	:	4.80 m
Water plane area	:	25.89 m^2
Displacement	:	55.73 m^3

Fig. 3. The final hull form as results of deadrise angle modifications.

deadrise angle was modified, the lines would be changed following the same displacement and the principal dimension of the lifeboat. Finally, the smallest acceleration response of designed hull form was considered as the new design of lifeboat hull form. The flow chart of development methodology is shown in Fig. 2, and the final design as a result of the deadrise angle modifications that proposed as the new type free-fall is shown in the Fig. 3.

IV. IMO CRITERIA USING SRSS METHOD

Table 1. SRSS acceleration limits for lifeboats.

direction	acceleration (g)	
	training	emergency
Gx	15	18
Gy	7	7
Gz	7	7

In the lieu of the evaluation with the dynamic response model, the injury potential for an occupant in a free-fall life boat is evaluated by the acceleration using the Square Root Sum of the Squares acceleration (SRSS) method. The limiting values incorporated into the revised recommendation for testing lifeboats by IMO are 15 g (gravity acceleration) in the x-axis and 7 g in the other axes, as shown in Table 1. The SRSS criteria formula is the Eq. (1), as follow:

$$CAR = \sqrt{\left(\frac{g_x}{G_x}\right)^2 + \left(\frac{g_y}{G_y}\right)^2 + \left(\frac{g_z}{G_z}\right)^2} \quad (2)$$

Where,

CAR = Combined Acceleration Ratio Index
g_x, g_y, g_z = The concurrent accelerations in the x, y, and z seat axes
G_x, G_y, G_z = Acceptance limit of acceleration

The Combined Acceleration Ratio (CAR) is a measure of the potential for the acceleration to cause human injury. It is varied according to the time and it is computed from acceleration time histories measured in the axes of the seat at the seat support. Before computing the CAR time history, the measured accelerations were filtered with 20.0 low pass filter because higher frequency accelerations are not generally injurious. The peak value of the CAR time history is called the CAR Index. Injury should not be occurred if the CAR Index is less than IMO criteria, (IMO, 2003).

V. SIMULATION MODEL

The free-fall lifeboat launching was simulated by ALE3D option of LS-DYNA. The outer surface of the lifeboat model was modeled using rigid shell elements to minimize the computational time. The number of elements that used was 5224 elements, as shown in Fig. 4. 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 the air must be modeled on top of the water to allow the water to form the wave that occurs. Since the air is assumed to have only a little influ-

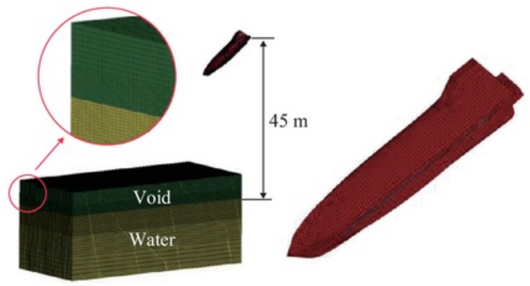


Fig. 4. Simulation model of free-fall lifeboat launching.

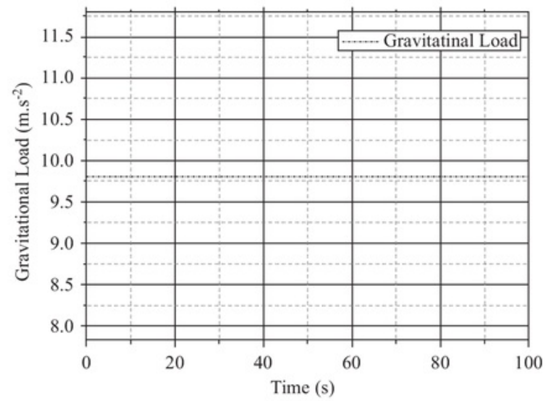


Fig. 5. Load curve for the gravitational acceleration time history.

ence on our simulation, it can be modeled as a void. The dimensions of the void and water block are 26.5 m × 58.97 m × 4 m and 26.5 m × 58.97 m × 21.8 m respectively. Fine mesh, 0.3 × 0.3 × 0.3 m of fluid element was used around at the free surface with mesh size increment of bias 20% along the vertical direction.

There are several command 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, (LSTC, 2009). 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 property of EOS linear polynomial of fluid model is shown in Table 2, (Shin, 2004).

Several parameters are very sensitive to the coupling between the fluid and structure in CONSTRAINED_LAGRANGE_IN_SOLID command. Coupling leakage and penalty force 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. Thus, the default setting is used for the penalty factor and number of quadrature coupling points. Additionally, continuum treatment and advection method can 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 free-fall lifeboat water entry on to the water. The following assumptions were considered as follows:

1. Only gravitational external load was applied to the whole system using a load curve for the gravitational acceleration time history, see Fig. 5.
2. Top, side and bottom boundaries of the fluid were fixed to the normal directions and were set free to the outer directions.
3. Initial velocity of lifeboat was set to zero.

VI. SIMULATION RESULTS

The explicit methods were used to solve the problem formulation. Explicit methods do not require matrix decompositions or matrix solution. Instead, the loop is carried out for each time step. However, for explicit codes to remain stable, the time step must be less than the time taken for a stress wave to cross the smallest element in the mesh. The default initial time step was used during calculation. The analysis was run using Intel Core-i7 processors for hardware and LS-DYNA version 971 R.4.2 single precision as a solver algorithm.

Considering the location of center of gravity (COG) and the weight of the free-fall lifeboats that influenced the magnitude of the acceleration response of free-fall lifeboat, the simulation result shows a good agreement with the study by Nelson, (Nelson et al., 1995). Based on the simulation results, the largest z-axis acceleration on the proposed lifeboat was achieved at the 50% backwards position of the occupant distribution, see Fig. 6. This tendency explains that the condition has shifted the COG point to the backwards. If the COG is shifted backwards, the severity of the slamming phase will increase, especially the acceleration response on the z-axis direction. However, if the COG shifts forwards, the opposite occurs. At the condition, the righting moment arms is reduced, therefore the severity of the slamming will be reduced, as it happened in 50% forwards conditions.

The magnitude of weight boat has an effect of the accelerations response, since the boat with a larger mass able to dive deeper into the water. Therefore, deceleration of the boat would take longer period of time and smaller peak accelerations. It explains the full conditions has a better acceleration response compares than the empty condition, (Table 3).

Regar ding the CAR Index on the all of loading conditions, the proposed free-fall lifeboat has passed the IMO Criteria. It can be explained that the acceleration response that generated during the impact with the water do not injured the lifeboats occupants. The deep V-shaped chine type hull form is reliable

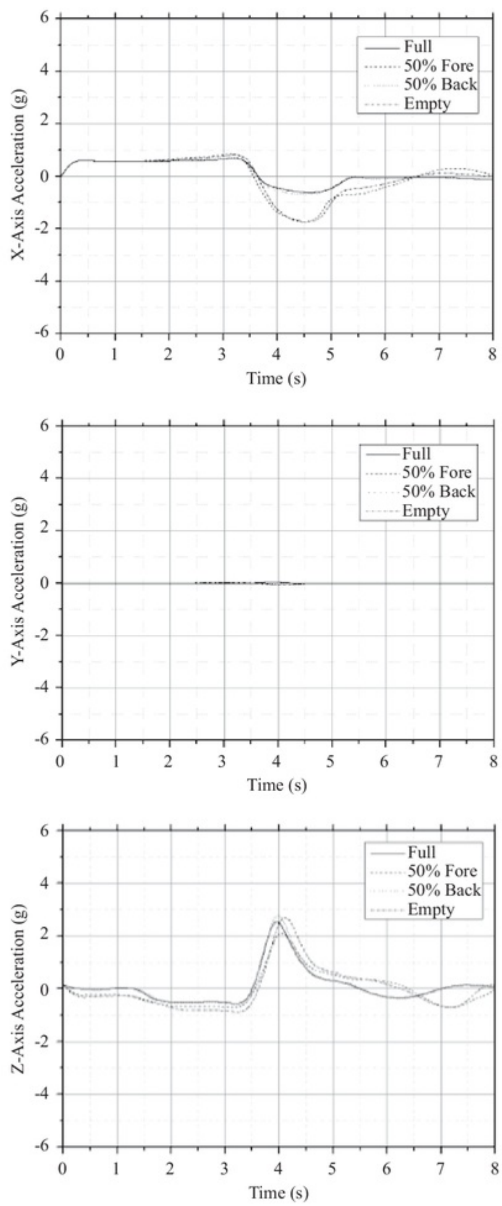


Fig. 6. Simulation result of acceleration response of proposed free-fall lifeboat.

to be applied as an alternative hull form for the free-fall lifeboat on the evacuation system of offshore platform.

VII. CONCLUSION

The deep V-shaped chine type hull form has been devel oped to obtain the alternative hull form of the free-falllifeboat

Table 3. Maximum acceleration response and CAR Index.

Loading Condition	Acceleration Response (g)			CAR Index
	X-Axis	Y-Axis	Z-Axis	
Full	0.892	0.038	2.541	0.368
Occupant 50% Forward	1.762	0.056	2.105	0.323
Occupant 50% Backward	0.687	0.049	2.782	0.400
Empty	1.729	0.059	2.698	0.402

for the evacuation system on the offshore platform. Since the development of the alternative hull form is difficult and expensive to obtain by the experimental methods, the simulation analysis by using LS-DYNA Fluid Structure Interaction (FSI) technique is adopted on the methodology of the hull form development. Estimation of the acceleration response of the free-fall lifeboat will be used to determine the Combined Acceleration Response Index which is measuring the potential for the acceleration to cause occupants injury.

The simulation results show that the acceleration response of the lifeboat has passed the requirement of IMO standard. It is indicated that the deep V-shaped chine type hull form is reliable to be applied on the free-fall lifeboat for the offshore platform evacuation system. Although numerical investigations have shown the performance of proposed design of the lifeboat, the experimental wet drop test of the proposed hull form should be made for the requirement of classification regulation to pass the design certification.

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