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공식안전평가기법의 선박해양구조설계에의 적용

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Application of Formal Safety Assessment Methodology to Marine Structural Design

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Abstract

Formal safety assessment (FSA) is defined as a structured and systematic methodology aimed at enhancing maritime safety including protection of life, health, and the marine environment and property, by using risk and cost/benefit assessment or, more specifically, it is a process of identifying hazard, evaluating risk and deciding on course of action to control those risks.

Emphasis is placed on the structural aspect of the failure of cargo hold. This study is expected to illustrate how a new methodology, i.e. the Formal Safety Assessment, can be applied to specific ship safety problems.

1. Introduction

In this paper, emphasis is placed on the bulk carrier casualty caused by flooding in the no. 1 cargo hold followed by the loss of structural integrity of the hold structural system and hull girder. FSA methodology consists of five steps as follows [1] :

Step 1. Hazard Identification
Step 2. Risk Assessment
Step 3. Risk Control Options
Step 4. Cost Benefit Assessment
Step 5. Decision Making

The purpose of the present study is to develop the structural safety assessment system by applying the FSA methodology, to apply the system to risk assessment of bulk carriers and to suggest possible risk control options (RCOs) aimed at reducing the potential loss of life (PLL) from viewpoints of structural design. This paper briefly addresses the trial application of FSA methodology to the structural safety assessment of bulk carriers.

2. FSA Steps

(1) Step 1 : Hazard Identification

Step 1 of the FSA methodology concerns definition of the problems under consideration followed by an initial screening of hazards, including identification of the significant accident scenarios which are taken forward for further development and analysis in step 2 (risk assessment).

According to survey report on bulk carrier casualties conducted by several Classification Societies[2-5], more than 40% of casualties were caused by flooding in cargo hold and the majority were considered to induce structural failure in the cargo hold, including shell plating loss and cracking. This implies that flooding in cargo space is very closely correlated with the structural failure in the cargo hold structural system. It can therefore be stated that structural failure in cargo holds directly leads to flooding in the cargo hold.

Risk is a combination of the frequency of occurrence of an accident type and the severity of its consequence, and is defined as[1] :

$$\text{Risk} = (\text{Consequence of a given accident}) \times (\text{Frequency of occurrence}) \qquad (1)$$

The generic unit of the consequence is loss, which may be loss of lives, environmental loss or property loss. In most trial application of the FSA methodology, the consequence is usually expressed in terms of loss of lives. Severity of consequence of the accident is defined in Table 1.

(2) Step 2 : Risk Assessment

The purpose of this step in the FSA methodology is to quantify the risks associated with the defined accident category in step 1, and the main task is to construct the quantified risk contribution tree (RCT). The RCT consists of fault trees, event trees and FN curves.

With reference to the reported accident scenarios, fault tree for the flooding accident in cargo hold is constructed as shown in Fig.1. All sub-events below the top event are related with the structural failure since flooding in cargo hold is closely correlated with the structural failure of hold system. Escalation of the accident is represented by means of event tree. For the present purpose, a bulk carrier of which dead weights are 70,000 tones, with LBP of 217 m, is selected. The probabilities of the initiating events in Fig.1 are evaluated through the structural reliability analysis[6]. The failure probabilities of the top event are calculated by Boolean algebra.

The underlying cause of structural failure in bulk carriers is the excessive thickness loss of side shell structure, especially main frame and transverse bulkhead due to corrosion, wastage and undesirable operation. In the structural reliability analysis thickness loss is also treated as a random variable. Event tree with the initiating event of flooding in cargo hold is illustrated in Fig.2. The probability at each node in event tree is assigned by the expert judgement in most cases. In case that structural failure problem is involved, the probability is evaluated through the structural reliability analysis.

The risk measure of each branch in event tree is obtained by multiplying the probability by the weighting factors corresponding to the consequence band (see Table 1). The resultant risk measure is the mathematical sum of risks of all branches in event tree.

(3) Step 3 : Risk Control Options

As described in [1], risk control options are presented by grouping several risk control measures. Through the brain storming study, risk control measures (RCMs) for accidents have been derived through HAZID meetings. Based on the derived RCMs, the feasible risk control options (RCOs) for the present study are proposed as listed in Table 2. Fig.3 shows the double hull side structure as an alternative configuration for no.1 cargo hold. The cargo space loss when this RCO is adopted is about 10%.

By applying the present safety assessment system to the bulk carrier model, the risk level for each RCO is derived. With these results PLL for each RCO can be calculated by multiplying the probability and the PLL for base case. The third column in Table 2 denotes the PLL for the base case and for the case that each RCO is implemented, and the fourth column is the risk benefit for each RCO in terms of PLL.

(4) Step 4 : Cost Benefit Assessment

Cost benefit assessment is required to rank the proposed RCOs in terms of risk benefit related to life cycle costs. Cost per unit reduction of risk (CURR) is an effective measure for this purpose[1 and is defined as :

$$CURR = \frac{cost\ \ of\ RCO\ -\ Benefit\ in\ [life + property + environmental]\ loss}{Change\ in\ PLL} \quad (2)$$

The cost of the RCO is the cost of the RCO, life, property and environmental losses are normalized to cost per vessel per year.

For the present cost benefit assessment, cost of each consequence in the event tree (Fig.2) is assumed to be proportional to the consequence of accident since the net present value (NPV) may not be easy to estimate for bulk carriers. Therefore when the total cost for the catastrophic case is evaluated, the costs for other severity cases can be easily obtained by multiplying 0.1 for each step from "major" to "insignificant". With reference to data for average values of total ship loss, cargo loss and clean up costs[1], the total loss in monetary terms for the catastrophic case of bulk carrier over 50k with 25 people on board can be calculated in US$ as US$50,614,000. Reference [7] details this figure. Hence the loss (cost) for each of the severity level is as follows :

Severity	Loss in US$
Catastrophic	50,614,000
Major	5,061,400
Minor	506,140
Insignificant	50,614

Cost for each RCO is summarized in Table 3. Cost per unit reduction of risk (CURR) when the proposed RCOs are implemented are summarized in Table 4.

(5) Step 5 : Recommendation for Decision Making

This step in the context of FSA provides a flexible decision support material so that balance of benefits between stakeholders can be achieved. There are many stakeholders who are affected by implementing the identified RCOs at Step 3. Since this paper is concerned with the effective structural design of no. 1 cargo hold, the primary and voluntary stakeholders to RCOs identified in Step 3 are designers, classification societies, ship owners, builders, cargo owners, crew and so on. According to the present findings at Step 4, discussion about RCOs is summarized in Table 5. This kind of discussions may be helpful in decision making stage. From Table 5 it can be found that RCOs 1 and 2 seem to be reasonable to implement, and for RCO 5 some more discussion is required to determine if the structural configuration of double hull type is acceptable and practicable.

3. Conclusions

In this paper, trial application of the FSA methodology has been carried out for bulk carriers. The accident type chosen is flooding in cargo hold. This trial application shows FSA methodology can be applied to bulk carrier safety problem. For complete study, reliable data are essential, and more detailed analysis on fault tree, event tree, and RCMs, RCOs are necessary.

References

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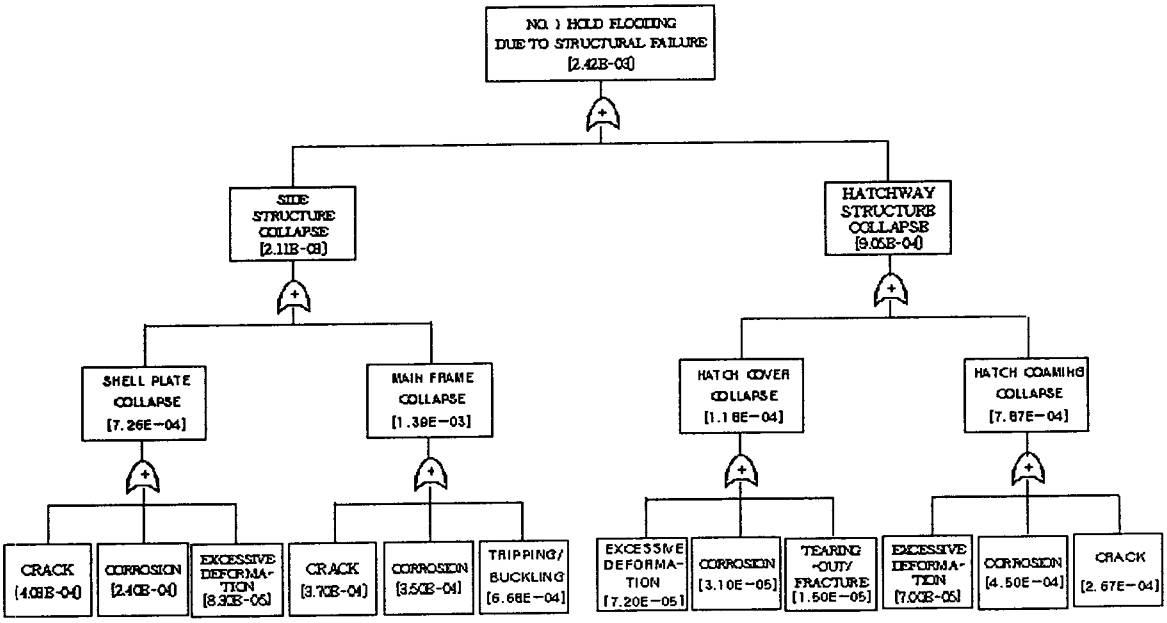

Fig. 1 Quantified fault tree : base case

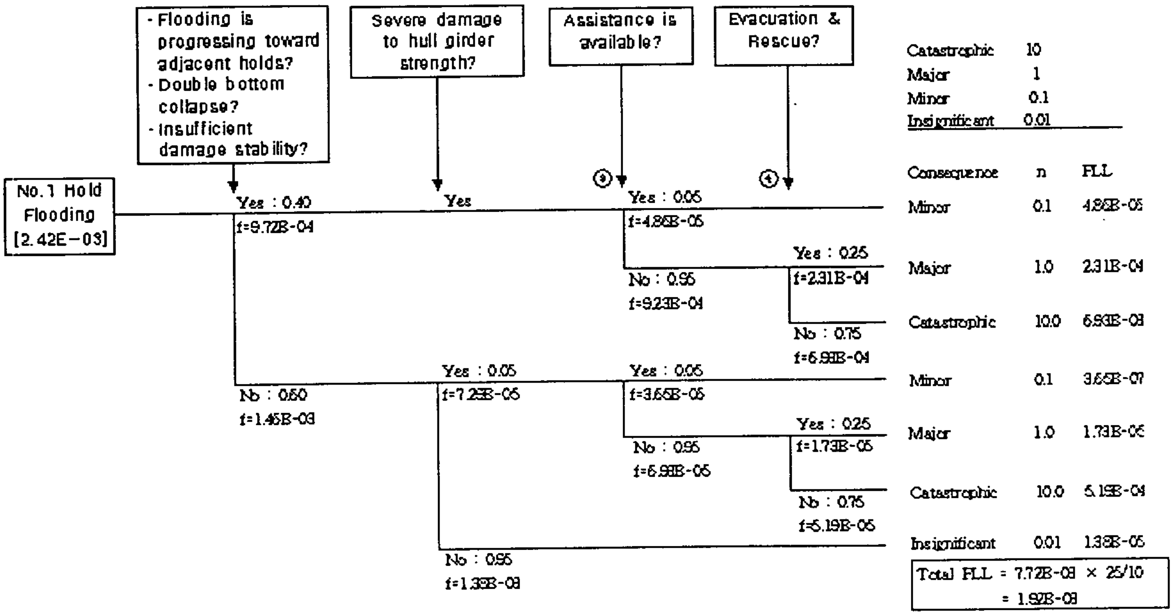

Fig. 2 Quantified event tree : base case

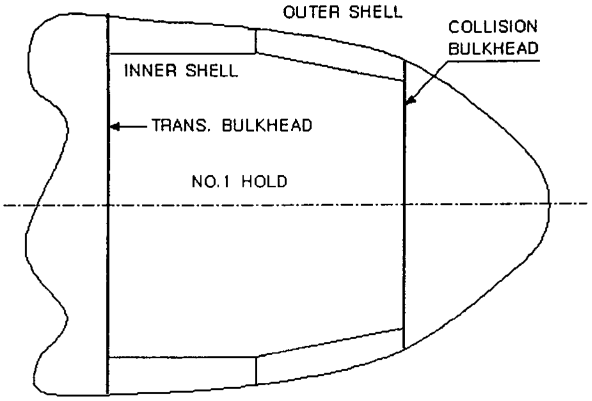

Fig.3 Configuration of double hull side structure for RCO 5 : no.1 hold only

Table 1 Consequence of accident

Category	Description	Consequence Band
Insignificant	· No significant harm to people, Property and the environment loss · Less than 10 minor injuries	0.01
Minor	· Minor damage / degradation of strength of the ship · Less than 1 equivalent death	0.1
Major	· Major damage / degradation of the ship · Less than 10 equivalent damage	1
Catastrophic	· Total loss of ship (actual loss and constructive total loss) · 10 or more loss of equivalent death	10

* 1 equivalent death = 10 major damage = 100 minor damage

Table 2 Risk control options and risk benefit

Ref.	Description	PLL	Risk benefit
Base case	-	1.92E-02	-
RCO 1	Strengthening design criteria for side structure (main frame & side shell plate)	1.67E-02	2.50E-03
RCO 2	Strengthening design criteria for fatigue consideration	1.38E-02	5.41E-03
RCO 3	Strengthening design criteria for connection area (improvement of shape design)	1.57E-02	3.44E-03
RCO 4	Strengthening the requirement against green water	1.79E-02	1.25E-03
RCO 5	Double Hull Side Structure (no.1 hold only)	1.02E-02	8.95E-03

Table 3 Cost for each RCO (US$ in 1993)

Ref.	Design cost	Construction cost	Cost due to reduction of cargo hold space	Total cost
RCO 1	-	6,150	-	6,150
RCO 2	14,643	-	-	14,643
RCO 3	14,643	6,150	-	20,500
RCO 4	14,643	5,000	-	19,643
RCO 5	14,643	-	47,850	62,493

Table 4 Cost per unit reduction of risk (US$ in 1993)

Ref.	RCO costⓐ	Cost savingⓑ	Change in PLLⓒ	CURR = $\frac{\text{ⓐ} - \text{ⓑ}}{\text{ⓒ}}$
RCO 1	6,150	12,658	2.50E-03	-2,602,281
RCO 2	14,643	27,372	5.41E-03	-2,353,758
RCO 3	20,500	17,413	3.44E-03	+897,352
RCO 4	19,643	6,345	1.25E-03	+10,607,605
RCO 5	62,493	45,305	8.95E-03	1,920,142

Table 5 Discussion on RCOs

Ref.	Description	Review
RCO 1	Strengthening design criteria for side structure	· Feasible and easy way to implement · High cost effective
RCO 2	Strengthening design criteria for fatigue consideration	· High risk benefit & high cost benefit · Since sturctural failure mainly involves fatigue failure, it can be strongly recommended to be implemented
RCO 3	Strengthening design criteria for connection area (improvement of shape design)	· Moderate risk benefit but the positive CURR suggests that implementation would not be financially beneficial
RCO 4	Strengthening the requirement against green water · strengthening design criteria for hatch cover and hatch coaming · installation of water breaker	· Low risk benefit but the positive CURR suggests that implementation would not be financially beneficial
RCO 5	Double Hull Side Structure (no.1 hold only)	· High risk benefit & high cost benefit · Its implementation should be seriously reviewed from view point of practicality in design & production. · In CBA, since 10% reduction of cargo space is overestimated, more financial benefit would be expected.