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A Study on Evacuation Safety of Trainingship HANBADA using FDS & maritimeEXODUS

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Abstract : *In this study, it was simulated and analyzed the evacuation safety to identify the cadets' evacuation time by using maritimeEXODUS which is applied IMO MSC.1/Circ.1238 theory as well as the trim and heel which are the major factor of reducing the ship evacuation speed. In addition, this study carried out a simulation through the special program for fire analysis - FDS (Fire Dynamics Simulator) in order to find the effective evacuation time, i.e. life survival time. Particularly, this study did comparative analysis of the influence on the survival of cadets based on the collected simulation data by fire size and sort. As a result of the analysis, It was analyzed the Evacuation Allowable Limit Temperature 60℃ and resulted that there is no influence in evacuation by temperature. As a result of the analysis on visibility evacuation limit 5 m, it was found that the only one evacuation rallying point could not meet the evacuation safety. However, it derived the perfect evacuation safety under the condition of two rallying points available on wood fire. In case of Kerosene, it was satisfied the evacuation safety if the heeling was under 10°. Moreover, it could not meet the evacuation safety by evacuating through upper deck although there were two evacuation rallying points. When it was set by the lifeboat descending maximum angle-20°heel and 10°trim which was described in SOLAS regulation, it was simulated that the wood fire having two evacuation rallying points in the center of the ship satisfied the evacuation safety.*

Key Words : *Evacuation time, maritimeEXODUS, FDS, Temperature, Visibility*

1. Introduction

It is mandatory to have onboard training for surviving guided by international and domestic rules. Fire-fighting and evacuation training is the most important from those surviving trainings so that it is operated regularly one time per month (Korea Registry, 1998). The evacuation training occurs at the last moment of onboard training and it let the passengers to leave the vessel at the sea accident. In this case, it shall be evacuated by lifeboat or life raft but it is not easy for the passengers to assemble at the evacuation muster station due to the complex and narrow structure of the vessel under the fluctuating condition. It is accordingly hard to survive under the maritime special condition. The study is tested for Korea Maritime & Oceans University (KMOU)'s training ship, HANBADA which is in actual operation and performed the evacuation safety on ship fire using FDS to analyze the fire and calculate the survivable time, Evacuation Allowable Limit Time. It also simulated various conditions and analyze the evacuation time by using maritimeEXODUS which is applied the representative ship dynamics and theoretical formula from IMO MSC.1/Circ.1238 (Choi et al., 2010).

2. Investigation on evacuation time

2.1 Theoretical investigation on evacuation time

In this chapter, it is calculated the necessary evacuation time which is spent for the passengers to evacuate. The evacuation time is composed of awareness time and travel time. As it is shown on the Table 1, the ratio of men to women in the experiment was nine to one in the age group of twenties in consideration of trainee as experiment object. In particular, the walking speed for the gender and age-specific was referred to the figures from maritimeEXODUS.

Table 1. Personnel organization

Persons	Age	Sex		Walking speeed
		Male	Female	
100	20~29	90	10	maritime EXODUS value

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The experiment object training ship HANBADA has the length of 114 m, width of 17 m and height of 2.6 m with the width of aisle and evacuation entry at 1.3 m shown on Fig. 1. The applied target was 100 people in general while it has slight changes on the numbers.

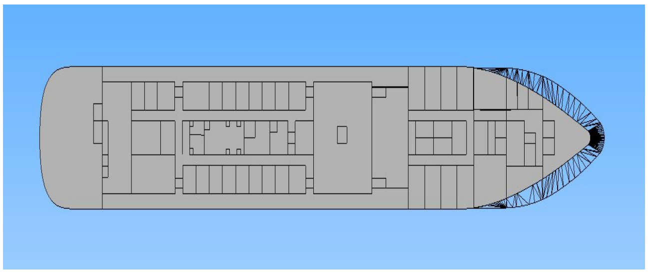

Fig. 1. Drawing of HANBADA.

The theoretical formula for evacuation response time was referred to Japanese Construction Department's formula (1) and applied the scenario of trainees's response time at accommodation and lecture room. By using this formula, it was calculated approximately 6.3 second for HANBADA's evacuation response time. In this case, the effective area shall be 1/2 of the total area.

$$t_{start} = \frac{\sqrt{A_{floor}}}{30} \quad (1)$$

The components of Formula (1) above stands for t_{start}: Evacuation Response Time (min) and A_{floor}: Floor area (unit : m^2). The evacuation travel time was calculated referring to the evacuation calculation method from the study of emergency movement written by Harold E. "Bud" Nelson and Frederick W. Mowre belongs to American SFPE (Korean Fire Protection Association, 2005). And it is the regulated formular by IMO MSC.1/Circ.1238. When the crowd density is below 0.54/m^2, the Formular (2) is applied as calculation method for evacuation completion time. In this case, it shall be checked the drawing and the effective area was set as 1/2 of the total area.

$$t_p = \frac{P(Persons)}{(k-akD)\,W_e} \quad (2)$$

The components of Formula (2) above stands for t_p: the time for a passenger from the crowd to pass the specific point on the evacuation route (s), k : Evacuation Speed Contact (1.4 applied for aisle and emergency exit), a: 0.266 (Constant), D: Crowd density [Number of people (n)/effective area (m^2)], W_e: Exit width (m). a is the evacuation speed constant and applied 0.266 in case of m/s. It was theoretically calculated the evacuation travel time at 56.5 seconds. It is just considered that there is no limit on walking speed by ship's inclination and visible distance and the only one exit was usable. Because the evacuation time is the sum of evacuation response time and evacuation travel time , the total time for the evacuation is expected 118.8 seconds. According to Galea's study, it reduces the walking speed at 23 % under the condition of 20 degree heeling (Galea, 2016). That is, it is calculated 146.1 seconds when the heeling is at 20 degree.

2.2 Investigation on evacuation time using maritimeEXODUS

In this chapter, it was analyzed the evacuation time based on location of ship's evacuation exit by comparing the result from theoretical formular and maritime EXODUS. It was included the walking speed variable upon the gradient angle as the special condition for the evacuation on its calculation of evacuation time. The experiment object was Korea Maritime and Ocenas University (KMOU) Training Ship HABADA (length 114 m, width 17 m, height 2.6 m and width of aisle and emergency route 1.3 m) with 100 people as trainee and it used the function of "person random" on maritimeEXODUS to set the trainee condition. It was also considered the lifeboat used for the evacuation of passengers and crews in real environment and set the lifeboat descending allowable angle (heel 20 degree and trim 10 degree) guided by SOLAS as Evacuation Allowable Time for the simulation. According to Sharp (2003)'s study, it is impossible to walk under the condition of ship's inclination angle over 30 degree so the simulation was set 25 degree as the maximum inclination. It was assigned the evacuation rallying point at the fore, center and astern shown on the Fig. 2 and the ship's inclination interval was set for 5 degree at the maximum of 25 degree with the lifeboat descending maximum angle, heel 20 degree and trim 10 degree. In order to analyze the evacuation time upon the location and numbers of the exits, it was set the location of evacuation exit at the bow, stern and center of the ship. In this case, the maximum walking distance is 85m for the bow and stern and 40m for the center in consideration of the length of ship.

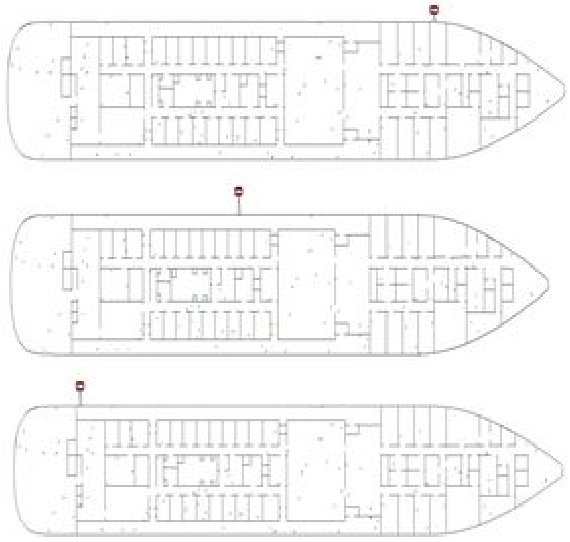

Fig. 2. One Assembly station (Abandonship Drill).

It is shown on Table 2 that the result of evacuation time under the condition of the only one evacuation rallying point located at fore, center and astern side of the ship.

Table 2. Evacuation time according to Heeling angle

Heeling angle(°)	Evacuation time		
	Bow	Mid	Stern
0	123.8	128.8	117.6
5	125.0	125.0	120.4
10	127.0	127.0	121.2
15	134.0	134.0	128.1
20	143.0	143.0	134.9
25	143.5	143.8	137.2

It is shown on the Table 3 that the result of Heel at 20 degree and trim at 10 degree which is regulated by SOLAS as maximum descent angle for lifeboat for this scenario.

Table 3. Evacuation time according to Heeling & Trim angle

Heeling angle(°) / Trim angle (°)	Evacuation time		
	Bow	Mid	Stern
20 / 10	161.0	146.0	134.1

Fig. 3 and Table 4 are the results of the evacuation analysis when it limits the rallying points for two locations at the center of the ship with the other conditions as same as Fig. 1.

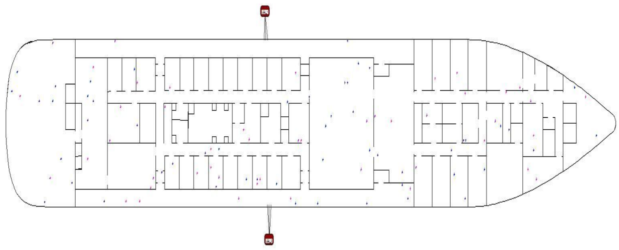

Fig. 3. Two Assembly station (Abandonship Drill).

Table 4. Evacuation time according to Heeling angle

Heeling angle(°)	Evacuation time
0	85.7
5	87.9
10	90.3
15	97.2
20	104.6
25	105.3

On Fig. 4, it is shown that the evacuation analysis by considering the evacuation through upper deck It is the record of this evacuation analysis on Table 5 and 6.

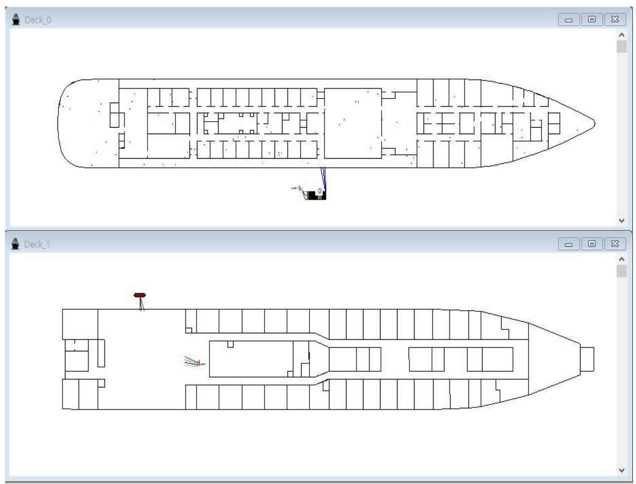

Fig. 4. One Assembly station (Abandonship Drill /Two floor).

And the Fig. 5 explains the particulars of stairs used.

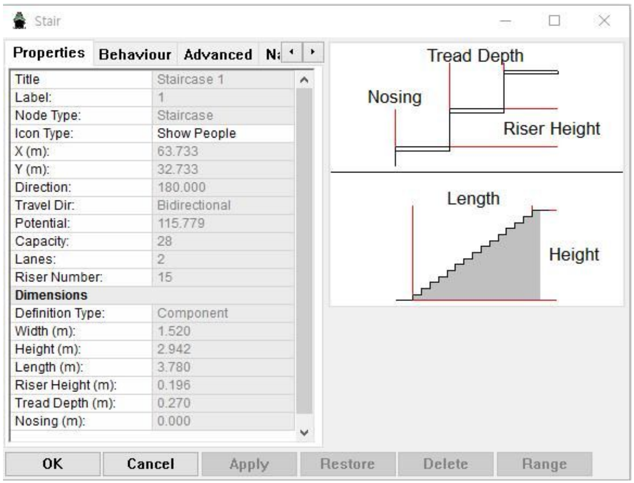

Fig. 5. Particulars of stairs.

It is the record of this evacuation analysis on Table 5.

Table 5. Evacuation time according to Heeling angle

Heeling angle(°)	Evacuation time
0	130.2
5	145.6
10	146.9
15	162.8
20	170.9
25	174.0

Table 6 that the result of Heel at 20 degree and trim at 10 degree which is regulated by SOLAS as maximum descent angle for lifeboat under the condition that limits the rallying points for only one.

Table 6. Evacuation time according to Heeling angle

Heeling angle(°) / Trim angle (°)	Evacuation time
20 / 10	172.1

Fig. 6 shows the analyzed figure by considering the evacuation through upper deck with two rallying points.

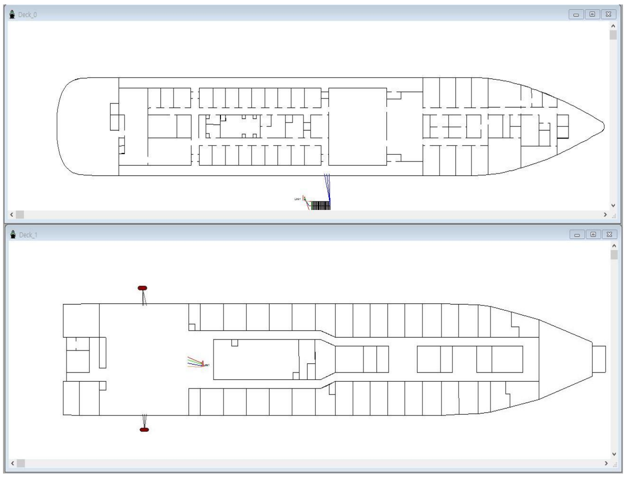

Fig. 6. Two Assembly station (Abandonship Drill /Two floor).

And the record of the evacuation analysis was shown on Table 7.

Table 7. Evacuation time according to Heeling angle

Heeling angle(°)	Evacuation time
0	126.1
5	135.6
10	145.7
15	160.5
20	165.3
25	173.2

Table 8. that the result of Heel at 20 degree and trim at 10 degree which is regulated by SOLAS as maximum descent angle for lifeboat for this scenario.

Table 8. Evacuation time according to Heeling angle

Heeling angle(°) / Trim angle (°)	Evacuation time
20 / 10	169.6

3. Fire simulation

In this chapter, it is analyzed the life safety by comparing the evacuation time calculated by maritime EXODUS with the Evacuation Allowable Limit which is the standard of survival rate.

3.1 Fire simulation

It was set the physical condition of the fire simulation and the fire scale was considered the experiment result from ISO 9705 that 100 kW for the first 10 minutes and flashover at 1 MW. Taking consideration of the trainee's accommodation environment, the wood was selected as the flammable material as well as Kerosene which is the common cause of fire. The details of condition is as follows.

○ Fire Space(X, Y, Z Axis): 114 m × 17 m × 2.6 m
○ Simulation Time: 600 Seconds
○ Fire Scale: 100 kW, 1 MW
○ Size of Fire Source: 2 m × 2 m × 0.5 m
○ Flammable Material: Wood, Kerosene
○ Interior Temperature: 25°C

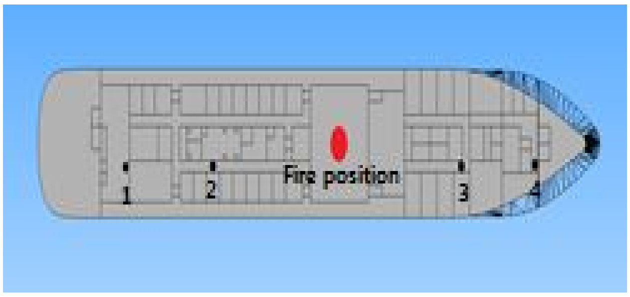

Fig. 7. Simulation Area & Measuring point.

From Fig. 7, the fire area and measuring point is indicated as the big red colored dot and the measuring points for temperature and visible distance are indicated as small black colored dots (x-axis: 25 m interval, y-axis: 6 m interval, z-axis: 1.5 m). Because it is blocked the ventilation when the fire is on board, it also assumed that there is no ventilation fire onboard. It is analyzed using FDS and the measurement of temperature and visible distance which is closely related to Trainee' lift were set that 60°C is he survivable temperature and 5 m is visible distance which are described on National Emergency Management Agency Notice #2014-31 about performance based design method and standard (appendix 1) for fire-fighting facility Rie and Lew (2003). The measuring the temperature was applied FPA method and the formula is as follows (KINS, 2008).

$$\frac{\Delta T_g}{T_a}=0.63\left(\frac{Q^{\cdot}}{m^{\cdot}\,C_pT_a}\right)^{0.72}\left(\frac{h_kA_T}{m^{\cdot}\,C_p}\right)^{-0.36} \tag{3}$$

The components of Formular (3) above stands for ΔT_g: Increase of temperature for high temperature gas layer (Tg-Ta) [K], T_a: Surrounding temperature [K], $Q^{\cdot}$: Fire heat release rate [kW], $m^{\cdot}$: Constraint ventilation flow rate [kg/s], C_p: Specific heat [kJ/kg K], h_k: Heat transfer coefficient [kW/m^2], A_T: Total area in the space [m^2].

3.2 Analysis on fire simulation result

It is clear that all of them did not reach to the range under the different type and size of the fire and shows that there is ont limit on evacuation by temperature.

When it is analyzed the visible distance shown on Table 9, it reached to the Evacuation Allowable Limit, 5m at 117 seconds in case the wood fire was 1 MW. It also reached to the Evacuation Allowable Limit, 5 m at 92.4 seconds under the condition of Kerosene 1 MW. That is, it could not reach to the Evacuation Allowable Limit when the fire scale was 100 kW for wood fire and Kerosene meanwhile it reached to 5 m, the Evacuation Allowable Limit at 117 seconds for the wood fire and 92.4 seconds for Kerosene under the condition of 1 MW.

Table 9. Time (s) to reach the visibility range of 5 m

Type	100 kW	1 MW
Wood	-	117
Kerosene	-	92.4

4. Analysis on evacuation safety

It is the overall result of the analysis on various evacuation scenarios by using maritimeEXODUS shown on Fig. 8. When there are two rallying points which are located in the center of the ship, it has the shortest evacuation time. By contrast, it has the longest evacuation time when there is one rallying point located at the astern of the ship. It is shown on Table 9, the visible distance was represented 117 seconds for the wood and 92.4 seconds for the Oil when the fire scale is 1 MW.

It is clear that all cases do not meet the evacuation safety under the condition of only one rallying point by testing various scenarios. On the other hand, it met the safety for all cases when there are two rallying points under the wood fire and it does finitely meet the safety under 10 degree for heeling for Kerosene. It however does not meet the evacuation safety when the passenger evacuates through upper deck although there are two rallying points.

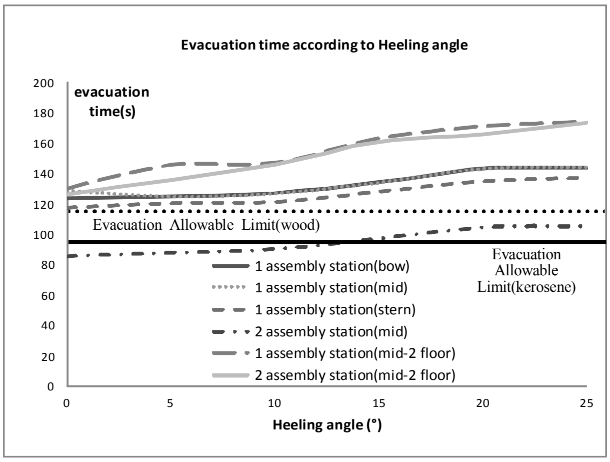

Fig. 8. Results of Evacuation according to assembly station & heeling angle.

It is shown the evacuation simulation result on Fig. 9 under the condition of heel at 20 degree and trim at 10 degree which are regulated by SOLAS as the maximum descent angle for lift boat assuming that the completion of evacuation is to board the lifeboat. As a result, it only meets the evacuation safety when there are two rallying points located in the center of the ship.

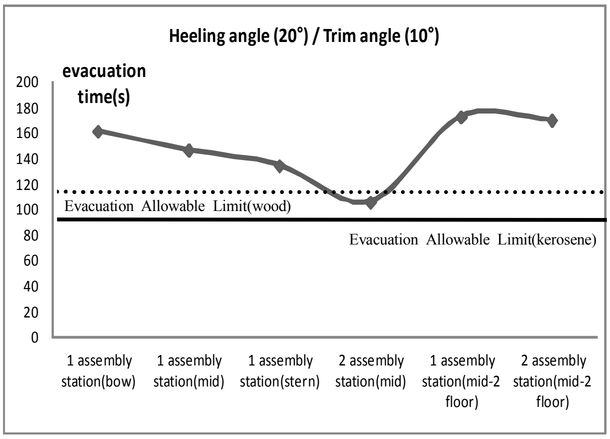

Fig. 9. Results of Evacuation according to heeling & trim angle.

5. Conclusion

It is now regulated the evacuation time by SOLAS at 10 minutes for Cargo ship and 30 minutes for Passenger ship. However, it does not only mean the evacuation time but includes the time for all passengers and crews to board and lunch the lifeboat. It is not defined the evacuation time to the rallying point but it seems to be less than minimum 1/2 of evacuation time regulated by SOLAS by considering the officers' experience. This study has the experiment with KMOU training ship HANBADA which is in actual operation to calculate the Evacuation Response Time from acknowledging the fire to activating the evacuation and Evacuation Travel Time and the conclusion of the following results.

1. It was analyzed the data of Evacuation Allowable Limit Temperature 60℃ and resulted that there is no influence in evacuation by temperature.

2. It was analyzed the data of Visible Distance Evacuation Allowable Limit 5 m and verified that the only one evacuation rallying point could not meet the evacuation safety. However, it derived the perfect evacuation safety under the condition of two rallying points available on wood fire. In case of Kerosene, it was satisfied the evacuation safety if the heeling was under 10°. Moreover, it could not meet the evacuation safety by evacuating through upper deck although there were two evacuation rallying points.

3. When it was set by the lifeboat descending maximum angle 20° heel and 10° trim which was described in SOLAS regulation, it was simulated that the wood fire having two evacuation rallying points in the center of the ship satisfied the evacuation safety.

Acknowledgement

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