

Study of damage safety assessment for a ship carrying radioactive waste

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ABSTRACT : *Ship damage caused by maritime casualties leads to marine pollution and loss of life and property. To prevent serious damage from maritime casualties, several types of safety regulations are applied in ship design. Damage stability regulation is one of the most important safety issues. Designs of ships for long international voyages must comply with these regulations. Current regulations, however, do not consider the characteristics of the operating route of each ship and reflect only ship size and type of cargo. In this paper, a damage safety assessment was undertaken for a ship carrying radioactive waste in actual wave conditions. Damage cases for safety assessment were constructed on the basis of safety regulations and related research results. Hull form, internal arrangement, loading condition and damage condition were modeled for damage safety simulation. The safety simulation was performed and analyzed for 10 damage cases with various wave heights, frequency and angle of attack on an operating route. Based on evaluation results, a design alternative was generated, and it was also simulated. These results confirmed that damage safety analysis is highly important in the design stage in consideration of the operating route characteristics by simulation. Thus a ship designer can improve safety from damage in this manner.*

KEY WORDS : Maritime casualty; Design for safety; Ship safety; Damage; Stability; Survivability; Simulation; Performance based design.

INTRODUCTION

A ship is designed with a safety margin, based on the rules of classification societies and international regulation. Therefore, the possibility of major casualties from capsizing or sinking in maritime accidents is extremely low. However, because most maritime accidents occur during bad weather, such as high waves, wind, rain and fog, damage to the ship, slight at first, may progress to become large enough to cause the ship to capsize or sink. Prescriptive regulations are best for routine situations and well-established practices. They provide a datum based on experience and a means for steadily improving baseline safety standards. It is difficult, however, to keep rules up to date with developing technology, and impracticable to write a rule for every eventuality (RINA, 2009).

Current regulations for damage safety consist of the subdivision relating to maximum capacity of compartment and dimension, and hydrostatic requirements after damage. Ship designers must comply with these regulations. Although a ship is designed with compliant safety regulations, the safety of a ship in an actual situation might not be guaranteed if the characteristics of such a ship were not considered with regard to the operating route in addition to its size and type of cargo.

To improve safety, risk assessment for design and safety case for operation were applied to offshore structures(Wang, 2001) and researches on safety culture of shipping industries including human factors also carried out(Havold, 2005; Hetherington,

Flin and Mearns, 2006). International Maritime Organization(IMO) adapted a new regulation concept including risk assessment and safety level approach for maritime safety, so-called Goal Based Standards(GBS) last year. IMO is preparing and discussing risk acceptance level and detail procedure for GBS(IMO, 2009). The alternative design concept to increase design freedom and to design new novel ships was permitted by IMO before adaption of GBS under the conditions that safety level of a designed ship is equivalent or higher than existing regulations(IMO, 2001). The alternative design concept was applied to fire safety in large sized cruise vessels to meet high level needs of passengers(Levander, 2010). The concept of ship safety is changing lately from prescript regulation to risk based design(Papanikolaou, 2009). If it will be mandatory for GBS, ships must be designed by GBS concept including risk based design. To do that, the performance and simulation based design are required basically.

In this paper, the analysis of damage safety and survivability was undertaken for a vessel carrying radioactive waste that was designed in compliance with safety regulations. Damage cases for safety assessment were generated on the basis of regulation requirements. Six degrees of freedom motions were analyzed for damage cases with several types of wave conditions, such as angle of attack, height and period. Based on evaluation results, a design alternative with an additional bulkhead was generated and also simulated. This design alternative, with a longitudinal horizontal bulkhead in a wing ballast tank, can effectively improve safety with very little additional expense.

SHIP CARRYING RADIOACTIVE WASTE

Radioactive waste is usually the product of nuclear processes, such as nuclear fission. Most radioactive waste is low-level waste that contains low levels of radioactivity per mass or volume. The issue of disposal methods for nuclear waste is one of the most pressing problems the international nuclear industry faces when trying to establish a long-term energy production plan.

There are many nuclear power plants at four different localities in Korea. The radioactive waste generated from these plants is managed and controlled by the Korea Radioactive Waste Management Corporation (KRMC). The disposal site for low-level waste is under construction, so the waste will be transported by ship in the near future. For that purpose a ship was designed for carrying low-level waste on the basis of current regulations and is under construction at a shipyard.

The main particulars of ship are as follow;

- LOA : 78.6 m
- LBP : 71.0 m
- B(Moulded) : 15.8 m
- Depth : 7.3 m
- Draft : 4.0 m
- Design speed : 12 Kts

Arrangement requirements

The ship for carrying low-level waste for KRMC was designed in compliance with safety regulations, especially the international code for the safe carriage of packaged irradiated nuclear fuel, plutonium and high-level radioactive wastes on board ships-INF code (IMO, 2000). Ships transporting low-level waste operate under class 2 of the INF code, which is universally applicable. Class 3 of the INF code, however, was applied to improve safety.

The location of the cargo tank and the damage assumption of the INF code must be referred to the international code for the construction and equipment of ships carrying dangerous chemicals in bulk-IBC Code (IMO, 2007). The cargo hold must be surrounded by a shell plate with more than 0.76 m clearance as shown in Fig. 1(a), according to the IBC code. The maximum extent of damage for the side and bottom for calculating damage stability is shown in Fig. 1(b). Based on these regulation requirements, the ship was designed as shown in Fig. 1(c). The cargo holds are protected by a double hull configuration, extending to 20% of the breadth on both sides of the ship and for a height of 1.25 m for the double bottom.

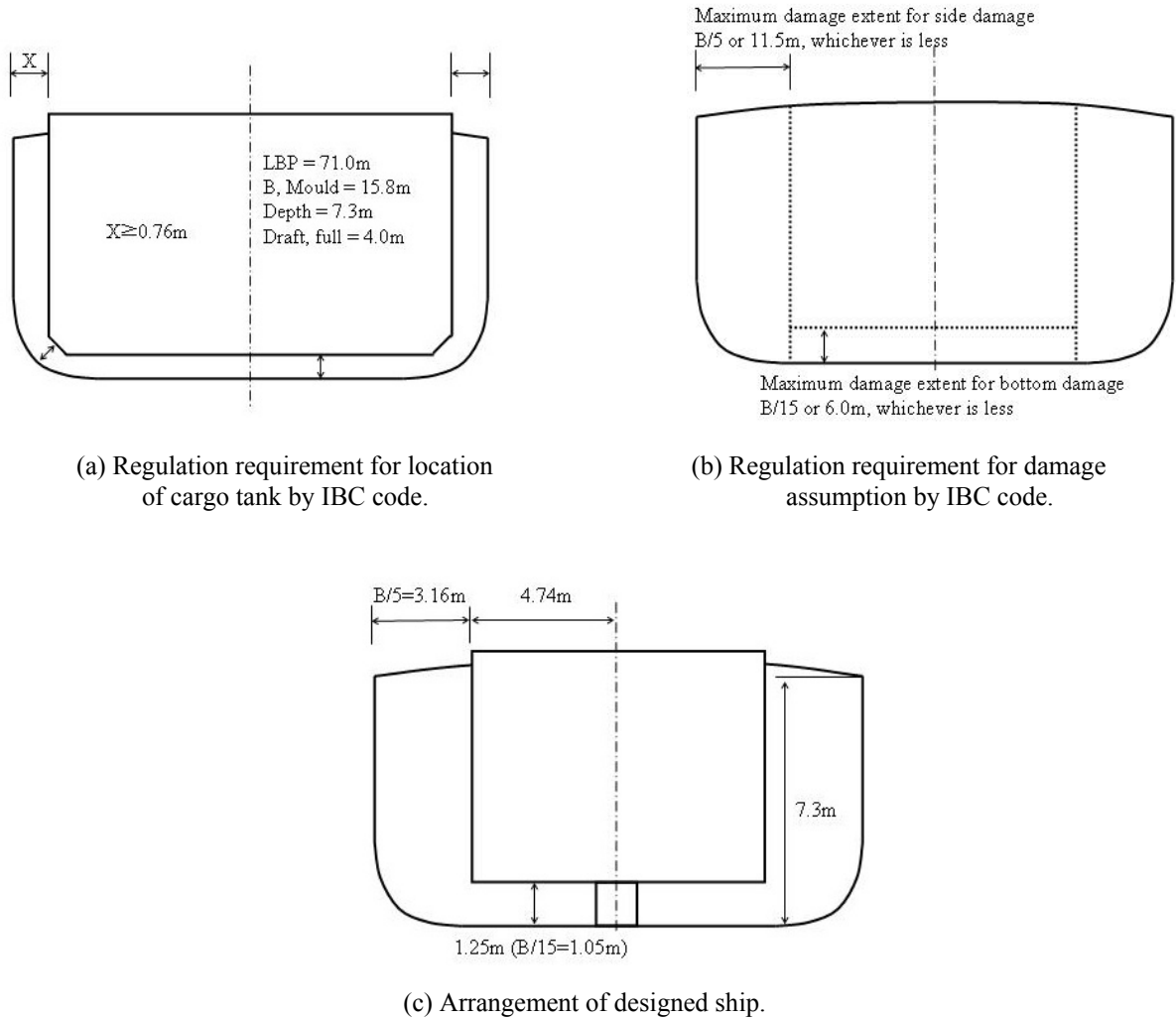


Fig. 1 Regulation requirements and ship design.

Operational routes

The longest operating distance from nuclear power plants to the disposal site is about 700 km, and the shortest one is about 70 km. The ship will be operated in the daytime only and will be anchored at night during operation. The ship does not operate to reduce the possibility of casualties in case of a storm, which means that maximum significant operational wave height is 3 m. The wave period for the operating route is about 10-12 seconds (KORDI, 2003).

NUMERICAL SIMULATION

Ship modeling for numerical simulation

A ship model with damaged parts for numerical simulation was built using a modeler that was developed on the basis of the three-dimensional (3-D) geometric modeling kernel, ACIS. The definitions of hull form, internal arrangement and major longitudinal structural members are a fundamental function of the modeler (Lee, Lee and Park, 2004). The modeler was interfaced with other applications used for ship safety assessment such as hydrostatic calculation, ship motion analysis in wave conditions, longitudinal strength analysis and so on (Lee, Lee, Park and Kim, 2005; Lee, et al., 2009). In this research the ship's structure for longitudinal strength analysis under damage conditions did not apply because it was not a research target. Figs. 2 and 3 show the results of ship modeling with 3-D and loading conditions, respectively.

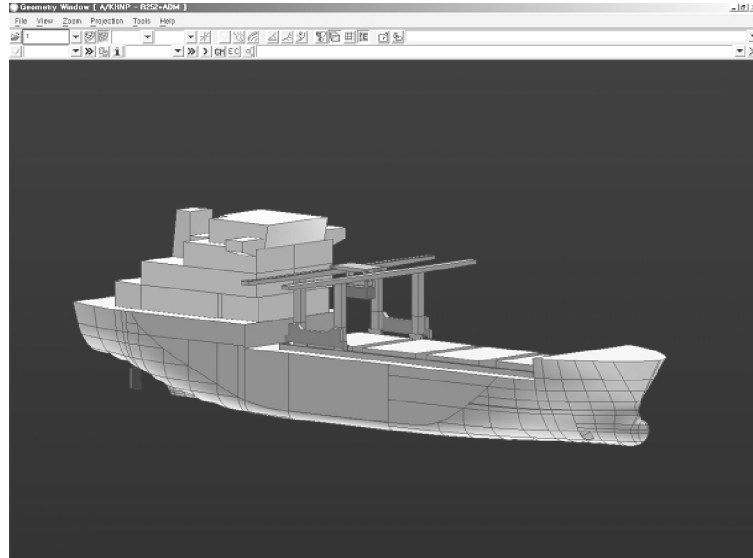


Fig. 2 3-D model.

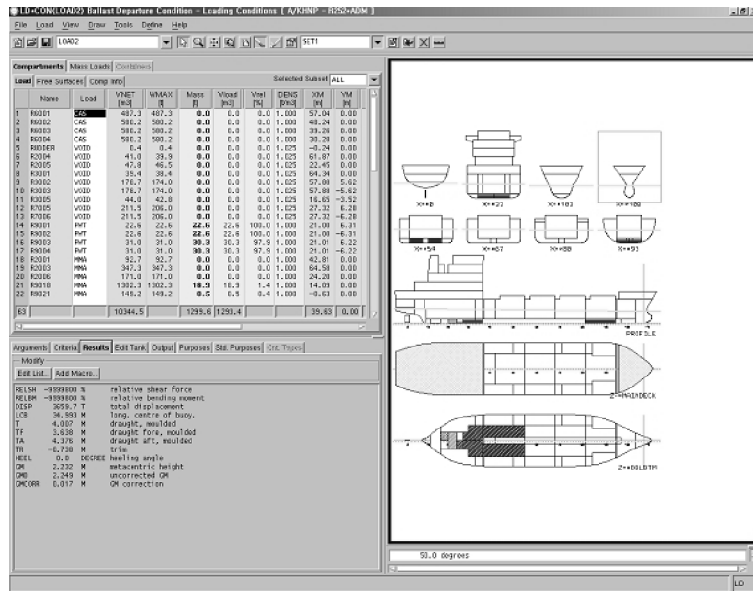


Fig. 3 Definition of loading conditions.

Generation of damage cases

There are three methods for generation of damage case in general. The first one is direct calculation by collision analysis method with damage scenarios. It requires information such as ship size, speed, collision angle, contact point and structural model to obtain damage extent. To analysis collision and grounding by this method, a sophisticated structural analysis package is required and it will be time-consuming job. The second one adopts damage extent of related regulations. The last one makes the best use of results of damage data analysis.

In this paper, 10 damage cases, considering collision and grounding, were generated on the basis of damage assumptions of the IBC code as explained in section 2.1, and results of damage data analysis (Laubensten, et al., 2001; Tagg, et al., 2001; Skjong and Vanem, 2004). Each damage case and its related damage compartments are shown in Table 1 and Fig. 4, respectively. The first seven cases in Table 1 are side-shell damages from strikes by other ships. Damage cases 8 and 9 are forepart damages from strikes. The last case is bottom damage by grounding. Cargo holds do not undergo damage under the assumptions of the IBC code. But in this paper the damage of cargo holds was included in damage cases to assess safety at severe conditions for cases 4, 5 and 6. The diameter of the hole in the side shell is given

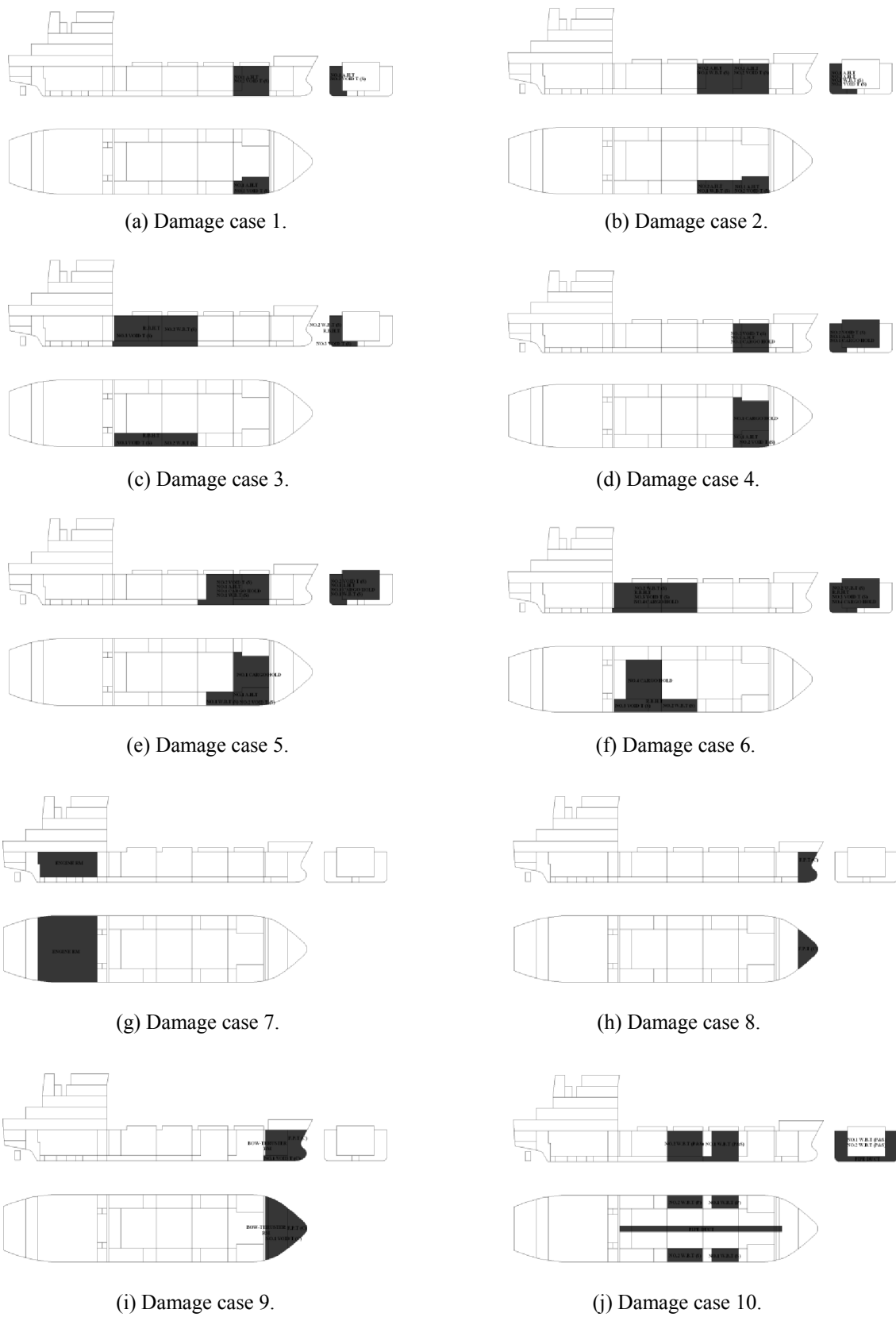


Fig. 4 Typical damage cases and related damaged compartments.

in Table 1, and the hole is below the waterline. In the case of grounding or longitudinal damage to the side shell, a rectangular hole was used.

Table 1 Damage cases and related damaged compartments.

Damage cases	Damaged compartments	Damage type, damaged size and location
1	No.1 AHT(S), No.2 Void Tank(S)	Damage type : hole Damage size : diameter 2 m, Center of location : 1 m below draft
2	No.1 & 2 AHT(S), No.2 Void Tank(S), No.1 WBT(S)	Damage type : rectangular Damage size : H 2 m × L 15 m Center of location : 1 m below draft
3	No.2 WBT(S), No.3 Void Tank(S), RBHT	Damage type : rectangular Damage size : H 2 m × L 15 m Center of location : 1 m below draft
4	No.1 AHT(S), No.2 Void Tank(S), No.1 Hold	Damage type : hole Damage size : diameter 2 m, Center of location : 1 m below draft
5	No.1 AHT(S), No.2 Void Tank(S), No.1 WBT(S), No.1 Hold	Damage type : hole Damage size : diameter 3 m, Center of location : 0.5 m below draft
6	No.2 WBT(S), No.3 Void Tank(S), RBHT, No.4 Hold	Damage type : hole Damage size : diameter 3 m, Center of location : 0.5 m below draft
7	Engine Room	Damage type : hole Damage size : diameter 2 m, Center of location : 1 m below draft
8	FPT	Damage type : rectangular Damage size : H 1 m × L 3 m × B 1 m Location : bottom of forepart
9	FPT, Bow Thruster Room, No.1 Void(C)	Damage type : rectangular Damage size : H 1 m × L 9 m × B 3 m Location : : bottom of forepart
10	Pipe Duct, No.1 & 2 WBT(P & S)	Damage type : rectangular Damage size : H 1 m × L 15 m × B 1.5 m Location : : bottom of midpart

Numerical simulation tool

The theoretical method for behavior prediction of the damaged ship in waves was developed on the basis of a nonlinear time domain simulation method considering the ship as a rigid-body inertial system and accounting for the nonlinearity of large-amplitude motion and floodwater effects (Lee, Hong and Lee, 2007). The six degrees of freedom motions are considered for describing the ship's motion. The restoring forces are related to the hydrostatic term of water forces, and are calculated by direct integration of hydrostatic pressure over the instantaneous wetted surface.

The ship's hydrodynamics, mainly wave interaction forces between ship and waves, were calculated by potential theory, applying strip theory. The radiation forces are calculated in the frequency domain and are transferred to the time domain using retardation functions. The diffraction forces in the time domain are obtained by superposition of wave harmonic components calculated in the frequency domain.

The wave excitation part, corresponding to the undisturbed wave Froude-Krylov forces, is calculated by direct integration of the wave dynamic pressure over the instantaneous wetted surface. Viscous effects, which are particularly significant for the roll motion simulation, are treated in a semi-empirical way.

The flooding process is uniformly approached by the use of hydraulic models. The basic Bernoulli equation modified by semi-empirical coefficients proved to be satisfactory for the modeling of the water ingress/egress through a damage opening. The same approach is also applied to the progressive flooding, namely the flow between ship compartments through open doors and ducts and other internal openings. The floodwater motion and its interaction with the ship are modeled by ignoring internal wave effects and assuming that the internal free surface is always horizontal.

Simulation conditions

The heading angles of the waves were 180°, 135°, 90°, 45° and 0°, corresponding to the head, bow quartering, beam, stern quartering and following sea, respectively. In the beam and quartering conditions the damage opening was situated in the weather side.

The regular waves were used for λ/L values of 1.4, 2.2 and 3.2. And wave heights were applied with 2.0 m and 3.0 m significant wave height, considering operational conditions. The combination of simulation is shown in Table 2.

Table 2 Combination of simulation.

Damage cases	Wave height	Angle of attack of wave	λ/L
For all cases	2 m	0°	1.4
	3 m	45°	2.2
	4 m	90°	3.2
		145°	
		190°	

Simulation results

The amplitude of roll, pitch and heave motion was used for decision criteria of safety. The angle of deck-edge immersion for roll, angle of fore and aft part-edge immersion for pitch and the freeboard height for allowable maximum heave were used as safety criteria. There are minimum requirements for preventing capsizing or sinking.

- Cases 1, 2 and 3: All simulation combinations, except for a wave height of 4 m with a beam sea and λ/L of 2.2, did not violate the safety criteria. The roll amplitude was exceeded only at the violated condition. Roll motion behavior of case 1 is shown in Fig. 5. The dotted lines in this figure are the boundaries of the safety criteria.

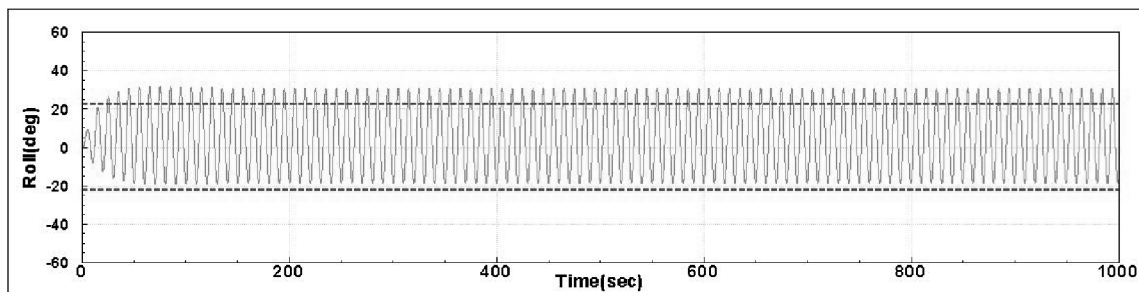


Fig. 5 Roll amplitude of case 1 with a wave height of 4 m, beam sea and λ/L of 2.2.

- Cases 4, 5 and 6: The simulation combination with a wave height of 3 m with a beam sea and λ/L of 2.2 exceeded the safety criteria of the roll, as shown in Fig. 6.

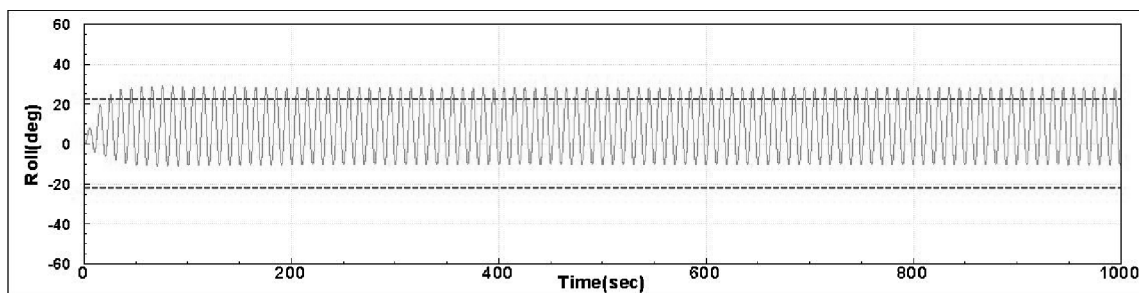


Fig. 6 Roll amplitude of case 5 with a wave height of 3 m, beam sea and λ/L of 2.2.

- Cases 7 and 10: The all-simulation combination, generated for symmetrical flooding, did not violate the safety criteria with roll, pitch and heave motion.
- Cases 8 and 9: These cases were for forepart damage and were concerned with pitch motion. None of the simulation combinations exceeded the safety criteria with roll, pitch and heave motion. The pitch amplitude at critical condition with a wave height of 4 m, a following sea and λ/L of 2.2 in case 9 is shown in Fig. 7. On the other hand, the roll amplitude of case 9 with a wave height of 4 m, beam sea and λ/L of 2.2 was exceeded, as shown in Fig. 8.

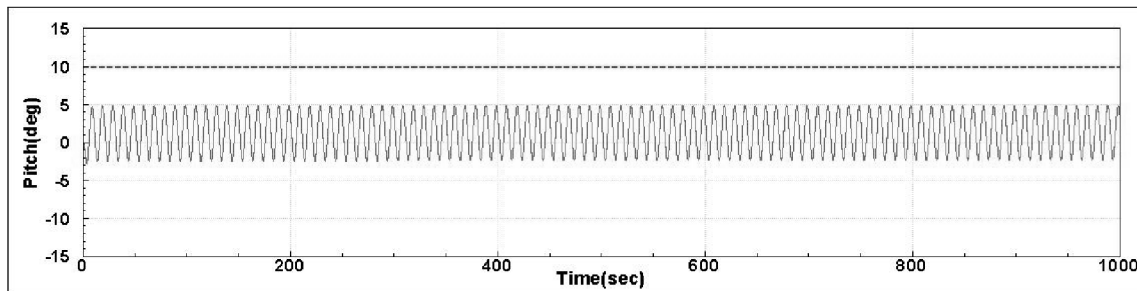


Fig. 7 Pitch amplitude of case 9 with a wave height of 4 m, following sea and λ/L 2.2.

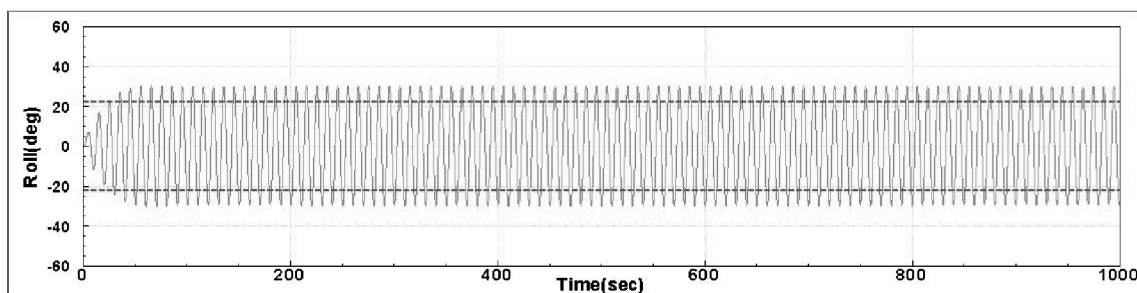


Fig. 8 Roll amplitude of case 9 with a wave height of 4 m, beam sea and λ/L 2.2.

Damage cases 4, 5 and 6 included the cargo hold, which did not require the extent of damage assumption in the regulation. In point of view of the regulation, the ship satisfied the safety conditions of the operating route, i.e. significant wave height of 3 m. In an actual situation, the possibility of severe damage, such as large-scale damage of cargo hold flooding and unexpected wave height, must be considered at the design stage. This is an important role of performance for design by simulation. In this paper, therefore, consideration of such possible damage was attempted in the design modification.

MODIFICATION OF MIDSHIP SECTION

The simple method for improving damage safety divides a ship into many compartments with small volume by bulkhead. But this would be the cause of several problems, such as increasing building cost, loading and unloading issues, adding the ship's weight and so on. Thus the original design was optimized, taking into account various design factors.

The damage assumption of the IBC code required a side-tank breadth of 20% of the ship's breadth for a smaller size ship than for a ship's breadth of 57.5 m. Therefore the side-tank breadth is large in comparison with a similar size ship. The purpose of this modification is the protection of the cargo hold and its dangerous cargo from accident. However, the amount of floodwater is also increased in case of a small-scale accident.

An additional bulkhead that divides the side tank into two parts could be considered for reducing the amount of floodwater in the side tank. First, the double bottom could be expanded to the side shell for structural continuity, as shown in Fig. 9(a). The other alternative is a preference for reducing the amount of floodwater, as shown in Fig. 9(b). In the latter case, the designer must decide on the proper height of the bulkhead in considering the location of the damage caused by a striking ship.

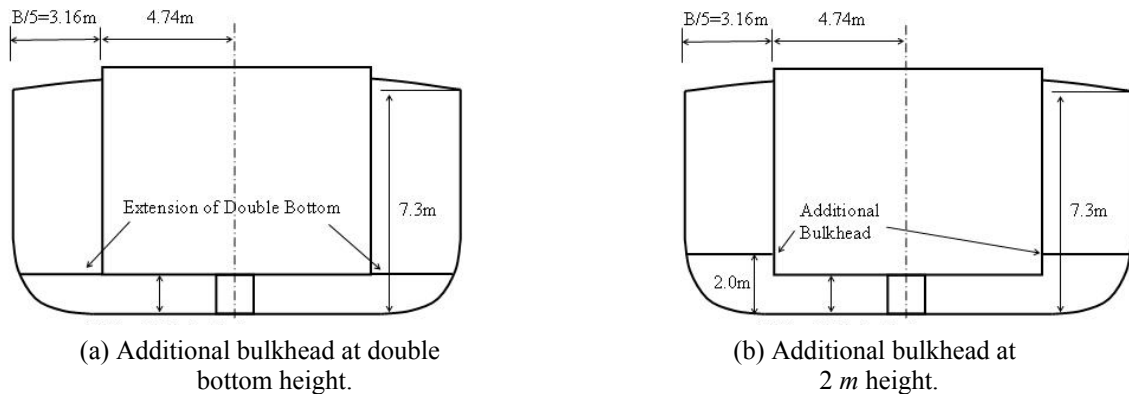


Fig. 9 Division of side tank by additional bulkhead.

For cases 3-6 for side damage that exceeded safety criteria at a wave height of 3 m, in this paper the latter was selected for additional simulation. The roll amplitude for case 5 of the original design was exceeded at a wave height of 3 m, beam sea and λ/L of 2.2, as shown in Fig. 6. However, the new design with the additional bulkhead significantly reduced roll motion and did not exceed the safety criteria with similar conditions, as shown in Fig. 10. Nevertheless, this could not satisfy the roll-motion criteria at a wave height of 4 m and λ/L of 2.2.

Important factors for damage safety include not only wave height but also wave period. The natural frequency of a ship also varies according to damage cases, because the mass of the ship will be increased in effect by the damage. Therefore the damaged ship has a long period in general. The reduced roll motion and the long period of it were due to reduced amount of flooded water and change of natural period by the additional bulkhead in Fig. 10.

The additional bulkhead added only about 0.1% to the ship's total cost, and the loss of deadweight was very small. This is one of those good design solutions with a valid cost-benefit.

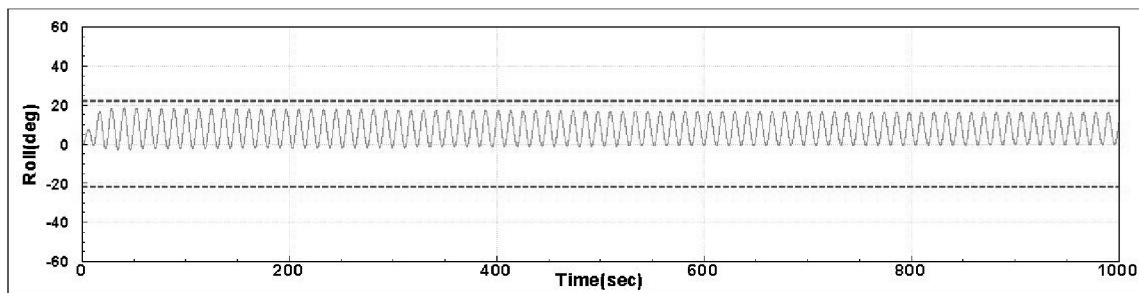


Fig. 10 Roll amplitude of case 5 with additional bulkhead for a wave height of 3 m, beam sea and λ/L of 2.2.

CONCLUSIONS

To prevent marine pollution and the loss of life and property from maritime casualties, the safety of a ship from damage is a very important component. Ship designers must comply with safety regulations. Furthermore, ship safety will be increased dramatically if performance-based simulation for damage safety applies to design-stage consideration of the ship's characteristics and operating route.

In this paper the performance-based simulation for damage safety applies to a ship carrying radioactive waste. The damage cases that took into account the various types of accidents were generated for simulation. The damage safety for those cases was evaluated in consideration of actual wave conditions. The survivability of ship safety was confirmed for regulation requirements for operational conditions. To improve safety in severe wave conditions, additional simulation was undertaken for a new design. It was shown that this simulation method can be applied at the design stage as a good design tool.

This study satisfied the procedure of alternative design and contained risk based design concept. Therefore the methodology and method in this paper will be a good guideline and example for ship safety taking into account damage survivability. The method can be also applied to military vessels that do not comply with international regulations.

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