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Evaluation of Adequacy of Current Design Criteria for Free-Fall Lifeboat. Literature overview

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1 Introduction

The free-fall lifeboat have been a common lifesaving appliance for cargo ships, tank ships, semisubmersible drilling platforms and fixed production platforms. The free-fall lifeboat was developed to reduce the risk of injury during evacuation in maritime emergency. The free-fall lifeboat offers advantages over conventional lifeboat system, particularly in harsh environments ([20]). Because of the increase in safety they represent compared to conventional lifeboats, the free-fall lifeboats are accepted by most maritime regulatory authorities, who have developed design and certification criteria for them.

The first free-fall launching system, which featured an open lifeboat on a tilting skid close to the stern of a vessel, was patented by A.E.Falk of Stockholm as early as 1897. The first manned lifeboat was launched in 1977 from stern of the Norwegian 120 000 dwt bulk carrier Tarcoola, in Oresundsvarvet shipyard. Currently, the free-fall lifeboats are used on cargo ships, tankers and offshore facilities. Free fall heights range from about 5 meters on small ships to over 30 meters on fixed offshore platforms. There are possibly up to 1500 free-fall boats installed on ships and platforms throughout the world ([15]).

The purpose of this study is to assess possibilities to minimize risks of injury for occupants during training with free-fall lifeboat launch and to make suggestions about future investigation of lifeboat launch by free fall. The study is initiated by Swedish Maritime Administration and SEKO (The Union of Service and Communication Employees, Sweden) in response to five accidents occurred in Sweden between 1998 and 2001. The launch height was more than 20 meters in all mentioned cases.

2 Literature overview

2.1 Accidents involving free-fall lifeboats

The following accidents with free-fall lifeboats occurred and were logged in Sweden (height of the free fall in all five accidents was about 20 meters):

- M/S Rigoletto, 30 October 1998. 1st engineer was in the middle of the free-fall lifeboat, three persons sat aftwards from him and 12 persons were forward of him. This person is 1.95 m tall and had only 1 cm between his head and the lifeboats top at this place. When the lifeboat entered the water he was pressed back and up and he hit his head in the lifeboat top which lead to whiplash injury. At first the injury was considered as minor but whiplash was discovered later at the hospital. This person has lost his licence for seagoing service.
- M/S Don Quijote, 16 December 1998. 3rd officer reported back pain after free-fall exercise. Pains lasted for 6 weeks.
- M/S Elektra, 13 May 1999. During an exercise of a newly installed free-fall lifeboat at the shipyard in Korea a yard worker was badly injured. This was caused by human error since the yard worker released his safety belt in order to assist in releasing the free-fall lifeboat.
- M/S Titus, 15 November 1999. During an exercise the free-fall lifeboat landed in the water slightly listing. After the exercise one able seaman was treated at a hospital for a small injury, many of the crew suffered from minor injuries.
- M/S Boheme, 29 October 2001. The free-fall lifeboat is certified for 30 persons. At this drill eight persons were in the boat. Height of the free fall was about 22 meters. During an exercise the Master received a spine injury. He was taken to a local hospital and later repatriated home assisted by two paramedics. 2nd officer suffered from severe pains in both thighs for a week after this exercise.

In [1] the accidental release of a free-fall lifeboat which caused serious back injuries on one person is described. The main factors contributing to this incident were crew member's lack of knowledge about the free-fall controls and the labelling and instruction for lifeboat release gear were not in the language of the crew. This incident has been mentioned also in [10] together with another accident resulted in an injury during free fall launch due to the failure of the seat anchorage.

It is interesting to note ([9]) that in a summary published at the end of 1988, it was estimated that approximately 34 500 people had attended a total of 1805 launches at the three training facilities in Norway and that only three minor injuries had been recorded. Two of these were caused by persons being hit by loose or handhold vhf radios and the other was caused by the person concerned not resting his head against the seat back. This resulted in a headache, which was claimed to be "a small concussion". About 150 ship launches of Harding's FF34s took place over the same period, all without reported injures ([9]).

Between 28th of November 1985 and 9th of November 1992 59 176 people participated in the free fall training in NUTEC Training Facilities in Bergen, Norway [14]. Free fall training carried out from a height of 28 meters (35 239 people) and a height of 12.5 meters (23 937 people). 16 minor injures were recorded during these tests, which is about 0.03% of the total number of tested people.

In [26] discussions during an informational meeting to exchange views on the subject of compulsory testing of free-fall lifeboat are presented. The meeting was organised by the Belgian branch of The Nautical Institute. As an introduction to the debate on safety, it was pointed out that there are several cases on record in which crew members became injured during boat drills.

2.2 Study of free-fall launching

During the launch of free-fall lifeboat, there are two primary considerations. The first consideration is the kinematics of the lifeboat. The lifeboat must remain clear of the vessel from which it was launched and after water entry it must make positive headway. The second consideration is the acceleration field to which the occupants in the lifeboat are subjected. The acceleration field should be of such a nature that the occupants are not injured during the free-fall and subsequent water entry. Both of these considerations are affected by changes in hull shape, lifeboat loading, the inertial characteristics of the lifeboat and the initial launch conditions ([21], [22]). The effect of these parameters can be evaluated experimentally with scale model and full-scale lifeboats.

2.2.1 Model and full-scale tests of free-fall lifeboat

Through model and full-scale test much has been learned about the behaviour of free-fall lifeboats.

In [8] measured accelerations and the corresponding CDRRs (dynamic response criteria, training) for the stern and bow seats of FL50 are presented. The acceleration components and CDRRs are for seats in an upright position, facing backwards. The drop height was 27 m and the test was repeated twice. The maximum acceleration in z-direction was about 12 g for the stern seat and 13 g for the bow seat. The CDRR index (training) was under 1.0 for the stern seat during the launching. For bow seat the CDRR was about 1.0 at the water entry.

In [17] the results from the acceleration measurements at midships and stern seat location are presented. The results are compared with computed acceleration. The launch height was 19 meters and the launch angle was 35 degrees. The measured accelerations were within the allowable range.

In [16] a procedure for measuring accelerations and an algorithms necessary to determine the kinematics behaviour of the free-fall lifeboat are discussed.

In [24] the measurements from the certification test of the free-fall lifeboat FFL32 are presented. The calculated DR (dynamic response) criteria meet requirements despite the magnitude of the acceleration in x- and z- directions are higher as allowable for evaluating by the SRSS method.

In [31] measured acceleration from the model and full-scale tests are presented. The launching height was 14 meters. The accelerations from the tests are compared with the computed acceleration history. The calculated DR index didn’t exceed 1 in all tested cases.

2.2.2 Mathematical modelling of free-fall lifeboat launch behaviour

The model and full-scale tests are expensive to conduct. A mathematical model can be used to quantitatively evaluate the kinematics of a free-fall launch and to provide a basis for interpreting the results of experimental studies. With mathematical modelling the launch behaviour of free-fall lifeboats can be predicted from the time the boat is released until it is in the water. Through comparison with full-scale test data, these models are shown to provide a reasonable prediction of the launch behaviour of free-fall lifeboats.

Arai M. ([3], [2], [4],[5] and [6]), Boef W.J.C. ([7] and [8]), Nelson J.K. ([16], [17] and [19]) , Khondoker M.R.H ([11], [12], [13]), Wiśniewski Z. ([27], [28] and [31]) present the methods of predicting the behaviour of free-fall lifeboat, when dropped from an offshore platform or a ship.

2.2.3 Studies of parameters influence

There are many factors that affect the behaviour of a free-fall lifeboat when it is launched. These factors include the mass of the lifeboat and the location of the centre of gravity, the radius of gyration and the geometric shape of the lifeboat, the length and angle of the launch ramp, the skid length, the launch height and a skid friction. The factors interact to affect the orientation and velocity of the lifeboat when it enters the water and behaviour of the lifeboat immediately after water entry.

The following studies have been done:

- In [2] (Arai M.) the acceleration force acting on the boat during its water entry depends on geometric shape of the boat, its loading and initial condition of launch such as launch angle, launch height, sliding length and guide rail length is examined.

- In [4] (Arai M.) four categories of the lifeboat motion after water entry are discussed. The relationships of four launching parameters (angle of launching skid, sliding distance of a lifeboat on the skid, fall height and guide rail length) to the motion categories are investigated It is also found that the horizontal velocity of the lifeboat at water exit is an effective criterion for identifying unfavourable motions of the free-fall lifeboat after water entry. The acceleration exerted on the occupants of the lifeboat during water entry is evaluated by SRSS method and the velocity criterion, the launching parameters and the angle of safe seating for the occupants are discussed.

- In [5] and [6] (Arai M.) a new skid-launching method of free-fall lifeboat is described. Numerical simulation and model experiments were carried out for purpose of comparing the performance of the two systems, i.e., the double-skid launching method and the conventional one.

- Effects of mass and mass distribution on the launch behaviour of free-fall lifeboats are investigated in [18] (Nelson J. K. and Fallon D. J. et al). These effects have been evaluated on basis of water entry orientation and acceleration profile in the lifeboat. Qualitative as well as quantitative observation of the launch phenomenon are discussed.

- In [19] (Nelson J.K) the behaviour of a free-fall lifeboat during different phases of the launch cause by variation of the parameters such as launch angle, the longitudinal location of the CG, coefficient of friction, ramp length in front of CG and the launch height are investigated. As the result of this study several issues regarding the certification of free-fall lifeboats become evident. First, a free-fall lifeboat and its launching arrangement should be certified as a single and complete system. The second issue is the data (launch ramp length, the launch angle and the maximum certificated free-fall height) to be included on lifeboat certificates. A third issue is the launch tests (the four different loading conditions) to which the lifeboat is to be subjected.

- In [11] and [13] (Khondoker M.R.H.) the motions of a free-fall lifeboat during launch are investigated. The motion of the lifeboat has been divided into four categories depending upon the headway and advance speed after water entry. The effects of launching parameters on the performance of the lifeboat have been evaluated corresponding to the motion categories and horizontal velocities at surfacing. Influence of the following parameters on behaviour of the lifeboat during launch has been studied: fall height, falling angle, skid length.

- In [12] (Khondoker M.R.H.) the behaviour of a hook-launching free-fall lifeboat is investigated. Time histories of acceleration are presented in the form of "polar diagram" which provides evaluation of the safe seat angle. Investigation have been carried out to evaluate different velocities of the centre of gravity of the lifeboat at water exit with respect to falling angles and falling heights. The values of maximum axial and normal accelerations in different longitudinal positions of the lifeboat with respect to these parameters have also been studied.

- In [28] (Wiśniewski Z.) the focus is on determination of the trajectory of the lifeboat and dynamic forces upon its occupants to minimize the risk of an injury. The simulation procedure, when used in course of design, makes it possible to improve the hull shape and properly position the seats to ensure minimum load exerted upon the occupants.

- Chances of safe evacuation of the disabled persons are evaluated in [29] (Wiśniewski Z.). The influence is analysed of the dynamic behaviour of the free-fall lifeboat on the casualties placed on various types of stretchers and differently located in the lifeboat.

- Two free-fall lifeboat projects developed in Norway are presented in [25] (Werenskiold P., Klem P.). The most important design parameters and their influence on system qualities, proposed main functional requirements and standard test procedure are summarized in the paper.

2.3 Methods to evaluating the potential of an acceleration field

During the launch of the free-fall lifeboat, there is a potential for the occupants to be injured. The potential exists because of the acceleration forces exerted upon the occupants when the lifeboat impacts the water.

There are three currently used methods to evaluate the potential for an acceleration field to cause injury. These methods are the square-root-sum-of -the- squares criteria (SRSS method), the dynamic response criteria (DR) and the Hybrid III human surrogate. The first two methods have been adopted by the IMO in Resolution MSC.81 (70) "Recommendation on Testing of Life-Saving Appliances" (IMO, 1999). The SRSS method considers only the magnitude of the acceleration force. By contrast, the dynamic response model includes also consideration of the duration of the acceleration force impulse.

The dynamic response model based on research conducted at the Aerospace Medical Research Laboratory at Wright-Patterson Air Force Base. In this model it assumes that the human body response in each coordinate direction can be characterized as an independent, single degree of freedom mass-spring system subjected to the acceleration field.

When using the SRSS criteria or the dynamic response it also must be remembered that neither method can predict if an injury will occur nor what that injury will be. Human surrogates (dummies) are commonly used to study the effects of impact and acceleration on humans, particularly when the impact may cause injury. The effects of occupant-seat coupling as well as the effects of the water entry forces can be investigated. Because the data obtained from a dummy are predictive, it is possible to identify the type of injury that would likely occur if injury were to occur.

When discussing injury and criteria for acceptable injury it must be remembered that injury is a spectrum extending from the trivial to the fatal. There is no clear definition of what is an acceptable injury or threshold for injury. A primary consideration, however, when evaluating injury caused by impact and acceleration is preservation of consciousness. The escape system must be designed and tested to minimize the risk of head injury ([23]).

Nelson J.K. et al. ([23]) used a human surrogate (Hybrid III) to evaluate the potential for injury. In this study the lifeboat was launched from a height of 25 metes. Measured accelerations at a forward seat support and accelerations which were measured in the head and in the neck of Hybrid III are presented. The computed SRSS and CDRR indexes are compare with HIC (head injury criteria) which was calculated with the help of data obtained from the Hybrid III. These data can be used as the basis for quantitative and qualitative prediction about the type and severity of injury that may result. Medical judgement also must be used to apply the results obtained from a dummy to the broad range of people that can use a free-fall lifeboat. The response of a dummy is representative of the response of a particular class of people (e.g. 50^{th} percentile males).

In [3] and [2] (Arai M.) an alternative concept of “polar diagram of acceleration” is introduced and the effectiveness of it to the study of the acceleration field in a free-fall lifeboat is showed. The safe seat angles for some positions in a lifeboat are discussed. In [4] four categories of the lifeboat motion after water entry are presented. The acceleration exerted on the occupants of the lifeboat during water entry is evaluated by SRSS method and the velocity criterion and also the angle of safe seating for the occupants are discussed.

In [11] and [13] (Khondoker M.R.H.) a horizontal velocity at surfacing of the lifeboat is investigated and a criteria which can be formulated on velocity ratio is proposed.

In [28] (Wiśniewski Z.) the need for using different position for the seat resting in the front and after part of the lifeboat is discussed.

In [30] (Wiśniewski Z.) an attempt is presented to analyse real possibilities of safe evacuation of the casualties of marine accidents with the use of the free-fall lifeboats. Evacuation of the casualties was analysed from the point of view of dynamic load distribution as well as of the evacuation scenario.

2.4 Inside design of free-fall lifeboats

"LSA Code" (IMO, 2003, "The International Life-Saving Appliance Code", chapter 4.4 and 4.7) includes a number of design criteria for carrying capacity of the free-fall lifeboats, among which are the vertical distance between the floor and the interior of the enclosure, width of the seat, clearance in front of the backrest and a backrest length. These requirements are based on body characteristics of "design person". Inspection and measurements of occupants spaces of an conventional free-fall lifeboat during the full scale test on M/S "Don Juan" (ref.[32]) indicated that the seat place and space around do not fit well even for people of medium size. This investigation showed that the current design criteria for free-fall lifeboats should be revised to fit for the realistic range of occupants.

2.5 Training

SOLAS (Regulation 19, paragraph 3.3.4) includes the requirement for emergency training and drills of free-fall lifeboats launching. The training onboard the ship incorporates two parts of training. The first part is the functional test of equipment and the second one is the training of crew members at boarding of the lifeboat and using the lifeboat equipment.

An analysis of injuries during the training of the free-fall lifeboat at the training facilities in Norway (ref. [9] and [14]) shows that the injury frequency is lower (about 0.03%) compared to the drills onboard (five accidents logged in Sweden, see 2.1). Moreover the injuries during training onboard were more complicated. The higher level of stress onboard and different training procedures are conceivable reason for the different injury frequency. However, these problems should be investigated completely.

Furthermore the goals and the necessity of carrying out the fall tests with occupants onboard even at the training facilities should be discussed.

3 Discussion and conclusion

At present a free-fall lifeboat is often used as a life-saving equipment in many ships and offshore facilities for emergency evacuation. To study behaviour of the lifeboat during launch model and full-scale tests can be carried out. However the tests are very expensive to conduct. Mathematical models can be used to evaluate the behaviour of the lifeboat during launch and to provide a basis for interpretation of the results of experimental studies.

During the launch of the free-fall lifeboat, there is a potential for the occupants to be injured. There are three currently used methods (SRSS, DR method and human surrogate method) to evaluate the potential for an acceleration field to cause injury.

There are a number of studies where the behaviour of the lifeboat and risks for occupants are investigated. These studies lead to requirements for certification of free-fall lifeboats. Despite the results of these studies and certification of the lifeboats a number of accidents occurred with personal injuries.

The following problems have received little attention in previous studies and should be more investigated in the future:

- Study of actual accidents occurring during free-fall lifeboat launch.
- Study of the body characteristics for the realistic range of occupants of free-fall lifeboats.
- Influence of occupant-seat coupling on risk of injury.
- Influence of human factors (e.g. stress) on risk to be injured during free fall
- Influence of training procedure (management) on risk injury.

As part of the study of influence of human factors and training procedure (management) on risk injury also discussions about acceptable risk during the free fall training as well as the need for the drills onboard during regular tour should receive more attention.

During an emergency evacuation in hard environment the initial launching conditions and launch behaviour during the fall and water entry will be different compared to training cases. The following issues can be examined more thoroughly:

- Influence of large ship motions on initial launching conditions and behaviour of the lifeboat during launch.
- Influence of environmental condition (e.g. waves) on the behaviour of the lifeboat during water entry.

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