Trial application of FE simulation on ships collision within the risk assessment on oil spills from oil tankers*

*Toshiro Arima**, Susumu Harada***, M. Abdul Rahim*****

*and Yoshimi Uraguchi******

Summary

Risk assessment methodologies have been widely used in the maritime industry. Formal Safety Assessment (FSA), a rule-making tool developed by the IMO in which risk assessment plays an important role, is coming to be used to an ever-greater extent by classification societies in the development of their ship classification rules.

The maritime world is, unfortunately, confronted with an overabundance of casualty data, and many people may make estimates of risk based on such statistical data. However, regulations in international Conventions such as SOLAS and MARPOL as well as classification rules have been continuously amended based on such data with the aim of preventing a recurrence of such casualties. Inherent in this approach is a concern that older data might not fully reflect the present risks of ships under consideration. Therefore, the usage of suitable theoretical and engineering tools should be encouraged to fill the gaps between the past and future.

In this context, the authors carried out risk assessment of oil tankers analyzing historical data of oil spills and conducted FEM simulations using LS-DYNA in order to estimate the consequence of the anticipated worst scenario in which a typical VLCC collides with an oil tanker of the same size.

Consequently, the authors confirmed the effectiveness of well-known risk control options such as early implementation of compulsory double hull construction designs and/or stochastic assessment of possible oil spills specified in MARPOL. It was also confirmed that such FEM simulations would be a powerful tool in predicting the collision damage to analyse oil spill risk.

1. INTRODUCTION

Risk assessment methodologies have been widely used in the maritime industry. With regard to Formal Safety Assessment (FSA) which is a rule-making tool developed by the IMO [1], classification societies has expanded its usage more and more. For example, International Association of Ship Classification Society (IACS) developed FSA training package and organized FSA training course upon the request several times. Figure 1, cited from the FSA training package developed by IACS, a flow chart of FSA.

In the maritime world, unfortunately there are so many casualty data and people may estimate the risk based on such statistical data. However, the regulations in International Conventions such as SOLAS and MARPOL and classification rules have been continuously amended so as to prevent the same kinds of casualties. It implies that the old data might not reflect the present risk of ships under consideration. Therefore, the usage of theoretical and/or engineering tools should be encouraged to fill the gap between the past and the future.

A surveillance study on the oil-spill risk of tankers had been executed by using the accident statistics analysis [2], [3]. As a result, it has been understood that the oil-spill risk of double hull tankers is greatly decreased compared

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** Development Department

*** Offshore Technology Division

**** London Office

***** Onomichi Branch

with single hull tankers as shown in Figure 2. On the other hand, the influence of collision is relatively large as a cause of oil spill from double hull tankers. It was found that collision accidents contributed to around 70% of the entire volume of the recorded oil-spill from double hull tankers. That is, there is still a possibility that a large-scale oil spill happens because of a large-scale collision of a double hull tanker.

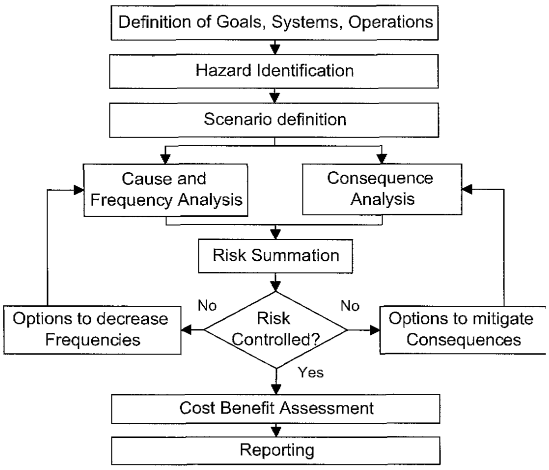


Fig. 1 Flow Chart of Risk Assessment in terms of FSA

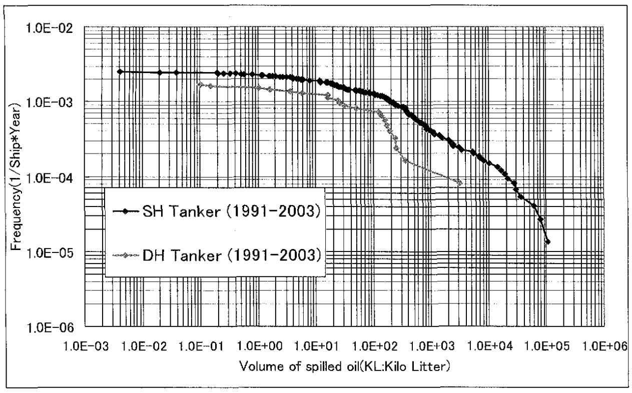


Fig. 2 FN diagram of oil spill from Tanker

When oil spill risk of tankers is considered, (1) Frequency of collision accident, (2) Extent of breakage due to collision, (3) Amount of oil spills due to breakage, (4) Spreading of oil spills, etc. must be studied. As a first step towards understanding the extent of breakage due to collision among the above 4 items, a series of non-linear FE analyses has been conducted in the present study. The consequence of the anticipated worst scenario in which a typical VLCC collides with an oil tanker of the same size has been studied. Many studies on collision of ships are found in Refs. [4], [5] among others. An emphasis is put on whether or not the FE simulations could be used to estimate the extent of breakage in the present study. It is confirmed that the FE simulations would be a powerful tool to estimate the extent of breakage due to collision as a basis of analysis of oil spill risk.

2. Conditions of Collision simulations

In order to investigate damage conditions of struck ships, a series of non-linear FE-analyses, whose system was developed by Dr. Endo's group of National Maritime Research Institute of Japan [6], has been performed. The general-purpose explicit finite element code LS-DYNA was employed in the present analysis. The type and size of the striking and struck ships are assumed to be the same, that is, a D/H VLCC with 290,000 DWT. The bulbous bow of the ship is relatively sharp and stiffened with longitudinals. The principal dimensions are as follows:

$$L_{pp} \times B_{mld} \times D_{mld} = 309.0 \times 58.0 \times 33.0 \text{ (m)}$$

Hydrostatic restoring forces are taken into consideration. Analytical cases are tabulated in Table 1.

Table 1 Analytical Cases

	Loading condition of striking ship	Collision angle θ (°)	Collision speed V_B (kt)
Case 1	Laden	90	12
Case 2	Ballast	90	9

Collision condition and geometrical modelling are shown in Figures 3 and 4. The navigating speed of the striking ship in laden condition (Case 1) and that in ballast condition (Case 2) are assumed to be 12 and 9 knots, respectively. For simplification, the struck ship is assumed to be standstill. It is assumed that collision occurs at the midlength between transverse bulkhead and swash bulkhead in No.3 COT.

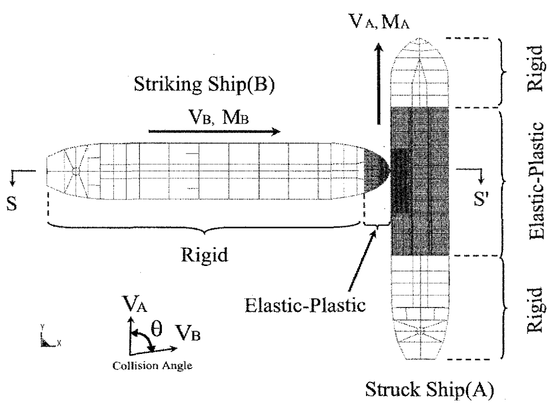
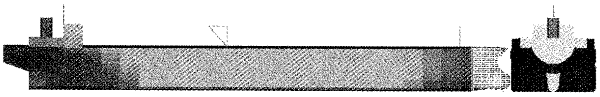


Fig. 3 Outline of Collision Condition and FE Modeling



(a) Case 1

(b) Case 2

Fig. 4 Start of Collision

Forward of the collision bulkhead of striking ship was modelled by elasto-plastic finite elements and the remaining parts were modelled by rigid elements. As for the struck ship, three tanks including the collided tank in the midst were modelled by elasto-plastic finite elements and the remaining parts were modelled by rigid elements. Ship's hull is mainly made of mild steels (partly high tensile steels). Stress-strain curves shown by solid lines in Figure 5 were used in the present analysis depending on the materials.

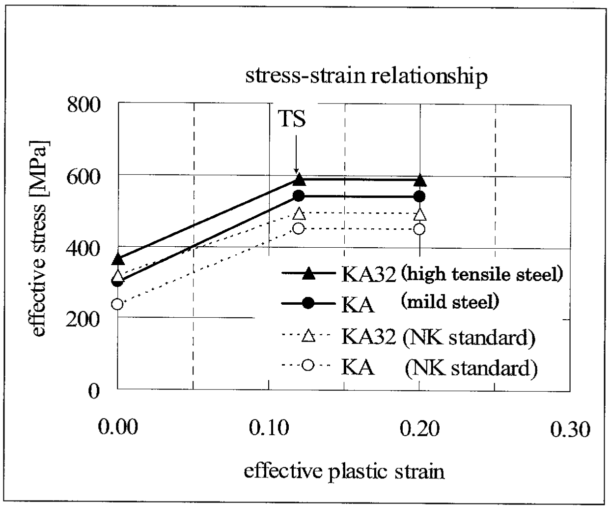


Fig. 5 Stress-strain Relationship Used in the Present Analysis (Shown by Solid lines)

Initial deflections and welding residual stress due to welding were not considered. Fillet welded joints of the struck ship were modelled by double nodes and fracture of fillet welded joints were evaluated. The elements are torn off when the equivalent tensile strain reaches the breaking effective plastic strain so that fracture of outer and inner hull could be predicted. The relationship between equivalent breaking effective plastic strain and gauge length is depicted in Figure 6. In the case of struck ship, the equivalent effective plastic strain depends on the gauge length (mesh size).

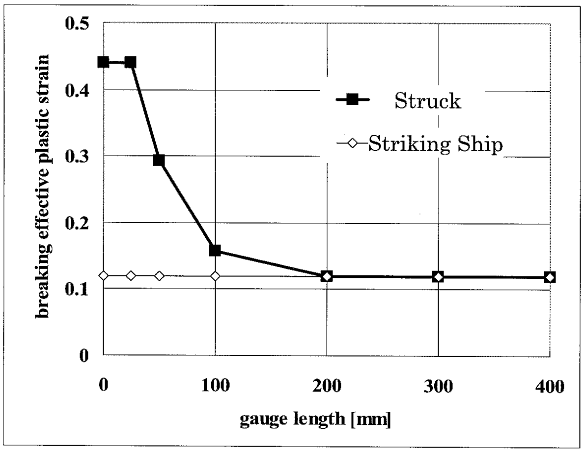


Fig. 6 Relationship between Breaking Effective Plastic Strain and Gauge Length

3. Simulation Results

3.1 Case 1: Striking ship in laden condition

Figure 7 shows the velocity of striking and struck ships in the direction of collision with respect to time. Figure 8 shows the time history of reaction force where RO and RI depict rupture in outer shell and that in inner shell, respectively. Figures 9 to 11 show the collision situations and extent of damage of the struck ship simulated in the present analysis. The analysis was stopped at t = 3.5 sec when the fracture due to collision fully developed.

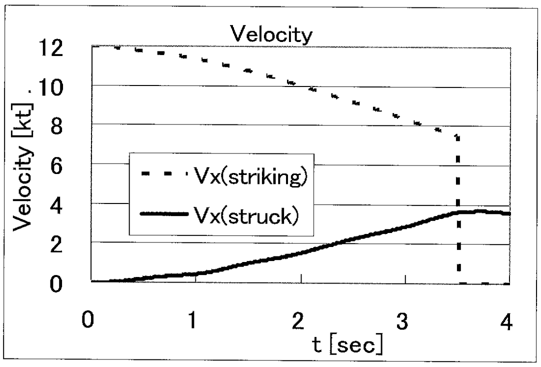


Fig. 7 Velocity of Striking and Struck Ships in the Direction of Collision with Respect to Time (CASE 1)

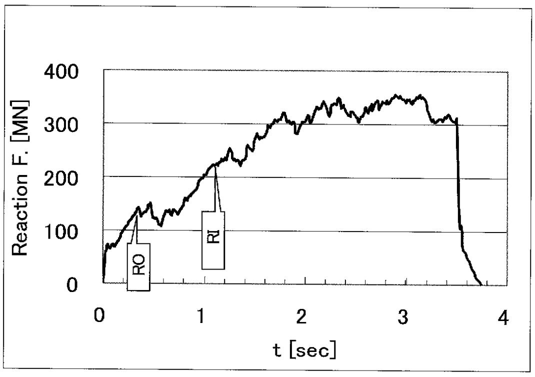


Fig. 8 Time History of Reaction Force (CASE 1, RO: Rupture in Outer Shell, RI: Rupture in Inner Shell)

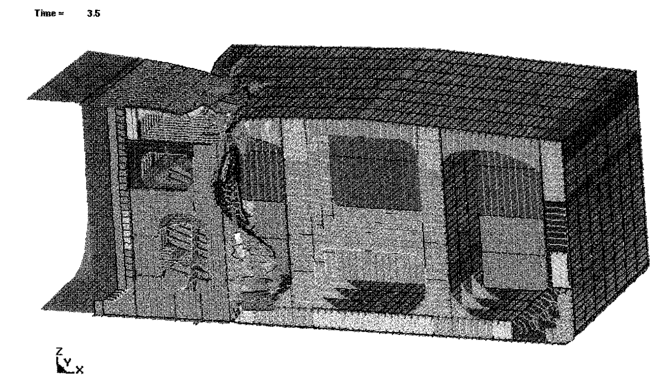


Fig. 9 Simulated Collision (CASE 1, t = 3.5 sec)

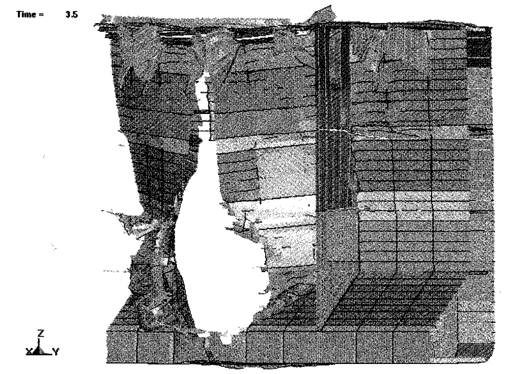
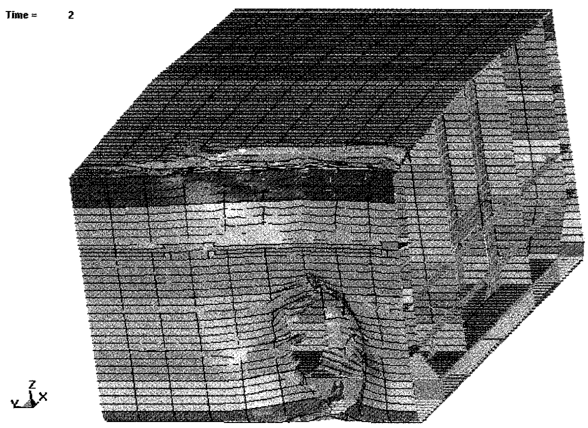
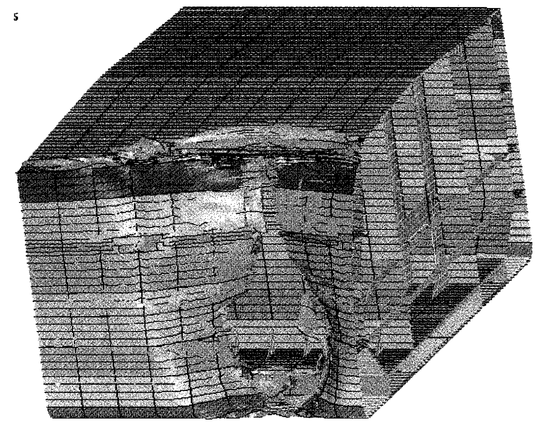


Fig. 11 Extent of Damage of Struck Ship (CASE 1, Inside, t = 3.5 sec)



(a) t = 2.0 sec



(b) t = 3.5 sec

Fig. 10 Extent of Damage of Struck Ship (CASE 1, Outside)

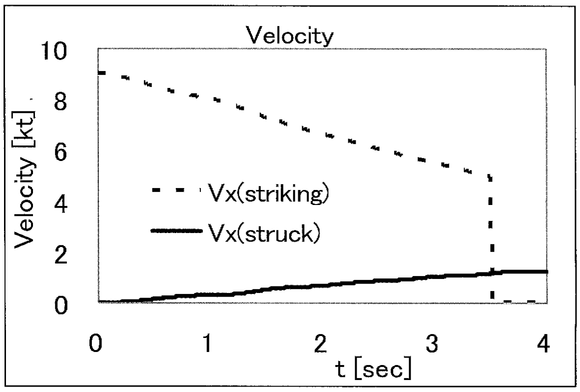


Fig. 12 Velocity of Striking and Struck Ships in the Direction of Collision with Respect to Time (CASE 2)

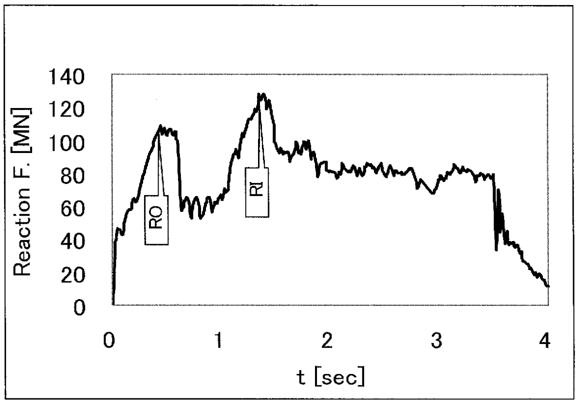


Fig. 13 Reaction Force (CASE 2)

3.2 Case 2: Striking ship in ballast condition

The time history of the velocity of striking and struck ships in the direction of collision is given in Figure 12. Figure 13 shows the reaction force with respect to time where RO and RI depict rupture in outer shell and that in inner shell, respectively. Figures 14 and 15 show the collision situations and extent of damage of the struck ship simulated in the present analysis. The analysis was stopped at t = 3.5 sec when the fracture due to collision fully developed.

3.3 Extent of breakage

In either cases of 1 and 2 above, the damage of bow structure is small. On the other hand, the damage of the side shell structure of struck ships is large and it can be

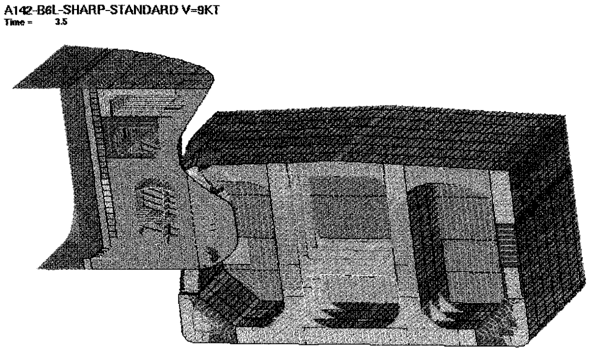
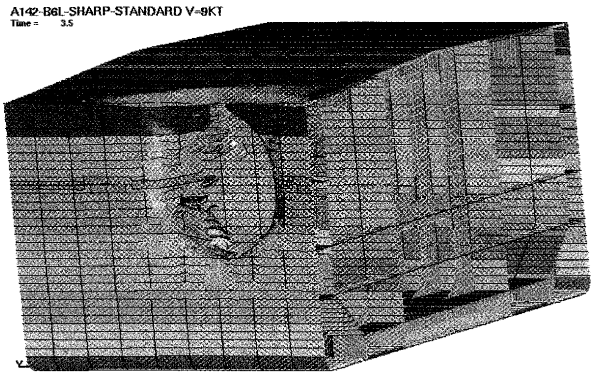
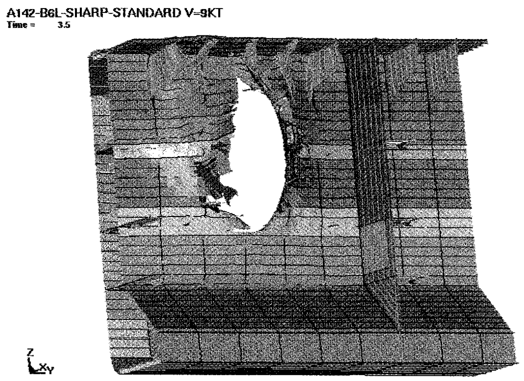


Fig. 14 Simulated Collision (CASE 2, t = 3.5 sec)



(a) Outside



(b) Inside

Fig. 15 Extent of Damage of Struck Ship (CASE 2, t = 3.5 sec)

seen that large breakage occurred in the outer and inner shells. The breakage is caused by the crush-in of bow of the striking ship. In the case where the striking ship is in ballast condition (Case 2), the breakage expands from around the water line along the shape of bow bulb of the striking ship. In the case where the striking ship is in laden condition (Case 1), the breakage starts at the vicinity of the double bottom structure and expands in the height direction. The bow bulb of striking ship is relatively sharp and the breakage of inner hull occurs

Table 2 Extent of Breakage

	Outer hull		Inner hull	
	Width	Height	Width	Height
Case 1	12.0m	33.0m	10.9m	33.0m
Case 2	10.9m	17.6m	8.9m	17.0m

immediately after the breakage of outer hull. The extent of breakage of the inner hull is a little smaller than that of the outer hull. The shape of breakage in the outer and inner hull is roughly the same. The size of breakage of struck ship is listed in Table 2. It is confirmed in the present study that FE simulation would be a powerful tool to predict the extent of breakage due to collision.

4. CONCLUSION

According to historical data analysis, it was confirmed that the risk level of double hull oil tankers is much lower than that of single hull tankers. Focusing on typical oil spill scenarios of double hull tankers, consequence analysis of collision needs to be conducted. In the present study, a series of non-linear FE analyses has been conducted to investigate the extent of breakage due to collision of ships as a basis of analysis of oil spill with a view to conducting qualitative risk assessment of double hull tankers. It is confirmed that FE simulation would be a powerful tool to predict the extent of breakage due to collision as a basis of analysis of oil spill risk. Lastly it should, however, be noted that the present study has just covered only a few cases where computational resources required were not so limited while many cases should be simulated for the purpose of risk assessment. In this context, from a practical view point to conduct risk assessment, it is desirable to develop a simplified computational method which can produce approximated outcomes using limited computational resources.

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