IMPROVEMENT OF SURVIVABILITY BY BEHAVIOUR SIMULATION OF A DAMAGED SHIP

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ABSTRACT

This paper describes the improvement in the damage survivability of a ship based on simulation. Simulation of a ship's survival in wave according to several damage assumptions adopted from the regulation is performed. Simulation of large amount of damage that is not required by the regulation was also performed and the results are evaluated. In survivability point of view, the original design is slightly changed to improve the survivability in serious damage cases.

Keywords: *Damage survivability, Safety, Simulation, Ship Design*

1. INTRODUCTION

The survivability of a ship under damaged condition is very important to prevent a disaster such as loss of life, property and maritime pollution. The regulations for maritime safety require a ship to have a proper safety level considering possible maritime casualties. The regulations include the location of cargo hold to prevent maritime pollution from a pollutant and damage assumptions to be used in evaluating damage survivability. These regulations are minimum requirements for maritime safety in general and although a ship is designed complying these regulation, there is no guarantee that the ship is safe since even when the ship experience damages that does not exceed casualty threshold, it can still be dangerous due to adverse weather condition.

Assessment of the damage stability is very complicated since the physical phenomena associated with the behaviour of the damaged ship is essentially highly nonlinear and the implementation of rigorous approach on the problem is still very limited in spite of rapidly increasing computing power. Nevertheless related technologies are continuously being developed. To apply these technologies to ship design process, the SLF subcommittee of the MSC of IMO required that ITTC should include further benchmark testing and assessment of computer codes that simulate time-to-flood and related ship motion behaviour of damaged ships in their current work program (SLF 2006). The benchmark test is now under way (Papanikolaou and Spanos 2008). These simulation technologies will contribute to the maritime safety.

In this paper, the behaviour simulation of the dangerous cargo carrying ships is carried out to evaluate and improve the damage survivability in waves. To do this several types of damage cases are created by referring to relevant regulations and related research papers. Simulation is performed considering wave conditions on operating plan. A new design modified from the original design based on evaluation of simulation results is also simulated to confirm that the ship survivability with a proper internal arrangement can be improved by simulation.

2. SHIP ARRANGEMENT

The ship was designed in compliance with safety regulations such as the SOLAS, MARPOL, IMDG code, INF code and so on. The role of the ship in this study transports Low Level Waste (LLW), therefore class 2 of INF code is universally applicable, but class 3 of INF code was applied to improve damage safety in design stage. The damage stability requirements of class 3 of INF code comply with the damage stability and the location of cargo spaces of the IBC code.

The damage assumptions in the IBC code are as follow

- Side damage (whichever is less);

  Longitudinal extent: $1/3L^{2/3}$ or 14.5m

  Transverse extent: B/5 or 11.5m

  Vertical extent: upwards without limit

- Bottom damage for 0.3L from forward perpendicular of the ship (whichever is less);

  Longitudinal extent: $1/3L^{2/3}$ or 14.5m

  Transverse extent: B/6 or 10.0m

  Vertical extent: B/15 or 6.0m

- Bottom damage for any other part of the ship (whichever is less);

  Longitudinal extent: $1/3L^{2/3}$ or 5.0m

  Transverse extent: B/6 or 5.0m

  Vertical extent: B/15 or 6.0m

According to the requirements of the regulations, the cargo holds of the ship was protected by a double hull configuration, extending to 20% of the breadth on both sides of ship and 1.25m height double bottom as shown in Table 1.

Table 1 Major particulars

LOA	78.6 m
LBP	71.0 m
Breadth	15.8
Depth	7.3 m
Draft, full load condition	4.0 m
Breadth of side tank	3.16m
Double bottom height	1.25m

3. DAMAGE CASES FOR SIMULATION

There are several types of damage cases. In the case of damage at ship mid-part, the effect of trim and pitching will be small. In this paper, therefore, the ballast tank and the hold in the forepart is selected as damaged compartment the damage survivability considering trim and pitching motion is investigated.

Case 1 is for two ballast tanks damage of rectangular type with the size of 15m×2m. The location of the damage is 2m under waterline. Case 2 is for a ballast tank and a cargo hold damage of circle type with the diameter of 2m. The centre of the hole is located 1.5m under waterline. The hole penetrates side shell and inner bulkhead. Case 3 is combination of case 1 and case 2. Case 4 is for two ballast tanks and duct keel damage at the bottom by grounding of rectangular type with size of 15m×3m. All damage cases were expressed in Figure 1 ~ Figure 4.

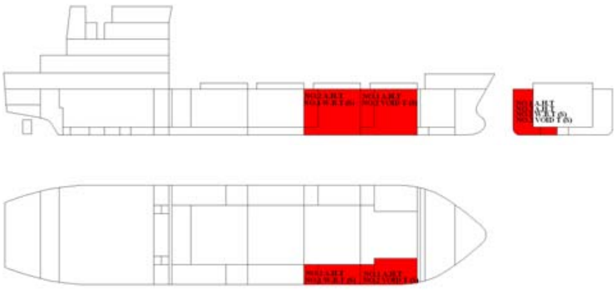

Figure 1 Two ballast tanks: Case 1

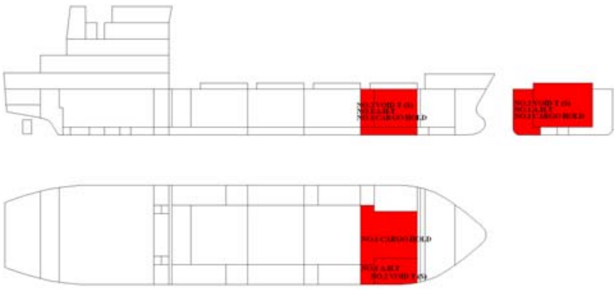

Figure 2 One ballast tank and cargo hold: Case 2

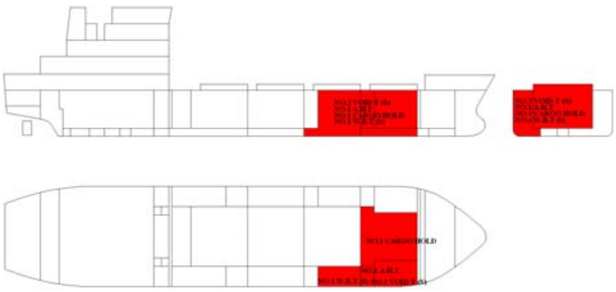

Figure 3 Two ballast tanks and one cargo hold: Case 3

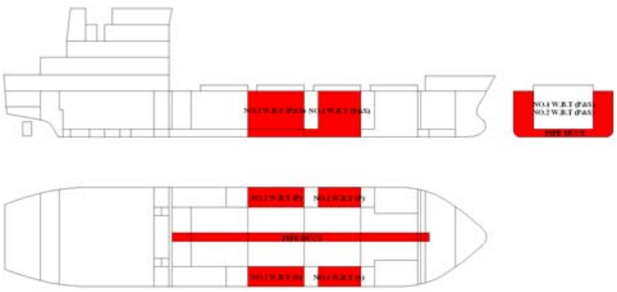

Figure 4 Two ballast tanks and duct keel: Case 4

4. BEHAVIOR SIMULATION IN WAVE ITS ASSESSMENT

4.1 Simulation Method

The simulation method used in this paper is as follow (Lee et al, 2007, and 2008). The theoretical method for behaviour simulation with 6 degrees of freedom of the damage ship in waves was developed based on a non-linear time domain simulation method considering the ship as a rigid body inertial system and accounting for non-linearity of large amplitude motion and floodwater effects. The radiation force from the ship motion was calculated for all frequency domains, and it is converted into impulse response function in time domain. Then convolution integral is used in motion equation to calculate the amount of the force in time domain. The force by wave is divided into Froude–Krylov force and diffraction force. The Froude–Krylov force is obtained in time domain by integrating the dynamic pressure acting on hull to waterline. The diffraction force is calculated from the cross-flow force assuming long wave. The amount of in- and outflow of sea water in damaged part are calculated from the difference in pressure between inside and outside. The fluid motion in the flooded part is assumed to be small, and the mean value is used. But the location and the force of inflow in inclined condition are calculated in Quasi-steady state. The buoyancy and the wave load of the superstructures above main deck are calculated to analyze capsizing and sinking.

4.2 Simulation Conditions

The heading angles of wave is 180°, 90° and 0° corresponding to the head, beam and following sea respectively. In the beam conditions, the damage opening is located in the weather side. The ship does not operate to reduce casualty possibility in case of a storm alter. It means that operational wave condition is below significant wave height 3m. Therefore, the applied wave height is 3m but, 4m is also considered for the unexpected operational condition. The save period of the operating route is about 10 ~ 12 seconds. The regular waves are used with λ/L values of 1.4, 2.2 and 3.2 equivalent to the wave period.

4.3 Simulation Results

The criteria of survivability used are the inception angle of deck edge immersion for roll motion, the inception angle of the fore and the aft part edge immersion for pitch motion and the freeboard height for the allowable maximum heave. The criteria of survivability can be changed according to the simulation purpose. The purpose of this research is to decide whether ship under damaged condition remains in floating state. Therefore, these criteria are acceptable because the concept "safe return to port" is not considered.

Table 2 Simulation results for damage case 4

Case No.	Wave Heading	Wave Height	λ/L	Heave(m)		Roll(deg)		Pitch(deg)	
	(deg)	(m)		min	max	min	max	min	max
C4_1	0	3	1.4062	-0.8865	0.0015	-0.2756	0.0771	-1.9000	2.6012
C4_2	0	3	2.1920	-1.3895	0.3089	-0.3290	0.0952	-2.3644	2.9383
C4_3	0	3	3.1639	-1.7171	0.6579	-0.3360	0.2306	-2.0019	2.5163
C4_4	0	4	1.4062	-1.0001	0.0027	-0.5186	0.2003	-2.5785	3.3640
C4_5	0	4	2.1920	-1.6633	0.6038	-0.4986	0.1742	-3.2570	3.8491
C4_6	0	4	3.1639	-2.0962	1.0714	-0.4664	0.3771	-2.7888	3.2624
C4_7	90	3	1.4062	-1.4434	0.2651	10.6534	10.2385	-0.5503	1.0920
C4_8	90	3	2.1920	-1.6914	0.7028	13.6241	13.5912	-0.0735	0.6338
C4_9	90	3	3.1639	-1.8970	0.9295	13.1712	14.0306	-0.0629	0.4574
C4_10	90	4	1.4062	-1.7197	0.4983	14.0321	14.7475	-2.1379	2.4578
C4_11	90	4	2.1920	-2.1428	1.3864	22.1916	23.0204	-0.0433	0.6586
C4_12	90	4	3.1639	-2.3559	1.4521	16.2633	17.5432	-0.0358	0.5011
C4_13	180	2	1.4062	-0.8197	0.0008	-0.2937	0.1085	-1.2023	1.7707
C4_14	180	3	2.1920	-1.4510	0.3571	-0.3336	0.1607	-2.1419	2.8004
C4_15	180	3	3.1639	-1.7478	0.6884	-0.3357	0.1505	-1.7387	2.4121
C4_16	180	4	1.4062	-1.0764	0.0064	-0.1592	0.4533	-2.6682	3.1823
C4_17	180	4	2.1920	-1.7459	0.6598	-0.1109	0.3898	-2.9649	3.6529
C4_18	180	4	3.1639	-2.1374	1.1105	-0.1627	0.3508	-2.4093	3.1420

The ship survived in case 1 and 4 for all combinations of wave heights, angles of attack of wave and λ/L values. The simulation results with maximum and minimum value of motion for damage case 4 are expressed in Table 2.

According to the damage assumptions of the IBC code, cargo hold of the ship never damage because of sufficient breadth of side tank. Nevertheless, case 3 and 4 are made to evaluate its survivability in severe damage. When the damage exceeds the casualty threshold as in cases 3 and 4, the ship did not survive at λ/L 2.19 and beam sea condition. Roll angle exceeds the criteria as shown Figure 5. Rolling angle was out of allowable range, i.e. dot line in Figure 5.

To investigate the possibility of survivability improvement by changing internal arrangement, horizontal and longitudinal bulkhead in side tank region at 2m height are added. The amplitude of roll for new design angle is reduced by about 15% as shown Figure 6 and the ship survived but, not at 4m wave height.

4.4 Review of Result

The additional cost for additional bulkhead installation was only 0.1 % of the total building cost. The additional bulkhead in side tank will reduce the amount of flooding water in case of side damage and bottom damage. And it will increase the resistance force in collision at side part as well as the ship strength at normal condition. It means that the survivability can be improved with small cost. The proper location of additional bulkhead has to consider the vertical location of the side damage.

The mass of the damaged ship is changed by flooding water, which leads to the change in natural frequency of the ship. The change of natural frequency of ship makes it difficult to predict its behaviour.

In this research, the excessive motions are observed at value of λ/L 2.19, i.e. wave period of 10 seconds. The relationship of the ship length and the wave period is also important factor in the damage safety analysis.

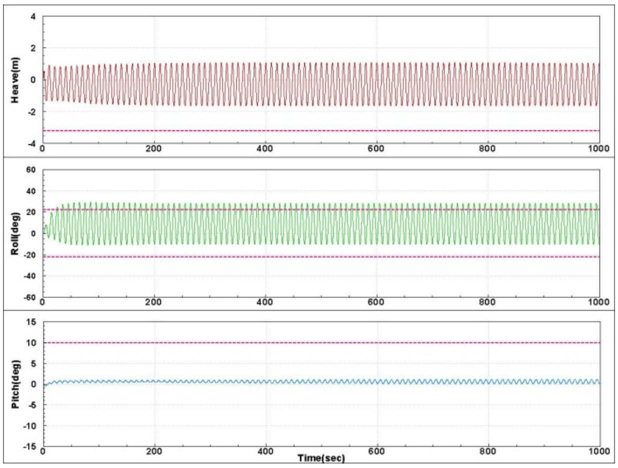

Figure 5 Motion characteristics of case 3: beam sea, wave height 3m and λ/L 2.19

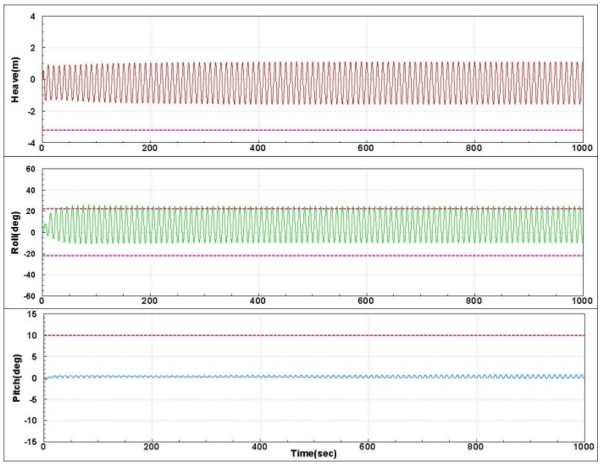

Figure 6 Motion characteristics of case 3 with additional bulkhead: beam sea, wave height 3m and λ/L 2.19

5. CONCLUSIONS

The damage survivability for the ship designed in compliance with the safety regulations were investigated in real sea conditions. The several types of damage cases were generated based on the requirements of the regulations and they also included the damage cases that are not required by the regulations. It was confirmed that the ship will survive at given operating condition and damage assumptions of the current regulations. In case of more severe case such as cargo hold damage, the survivability could not be guaranteed based on simulation results. To investigate the possibility of improvements in the survivability by changing internal arrangement, simulation was carried out with additional bulkhead.

Several factors such as change in natural frequency of ship by flooding and the relationship between the ship and the wave length have to be considered in improving survivability at design stage. The application of simulation method for maritime safety is important and it will be realized as a design tool in near future.

6. ACKNOWLEDMENTS

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