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Agenda item 5

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BULK CARRIER SAFETY

Report on FSA Study on Bulk Carrier Safety

Submitted by Japan

SUMMARY

Executive summary:	This paper presents a report of FSA study on bulk carrier safety carried out by Japan
Action to be taken:	Paragraph 8
Related documents:	MSC/Circ.829 and MEPC/Circ.335, MSC 69/22, MSC 70/23, MSC 70/WP.11, MSC 71/23, MSC 72/23, MSC 72/INF.7, MSC 72/INF.8, MSC 73/INF.10, MSC 74/5/3, MSC 74/INF.9, MSC 74/INF.10, MSC 74/INF.11, MSC 74/INF.12, MSC 75/INF.6

Background

1 IMO, recognizing the importance of enhancing the safety of bulk carriers, had considered and developed, in the Committee in 1990s, provisions for safety of bulk, which was adopted as chapter XII of SOLAS 74, as amended, in SOLAS Conference held in November 1997. The Conference also adopted several resolutions concerning the safety of bulk carriers. Taking the resolutions into account, the Committee at its 69th session, agreed that it should further consider safety of bulk carriers (MSC 69/22).

2 At the seventieth session of the Committee, the United Kingdom offered a plan of conducting an internationally organized FSA study regarding bulk carrier safety. At that session, Japan announced that it would also conduct an FSA study on bulk carrier safety by itself. (MSC 70/23, MSC 70/WP.11).

3 At the seventy-first session, the Committee noted the progress of the FSA study by Japan (MSC 71/23). At the seventy-second session of the Committee, Japan submitted a progress report of the FSA study (MSC 72/INF.7 and MSC 72/INF.8), and the Committee noted the progress (MSC 72/23). At the 73rd session of the Committee, Japan further informed the Committee, by a paper MSC 73/INF.10, of the progress of the FSA study, and the Committee noted the information (MSC 73/21). At the 74th session of the Committee, Japan submitted a set of reports of the FSA study (MSC 74/5/3, MSC 74/INF.9, MSC 74/INF.10, MSC 74/INF.11 and MSC 74/INF.12) and informed that it would submit the FSA full report to the Committee at the seventy-fifth session, and the Committee noted the information (MSC 74/WP.12/Add.2).

Progress of the FSA study in Japan

4 A research committee (RR74BC-WG) has been established, since 1 January 1999, in the Shipbuilding Research Association of Japan, under the supervision of the Ministry of Land, Infrastructure and Transport of Japan, for the purpose of conducting the FSA study on bulk carrier safety. The constitution and method of work of the research committee comply with the Interim Guidelines for FSA (MSC/Circ.829 and MEPC/Circ.335) as far as practicable.

5 Until February 2002, the research committee conducted the FSA study, according to the FSA Guidelines, on limited types of bulk carriers, which have topside tanks and hopper side tanks in the cargo spaces. The size of the bulk carriers under study was categorized into 4 groups by deadweight tonnes. The results of the FSA study including final recommendations are attached to the annex of this paper.

6 The final FSA report is attached to this document in the annex, following the standard reporting format for FSA studies (MSC/Circ.829, annex 2). All other background material is made available as annexes to the FSA report. All these annexes have been made publicly available on the world wide web as given in the list of references at the end of the report.

7 Being aware that the final report has not covered some items, such as FSA for other types of bulk carriers and for other elements (e.g. human element, RCOs mentioned during the discussion at the previous sessions of the Committee) and that other FSA studies were/will be submitted to the Committee, Japan will continue to work on bulk carrier safety and will report its consideration to the Committee in a future session of the Committee.

Final recommendations for decision-making

8 Japan has carried out all five steps of FSA on typical bulk carriers which have single deck, topside tanks and bilge hopper tanks, and are categorized into 4 types, i.e. cape size, panamax size, handy size and small handy size. The final recommendations for decision-making from the study are as follows:

.1 It was judged that the risk level of whole bulk carriers in future would stay at a relatively upper part of the ALARP region even after recently adopted RCOs are implemented and become perfectly effective. Moreover it is higher than other types of ships such as tankers and container carriers. Therefore, IMO should pursue further safety measures that could reduce the risk of bulk carriers, in cost-effective way, as low as reasonably practicable (ALARP) with high priority. The risk level of the bulk carriers under 150m in length is higher than that of the other size of bulk carriers, based on the estimation of the risk of each size of bulk carriers. This means that IMO should give priority to such smaller bulk carriers at first.

.2 With regard to post-estimation of validity of SOLAS chapter XII, SOLAS chapter XII can be justified based on the comparison of the cost effectiveness of SOLAS chapter XII and that of the other relevant RCOs such as a mandatory requirement of double side skin referring to the criterion proposed by Norway in MSC 72/16. At the same time, exemption of double side skin bulk carriers from SOLAS chapter XII can be justified based on the same comparison and consideration on the magnitude of risk of double side skin bulk carriers.

.3 With regard to single side skin bulk carriers of less than 150 m in length, they have been exempted from SOLAS chapter XII. The necessity of the countermeasures for safety of such ships is higher than that of the other sizes of bulk carriers, because the magnitude of the risk of single side skin bulk carriers of less than 150 m is relatively higher than that of the other sizes of bulk carrier. On the other hand, RCOs for mitigating consequences after hold flooding as required in SOLAS chapter XII are not considered to be appropriate, because only one hold flooding is fatal for bulk carriers of less than 150 m in length, if the number of cargo holds of current design practice for such smaller ships can not be changed. Therefore, measures to prevent flooding are much important for such smaller bulk carriers. Then, in short, further investigation on following preventive measures of RCO is recommended:

.1 Increased corrosion margin (design stage)

.2 Corrosion control of single side skin (in-service)

.4 With regard to single side skin bulk carriers of 150m and over in length, the mitigating safety countermeasures as a secondary barrier after hold flooding have already been implemented in SOLAS chapter XII. Nevertheless, preventive measures against water ingress from a breach of side shell structure would be cost effective as a further safety countermeasure. According to the cost effectiveness assessment, it is recommended that corrosion control requirements such as an increase of corrosion margin and preventive coating should be considered, because such measures are much cost-effective than double side skin (see figures of GCAF). In short, further investigation on following RCOs is recommended:

.1 Increased corrosion margin (design stage)

.2 Corrosion control of single side skin (in-service)

Action requested of the Committee

9 The Committee is invited to:

.1 consider the recommendations given in paragraph 7 above and Chapter 7 of the FSA report attached to this document in the annex,

.2 review the FSA report in the annex in general, and

.3 decide as appropriate.

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ANNEX

1 TITLE OF THE FSA STUDY

"FORMAL SAFETY ASSESSMENT OF BULK CARRIER SAFETY"

2 SUMMARY

2.1 Executive summary

This paper presents a report of FSA study on bulk carrier safety carried out by Japan. The focus of the study has been on the water ingress to cargo holds and/or structural failures of a typical bulk carrier, which is constructed generally with single deck, topside tanks and hopper side tanks in cargo spaces.

Hazard Identification and Risk Assessment has been carried out mainly based on historical data analysis together with creative activities such as brain storming sessions. As a result, a number of significant accident scenarios were identified by screening of identified hazards and by the investigation on LMIS casualty database (see Figure 2.1). Current base risk level of bulk carrier has been estimated by some techniques such as a simulation of effects of SOLAS chapter XII in future and judged to be in ALARP region.

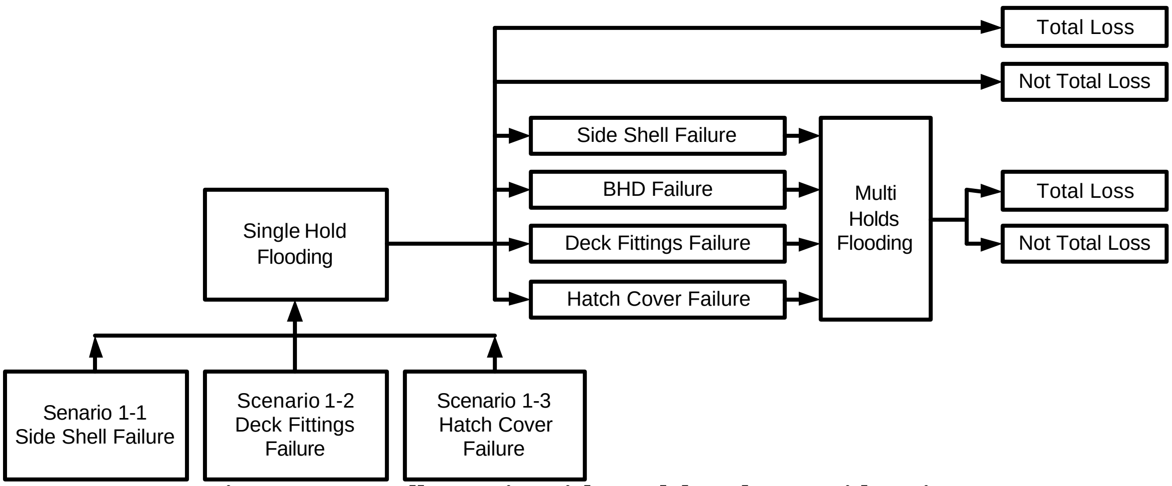


Figure 2.1 Illustrative risk model under consideration

Risk Control Options (RCOs) that are investigated in terms of cost effectiveness were as follows:

- RCO11: Extended application of SOLAS chapter XII to new bulk carriers (<150m in length)
- RCO15: Double side skin (all cargo holds)
- RCO16: Corrosion control of hold frames (Increase of corrosion margin)

- RCO51: Corrosion control of hold frames (Severely control of paint condition)
- RCO52: Corrosion control of hold frames (Application of enhanced corrosion allowance)
- RCO21: Extended application of SOLAS chapter XII to existing bulk carriers (<150m in length)
- RCO23: Application of UR S21 to existing ships
- RCO25A: Application of double side skin construction for existing ships (all cargo holds)
- RCO25B: Application of double side skin construction for existing ships (Nos.1 and 2 cargo holds)

Based on the results from the cost effectiveness assessment using Gross CAF as indices, the risk control options referred below will be recommendation for further investigation and/or discussion under the agenda items of bulk carrier safety in MSC. The priority should be given to bulk carriers of less than 150m in length because of their relatively higher risk level.

Risk control options for bulk carriers of less than 150 m in length:

- Corrosion control of hold frames by increase of corrosion margin (at design stage)
- Corrosion control of single side skin (in service)

Risk control options for bulk carriers of equal and more than 150 m in length:

- Corrosion control of hold frames by increase of corrosion margin (at design stage)
- Corrosion control of single side skin (in service)

2.2 Actions to be taken

The Committee is invited to consider the recommendations given in Chapter 7 of the FSA report and to decide as appropriate, together with recommendations of other FSA studies on bulk carrier safety.

2.3 Related documents

MSC/Circ.829 and MEPC/Circ.335, MSC69/22, MSC70/23, MSC70/WP.11, MSC 71/23, MSC 72/23, MSC 72/INF.7, MSC 72/INF.8, MSC 73/INF.10, MSC 74/5/3, MSC 74/INF.9, MSC 74/INF.10, MSC 74/INF.11, MSC 74/INF.12

3 DEFINITION OF THE PROBLEM

3.1 Definition of the Problem

The primary objectives of Japanese FSA study is to provide a base for discussion in IMO of bulk carrier safety, considering controversial issues that has been discussed at the IMO. Especially issues summarized in Table 3.1.1, which initiated FSA studies, have been focused on. For this purpose, following has been carried out.

- to investigate the safety level of bulk carriers (step 0);
- to investigate the hazards and risks of bulk carriers (step 1 and 2);
- to investigate the necessity of improvement of safety of bulk carriers (step 2);
- if the necessity is confirmed, to seek measures for improving safety of bulk carriers (step 3); and
- identified measures are prioritized in terms of cost effectiveness (step 4).

At the beginning, it was decided that the FSA study on bulk carriers should consider entire hazards and risk that are particular for bulk carriers, and to seek reasonable risk control options to encounter the hazards and risks. FSA methodology followed interim Guidelines on FSA (MSC/Circ.829 and MEPC/Circ.335) as far as practicable. In this FSA study, it was decided not to review other hazards and risk, which are common to all types of ships.

Table 3.1.1 Items discussed regarding bulk carrier safety before MSC71

In relation to resolution 8 of SOLAS Conference	• Safety of bulk carriers of less than 150 m in length
	• Safety of new bulk carriers of double side skin construction
	• Safety of single side skin bulk carriers carrying solid bulk cargoes having a density of less than 1,780 kg/m^2
	• Safety of bulk carriers with an insufficient number of holds/transverse watertight bulkheads to satisfy regulation XII/4.2
In relation to the Report of investigation on "M.V. **Derbyshire**"	• Fore deck and fore end space access
	• Life-saving appliances for bulk carriers
Matters to be considered in SLF Sub-Committee as decided at MSC70.	• Protection of the ship's fore end from green water
	• Fore deck and fore end space access

3.2 Reference to the regulation(s) affected by the proposal to be reviewed or developed

Firstly all relevant regulations were tried to be taken into account. After prioritization of accidents scenario, risk control options (RCOs) etc., recommended RCOs might affect mainly SOLAS.

3.3 Definition of the generic model

As FSA is a holistic approach, investigation on generic model of bulk carrier in general such as definition of bulk carriers were carried out as wide as possible. Details of generic model are described in annex 1. After that, generic model has been limited in order to concentrate problems with high priority considering the magnitude of risk and peculiarity of bulk carriers. The generic model dealt in this final report is summarized as follows:

Definition	SOLAS IX
Cross Section	Figure 3.3.1
Segmentation by size	Table 3.3.1 (Typical Principal Dimensions are shown in Table 3.3.2)

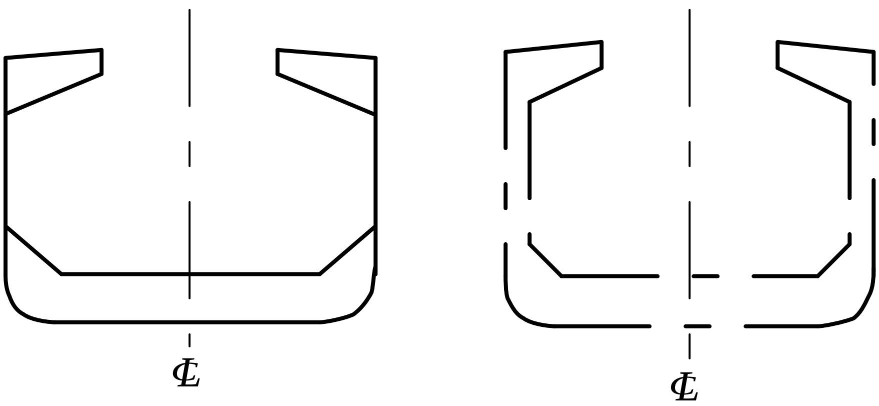


Figure 3.3.1 Midship section of ordinary type bulk carrier

Table 3.3.1 Classification of Bulk Carrier in size

	Lf (m)	GT	DWT (ton)	(DWT*)
Small-Handy	100-150	5K-14K	10K-23K	(10K-35K)
Handy	150-200	14K-30K	23K-55K	(35K-50K)
Panamax	200-230	30K-45K	55K-80K	(50K-80K)
Cape size	230-270	45K-	80K-	(80K-)

Note: * For the reference, these values are cited from the report of Bulk Carrier Report, An analysis of vessel losses and fatalities Statistics for 1999 and ten years of losses 1990-1999.

Table 3.3.2 – Principal Dimensions of Generic Model Vessels

Size / Type	Lf (m)	B (m)	D (m)	d_{mold} (m)	DWT (ton)	GT	Number of Cargo spaces
Cape Size	281.50	47.00	24.00	17.80	182,700	92,200	9
Panamax	216.70	32.26	18.60	13.50	72,000	37,500	7
Handymax	180.40	32.20	16.10	11.40	46,800	26,800	5
(Small Handy)	150.20	26.00	13.30	9.50	24,200	14,600	4
Small Handy	136.50	22.80	12.20	9.10	18,200	11,200	4
(Coal Carrier)	227.10	38.00	20.00	13.80	88,000	49,000	5

4 BACKGROUND INFORMATION

4.1 Lessons learned from recent studies

The results of investigation on literature survey regarding bulk carrier safety are also described in annex 1.

4.2 Recently introduced risk control options

Serious concerns have been expressed about the safety of bulk carriers for some time particularly following a spate of losses in the early 1990s. As a result, a number of regulations such as Enhanced Survey Programme (ESP) and SOLAS chapter XII were introduced. At the same time, ISM Code and PSC, which is not limited to bulk carriers and tankers, were introduced during the 1990s. Table 4.2.1 shows a summary of such regulations.

Table 4.2.1 Regulations regarding bulk carrier safety

SOLAS		Chapter XII - Safety Measures for Bulk Carriers, including IACS Unified Requirements S12 and S17 to S24
	ISM Code	Chapter IX - International Safety Management Code (ISM Code)
	ESP	Chapter XI - Enhanced Survey, and IMO resolution A.744(18)
	LSA	Chapter III - Life-Saving Appliances and Arrangements
	BC Code	Chapter II-2, VI and VII - Code of Safety Practice for Solid Bulk Cargoes as amended
	IMDG Code	Chapter II-2 and VII - International Maritime Dangerous Goods Code as amended
ILLC66		International Convention on Load Line, 1966 (ILL 66) and the relative Protocol
MARPOL73		International Convention for the Prevention of Pollution from Ships, 1973 as amended (MARPOL 73) and the relative Protocol
STCW		International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1995 as amended (STCW)
IACS Urs	S12	Side structures in single side skin bulk carriers
	S17	Longitudinal strength of hull girder in flooded condition for bulk carriers
	S18	Evaluation of scantlings of corrugated transverse watertight bulkheads in bulk carriers considering hold flooding
	S19	Evaluation of scantlings of the transverse watertight corrugated bulkhead between cargo holds Nos. 1 and 2, with cargo hold No. 1 flooded, for existing bulk carriers
	S20	Evaluation of allowable hold loading for bulk carriers considering hold flooding
	S21	Evaluation of scantlings of hatch covers of bulk carrier cargo
	S22	Evaluation of allowable hold flooding of cargo hold No. 1 with cargo hold No. 1 flooded, for existing bulk carriers
	S23	Implementation of IACS Unified Requirements S19 and S22 for existing side skin bulk carriers
	S24	Detection of water ingress into cargo holds of existing bulk carriers

4.3.3 Relevant limitations

The following items should be noted as limitation of the study:

- type of bulk carriers is limited to typical one,
- human element is not included (it would be dealt with in another paper),
- estimation of risk reduction is carried out coarsely based on very simple assumptions,
- estimation of cost of RCOs is biased because unit cost of personnel expenses and materials varies significantly when seen worldwide.

5. METHOD OF WORK

5.1 Composition and level of expertise of those having carried out the application

The composition and level of expertise of the committee members are shown in annex 2.

5.2 Description on how the assessment has been conducted

A research committee has been established, since January 1999, in Shipbuilding Research Association of Japan, under supervision of MLIT (Ministry of Land, Infrastructure and Transport) of Japan, for the purpose of conducting FSA study on bulk carrier safety. The constitution and method of work of the research committee comply with the FSA Guidelines of MSC/Circ. 829 and MEPC/Circ. 335 as far as practicable.

5.3 Start and completion date of the assessment

The assessment was initiated 1st January 1999 and finished 12th February 2002.

6 DESCRIPTION OF THE RESULTS ARCHIEVED IN EACH STEP

6.1 Step 1; Hazard Identification

Some parts of the results of the STEP 1 hazard identification have been presented to the Committee by paper MSC 72/INF.8 and MSC 73/INF.10. Details of Step 1 are described in Annex 4.

6.1.1 Method and technique, and area of hazard

A set of HAZID Worksheets whose example is shown in Table 6.1.1 was developed by HAZID meetings and by correspondence within the research committee. In addition, hazards were derived by investigation on LMIS casualty database. The main accident categories covered are as follows and HAZID worksheets for rest of accident categories were also developed:

- Accident Category 1: Structural failure of cargo hold part;
- Accident Category 2: Structural failure of fore end part;

- Accident Category 3: Structural failure of aft end part; and

- Accident Category 4: Water ingress through openings.

In order to rank identified hazards, Frequency Index (F.I.) and Severity Index (S.I.) are defined as shown in Table 6.1.2 and Table 6.1.3 respectively. Then, a risk matrix was developed (Table 6.1.4), which is used for hazard ranking analysis.

With regard to screening of identified hazards, an investigation through questionnaire to experts was carried out. 14 experts were selected and asked to fill S.I. and F.I. for each identified hazard. Risk Index (R.I.) was calculated by adding Frequency Index (F.I.) and Severity Index (F.I.). For each hazard, average of R.I. among the value given by the experts was calculated.

6.1.2 Results of Step 1; Prioritized hazard

Table 6.1.4 shows a part of the major hazards, which have large number of R.I. obtained from the investigation through questionnaire to the experts.

6.1.3 Results of Step 1; Prioritized accident scenario and qualitative fault trees

The following significant accident scenarios were identified based on the results of screening of the identified hazards and investigation on LMIS casualty database:

- Scenario-1: Progressive flooding after the following initial failures/flooding
  - Scenario-1-1: Flooding due to structural failure such as side shell failure
  - Scenario-1-2: Flooding into Fore Peak from failure of deck fittings
  - Scenario-1-3: Flooding due to hatch cover failure or their securing failure
- Scenario-2: Structural failure without water ingress in heavy weather
- Scenario-3: Structural failure during loading operation
- Scenario-4: Accident due to cargo shift at sea

At the same time, qualitative event trees were developed considering hazards and main events in the prioritized accident scenario. Figures 6.1.1and 6.1.2 show event trees for structural failure and loss of ships respectively.

**Table 6.1.1 An example of Hazard Worksheet
(Accidents Category: Structural Failure in Cargo Hold Part)**

ID	*Hazard Description / Hazardous Situation*	*Phase*	*Cause*	*Effect*	*Detection*	*Scenario / Accident Sub-category*	*Regulation*	*F.I.*	*S.I.*	*Remarks (including Frequency of Hazards)*
1.1	Cargo Hold									
1.1.1	**Corrosion**									
1.1.1.1	Rapid corrosion of hold frame	All	1) Incorrect selection of coating specification 2) Poor painting workmanship 3)Paint damage by cargo 3) Paint damage by inadequate discharge manner of bulldozer etc. *(to be continued)*	1) Thickness diminution of structural members including welding parts 2) Crack initiation or Penetration 3) Frame separation in part from shell plate	Visual inspection by crew and surveyors	Structural failure of side shell structure in way of cargo hold	SOLAS XI A.744(18) IACS UR S12 and Z10.2 (introduced into Class Rules) Class Rules	***X.Y***	***Y.Z***	ESP and IACS URs are effective (Reasonably probable)

Table 6.1.2 Definition of Frequency Index

Frequency Index (F.I.)	Frequency	Definition	per ship-year
1	Extremely Remote	- Likely to occur several times in 10 years in the world fleet of bulk carriers (about 5000 ships)	equal or less than 0.0001/ship-year (representative value: 0.00001)
3	Remote	- Likely to occur several times per year in the world fleet of bulk carriers (about 5000 ships)	0.001/ship-year
5	Reasonably Probable	- Likely to occur once in 10 years in a bulk carrier	0.1/ship-year
7	Frequent	- Likely to occur yearly or more frequently in a bulk carrier	equal or more than 1.0/ship-year (representative value: 10)

Table 6.1.3 Definition of Severity Index

Severity Index (S.I.)	Severity	Definition	Number of Fatalities
1	Insignificant	- Failure that can be readily compensated by the crew - No significant harm to people, property or the environment	0.01
2	Minor	- Local damage to ship - Marginal conditions for, or injuries to, crew	0.1
3	Major	- major casualties excluding total loss - single fatality or multiple severe injuries	1
4	Catastrophic	- total loss (actual loss and constructive total loss) - many fatalities	10

Table 6.1.4 Risk Matrix for Bulk Carrier FSA Study

7	Frequent	Level 4 (8)	Level 3 (9)	Level 2 (10)	Level 1 (11)
6		Level 5 (7)	Level 4 (8)	Level 3 (9)	Level 2 (10)
5	Reasonably	Level 6 (6)	Level 5 (7)	Level 4 (8)	Level 3 (9)
4		Level 7 (5)	Level 6 (6)	Level 5 (7)	Level 4 (8)
3	Remote	Level 8 (4)	Level 7 (5)	Level 6 (6)	Level 5 (7)
2		Level 9 (3)	Level 8 (4)	Level 7 (5)	Level 6 (6)
1	Extremely Remote	Level 10 (2)	Level 9 (3)	Level 8 (4)	Level 7 (5)
F.I.		Insignificant	Minor	Major	Catastrophic
	S.I.	1	2	3	4

Note: Figures in parenthesis following risk levels shows Risk Index (R.I.).

Table 6.1.5 Result of Screening of the identified hazards

No	ID	R.I.	Level	HAZARD	MOD
1	*1.1.3.1*	7.86	4	Dents on inner bottom plate, side shell structure, hopper plate and BHD	Load
2	*1.1.4.3*	7.71	4	Excessive impact load to forward side shell structure (in No.1 cargo hold)	All
3	*1.1.1.1*	7.29	5	Rapid corrosion of hold frame	All
4	*1.1.4.1*	7.29	5	Extreme dynamic sea water pressure to side shell of cargo holds (without counter pressure by cargo)	All
5	*1.4.3.2*	7.00	5	Dents on tank top plate (inner bottom plate)	Load
6	*1.1.1.2*	6.64	5	Rapid corrosion of side shell (including welding bead)	All
7	*1.1.5.1*	6.64	5	Excessive hull girder bending moment/ shearing force	All
8	*1.1.3.2*	6.57	5	Dents on hatch cover top	Load
9	*1.1.1.3*	6.50	5	Rapid corrosion of transverse bulkheads including lower and upper stools	All
10	*1.1.1.5*	6.50	5	Rapid corrosion of cargo hatch coamings	All
11	*1.4.1.2*	6.50	5	Rapid corrosion of bottom shell plate underneath bellmouthes / sounding pipes	All
12	*2.2.4.1*	6.50	5	Excessive wave load to foremost exposed deck	All
13	*1.2.1.1*	6.43	6	Rapid corrosion of structural members	All
14	*1.3.3.2*	6.42	6	Dents on hopper plate	Load
15	*1.1.2.1*	6.36	6	Excessive (/Over) Stress concentration at hold frame bracket end	All

No	ID	R.I.	Level	HAZARD	MOD
16	*1.1.4.2*	6.36	6	Excessive wave impact load on cross deck	All
17	*2.2.4.2*	6.36	6	Excessive wave impact load to foremost shell structure	All
18	*1.2.4.3*	6.31	6	Excessive water pressure in ballast tanks at ballast water exchange operation	WBE
19	*4.1.1.*	6.31	6	Water Ingress through chain pipe	All
20	*1.1.2.7*	6.29	6	Stress concentration at hatch coaming end bracket	All

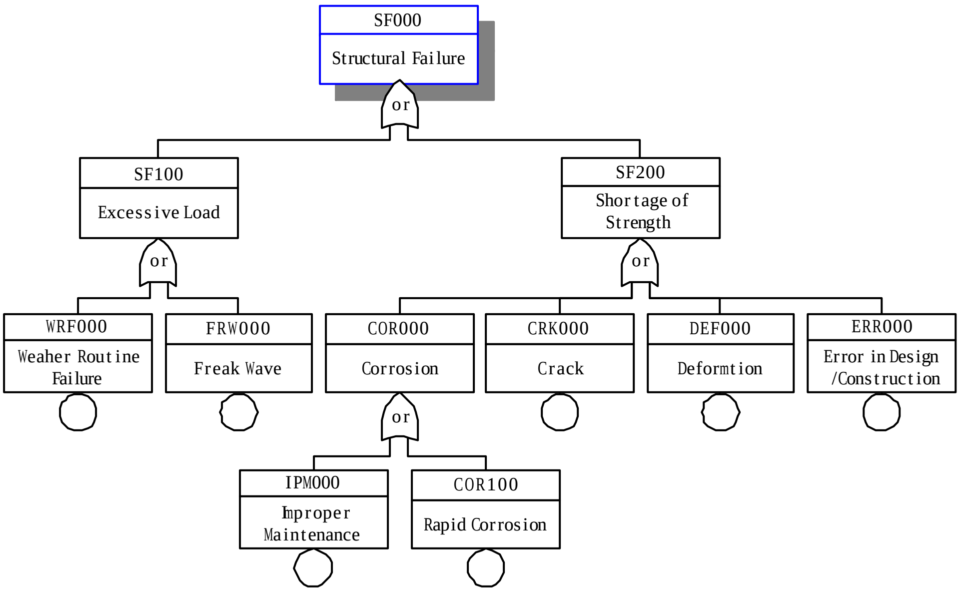


Figure 6.1.1 Fault tree to structure failure (corresponding to "SF" in the event trees)

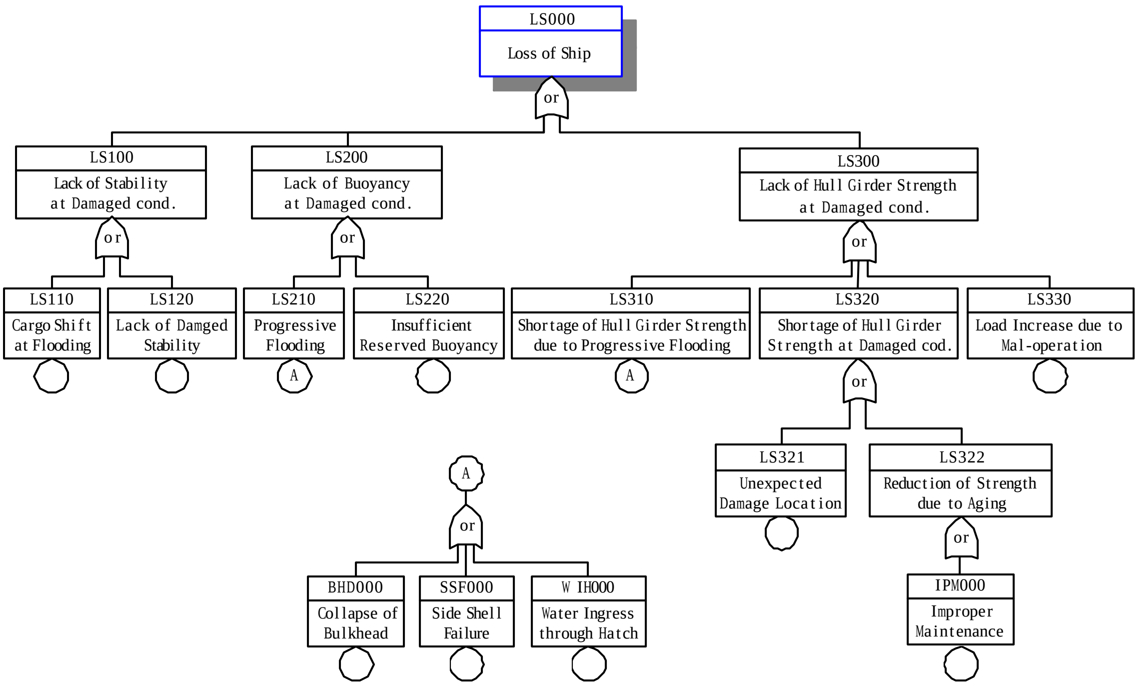


Figure 6.1.2 Fault tree to loss of ship (corresponding to "LS" in the event trees)

6.2 STEP 2; Risk Analysis

6.2.1 Method

In the risk analysis, quantification of the risk was carried out on the basis of casualty analysis, with regard to each casualty scenario that was screened out by investigation, analysis and classification of the casualty data and hazard identification. Furthermore, the risks of bulk carrier were estimated in the following 2 stages of risk analysis:

1) Assuming that the effects of recently implemented measures such as ESP (Enhanced Survey Programme), SOLAS chapter XII, etc. are practically not reflected in the past casualty data, the risk level before implementation of these measures, was estimated at the 1st stage of analysis.

2) Examining the potential effect of these measures to each accident case, the historical data was simulated, as if sufficient years have passed after these measures came into effect, and imaginary risk levels supposed to be improved by these measures were estimated.

6.2.2 Estimation of the Risk Level before the implementation of the SOLAS chapter XII

6.2.2.1 Results of Casualty Data Analysis (including F-N Curve and PLL)

It was found that 1,126 of lives were lost since 1978 to August 2000, on the analysis of historical casualty data. The itemization of these fatalities by accident scenario or scenario groups is shown in Figure 6.2.1. It accounts for about 54% of 2067 fatalities by any causes.

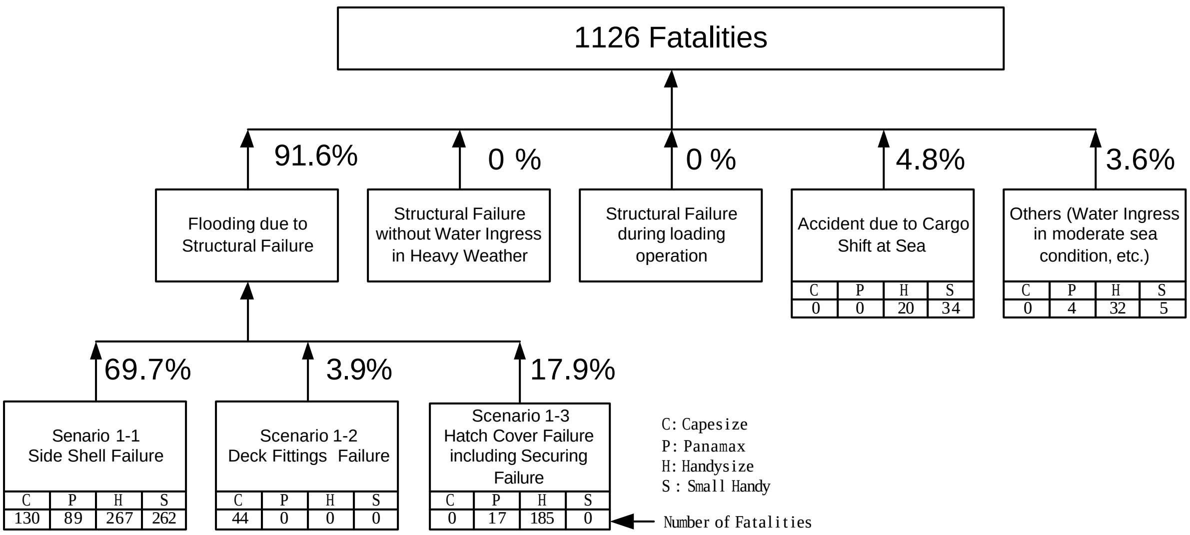


Figure 6.2.1 Itemization of Fatalities by casualty scenario or scenario groups

This figure shows that the accident scenario group No.1 is most significant, in case of considering the fatalities on the bulk carrier casualties related to structural failure and flooding. As the result of the analysis, 208 casualties are categorized into scenario 1-1 and about half of them (95 casualties) are resulted in total loss. This consequence corresponds to many fatalities. Although there are 9 cases that could be identified as casualties caused by deck fittings failure, the one resulted in total loss is only one case. There are 20 casualties caused by the damage of the hatch cover including securing devices, and 8 cases of them are resulted in total loss. Details of the analysis are shown in Annex 5.

6.2.2.2 Event Tree Analysis (ETA) based on the Historical Casualty Data

As a result of the investigation of historical data, event tree diagrams were developed with regard to progress of the typical accident sequence and event that caused serious casualties. Figure 6.2.2 shows an event tree diagram with casualty breakdown on hull structural failures of bulk carrier of 10,000 DWT or over. Figure 6.2.3 also shows an event tree diagram specialized to the casualties caused by failure of hatch covers or their securing devices.

From these figures following findings are derived:

1) Frequency of serious casualty leading from securing/tightening failure of hatch cover is same as that of structural failure of hatch cover. However, number of fatalities in consequence of securing/tightening failure is extremely larger in comparison with the case leading from structural failure.

2) The reason why is simply considered that the securing failure (including structural failure of cleating device, human elements, etc.) cause the cargo hold exposed widely to the sea at once by hatch cover being opened or washed away. This probably causes as many as 200 fatalities.

3) Judging only from historical data analysis, as the first barrier against hold flooding, the soundness (including both mechanical and human elements) of securing device for hatch cover including hatch coaming seems to be closely related to fatal casualty rather than strength of hatch cover panels.

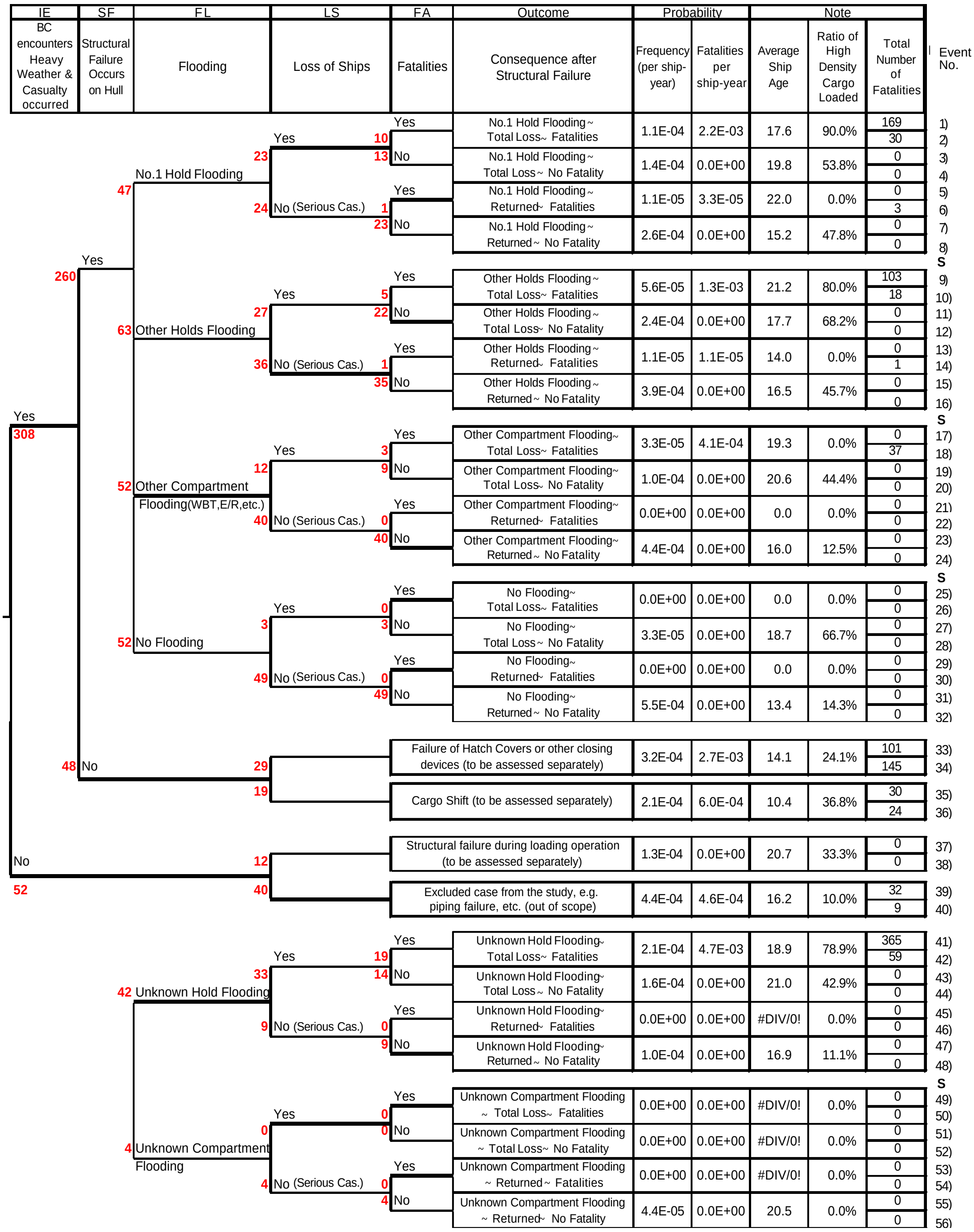


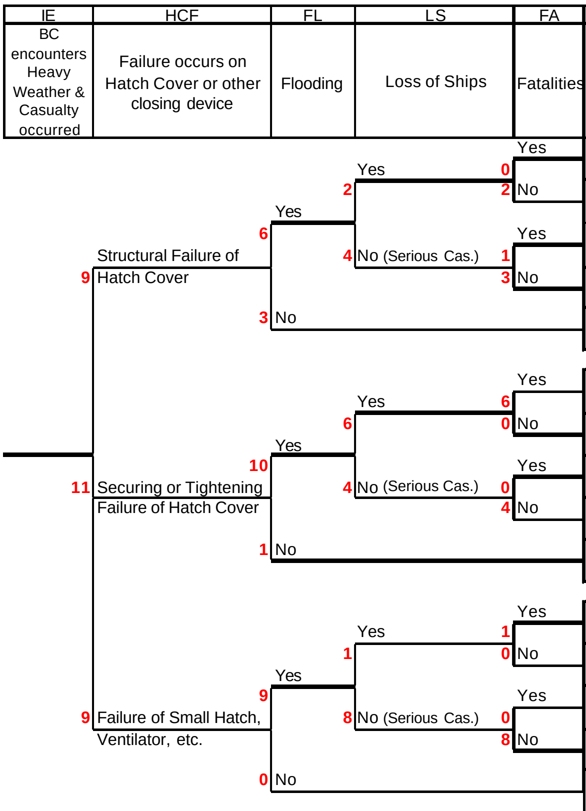
Figure 6.2.2 Event tree diagram with casualty breakdown (10,000dwt+)

Note:

* Odd numbers at right side indicates the casualties occurred in high-density cargo loaded condition. (1.78 t/m^3 or above)

** The figures at shoulder of each branch indicate the classified number of casualty in each event.

*** In case of unknown hold flooding, flooded hold is assumed by expert judgment. Therefore, the numbers of casualties/fatalities on each event may not correspond to the estimation in the study.



Sequence of Casualty	Frequency (per ship-year)	Fatalities per ship year	Average Ship Age	Ratio concerning Fore End or No.1 Hold	Total Number of Fatalities	Event No.
HC Structural Failure-Flooding-Sank-Fatalities	0.0E+00	0.0E+00	0.0	0.0%	0 0	1) 2)
HC Structural Failure-Flooding-Sank-No Fatality	2.2E-05	0.0E+00	15.5	50.0%	0 0	3) 4)
HC Structural Failure-Flooding-Returned-Fatalities	1.1E-05	2.2E-05	3.0	0.0%	0 2	5) 6)
HC Structural Failure-Flooding-Returned-No Fatality	3.3E-05	0.0E+00	18.0	100.0%	0 0	7) 8)
HC Structural Failure-No Flooding-Returned	3.3E-05	0.0E+00	11.3	33.3%	0 0	9) 10)
HC Securing or Tightening Failure-Flooding-Sank-Fatalities	6.7E-05	2.2E-03	21.5	100.0%	200 0	11) 12)
HC Securing or Tightening Failure-Flooding-Sank-No Fatality	0.0E+00	0.0E+00	0.0	0.0%	0 0	13) 14)
HC Securing or Tightening Failure-Flooding-Returned-Fatalities	0.0E+00	0.0E+00	0.0	0.0%	0 0	15) 16)
HC Securing or Tightening Failure-Flooding-Returned-No Fatality	4.4E-05	0.0E+00	20.5	50.0%	0 0	17) 18)
HC Securing or Tightening Failure-No Flooding-Returned	1.1E-05	0.0E+00	17.0	0.0%	0 0	19) 20)
Miscellaneous Closing Device Failure-Flooding-Sank-Fatalities	1.1E-05	4.9E-04	4.0	100.0%	44 0	21) 22)
Miscellaneous Closing Device Failure-Flooding-Sank-No Fatality	0.0E+00	0.0E+00	0.0	0.0%	0 0	23) 24)
Miscellaneous Closing Device Failure-Flooding-Returned-Fatalities	0.0E+00	0.0E+00	0.0	0.0%	0 0	25) 26)
Miscellaneous Closing Device Failure-Flooding-Returned-No Fatality	8.9E-05	0.0E+00	8.4	100.0%	0 0	27) 28)
Miscellaneous Closing Device Failure-No Flooding-Returned	0.0E+00	0.0E+00	0.0	0.0%	0 0	29) 30)

Figure 6.2.3Event tree diagram with casualty breakdown with regard to hatch cover failure (Failure of hatch cover or other closing device as initial event)

Note: * Odd numbers at right side indicates the casualties with regard to fore end or No.1 cargo hold.

** The casualty with 44 fatalities classified in Event No.21 is a noted casualty with M.V. Derbyshire.

6.2.2.3 Fault tree analysis based on historical casualty data

Corresponding to the occurrence of a total loss casualty in qualitative fault tree (FT), historical casualty data were classified and put into the diagram as shown in Figure 6.2.4. The most significant factor, which rules consequence of water ingress, is whether or not progressive flooding will occur. Each primary event in event trees was also qualitatively investigated by using fault tree. Details are shown in Annex 5.

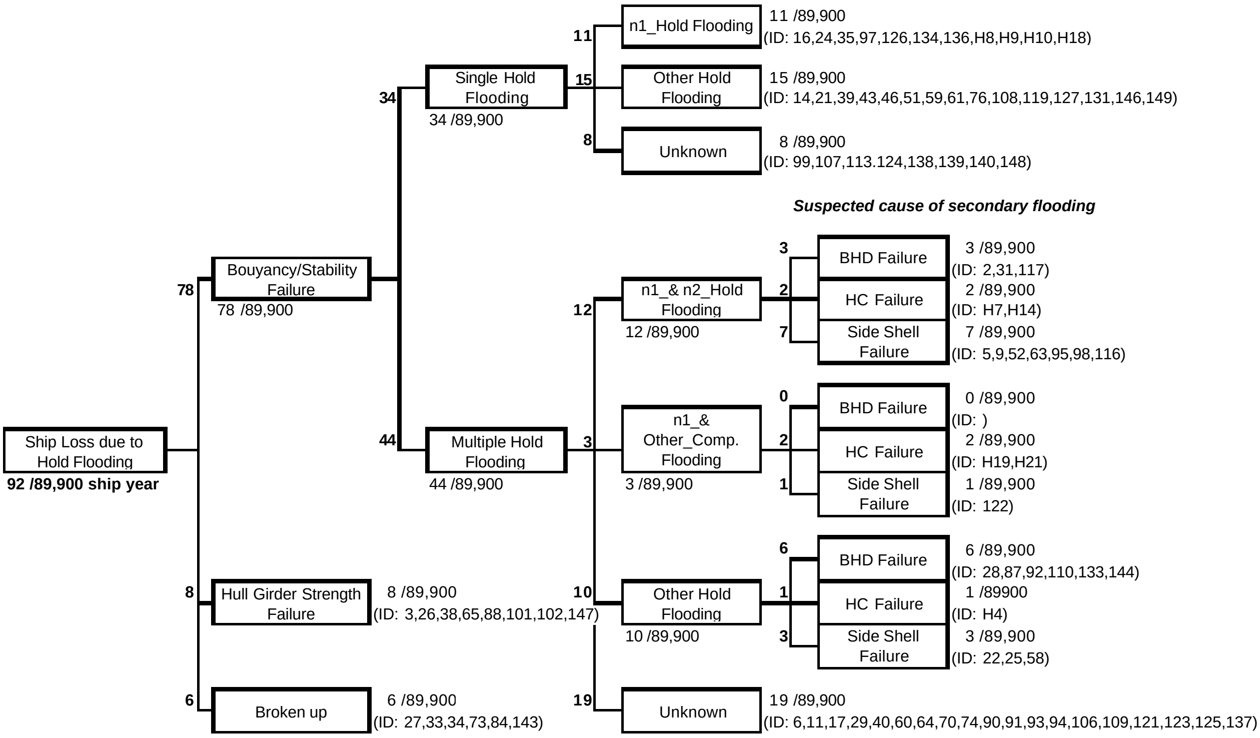


Figure 6.2.4 Breakdown diagram with regard to ship loss due to hold flooding

6.2.2.6 Risk model

Considering the circumstances mentioned above, the risk model for risk analysis and evaluation of risk control measures was screened out as shown in Figure 6.2.5.

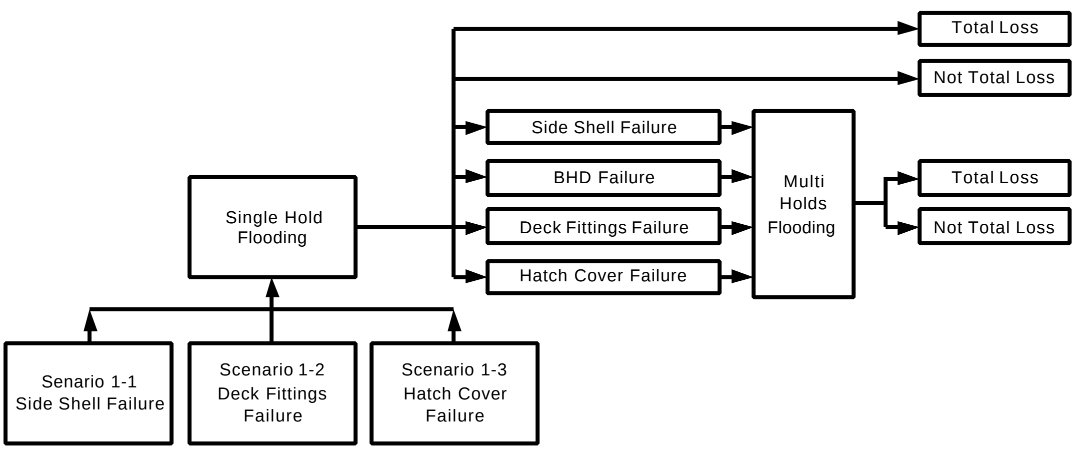


Figure 6.2.5 A model of serious casualty involving hold flooding

Even excluding "Accident group -2: Presumed water ingress (detail unknown)" from "Scenario-1", total 231 casualties are relating to eventual flooding. As for accident group -2, it is possible that the actual scenario of casualties classified in this group was scenario 1-1. Furthermore, considering the comparatively small number of the casualties classified in accident group -2, the frequency of a serious casualty was estimated as the following, that represents the upper bound of occurrence probability of a serious flooding casualty (per ship-year).

$$f_{upper} = \frac{g}{m} = \frac{237}{89{,}900} = 2.64 \cdot 10^{-3}$$

Similarly, the upper bound of the Potential Loss of Life (PLL) (fatalities per ship-year) of scenario 1 estimated by the historical casualty data is calculated as the following.

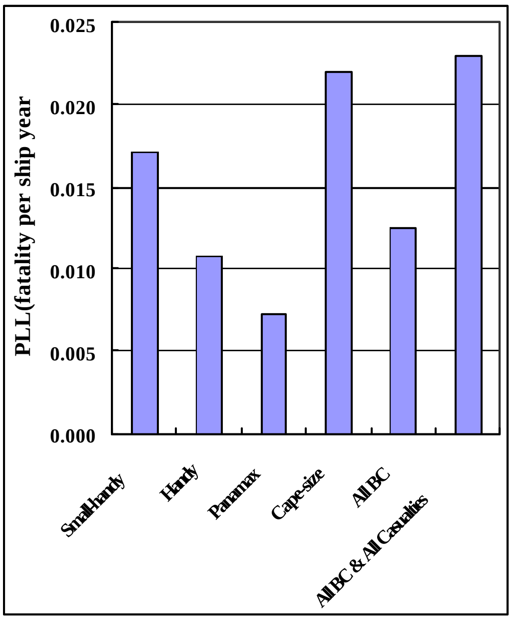


Figure 6.2.6 PLL for bulk carriers in each size

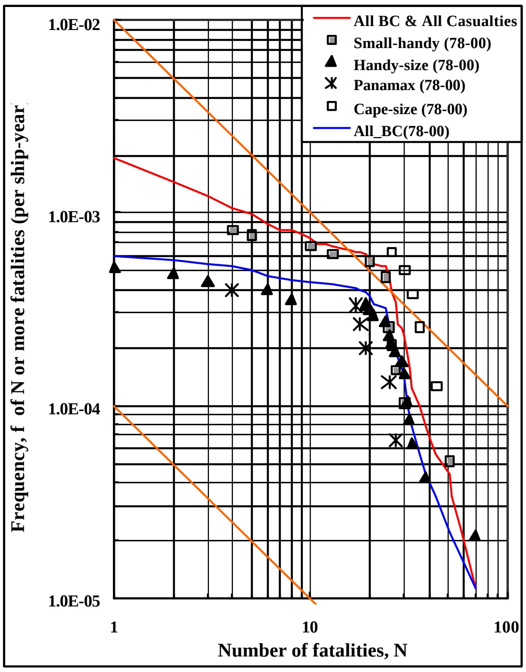


Figure 6.2.7 F-N Curves of Bulk Carrier

$$PLL_{\text{water\_ingress}} = \frac{1{,}031}{89{,}900} = 1.15 \cdot 10^{-2}$$

The PLLs estimated for each size is shown in Figure 6.2.6. Also, the result of examination with F-N Curve that is one of method that expresses social risk is shown in Figure 6.2.7. Straight lines dropping the right in F-N Curve are the boundary lines of the intolerable range, the ALARP range, the negligible range that were proposed in MSC72/16. The accident scenarios examined in this study which are reaching about 70 % of all casualties including those out of scope in this study such as fire, explosion etc. which is shown as F-N curves for comparison in the figure, are conceivable to be given high priority. Considering the hull structural casualties targeted in this study, the PLLs with regard to Cape-size and Small handy are comparatively high on the observation by each size. This trend is also appeared in the F-N curve.

The result of the PLL estimation by each flooded compartments from the historical casualty data analysis, is shown in Figure 6.2.8. Where flooded compartment could not be identified, in this analysis, it is assumed that the number of fatalities, where water ingress location is unknown, could distribute to those of No.1 cargo hold, No.2 cargo hold and other cargo holds according to their ratio of number of fatal cases. According to this analysis, it is obvious that the PLL of the casualties leading from flooding into No. 1 cargo hold is comparatively high.

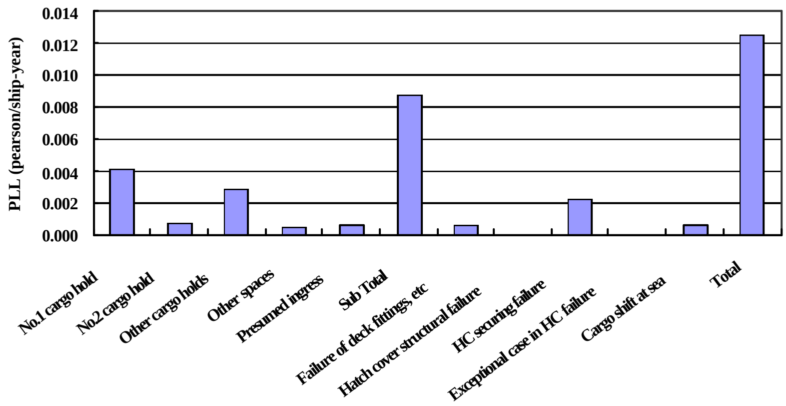


Figure 6.2.8 PLL of total loss case by location of water ingress

6.2.3 Evaluation of risk after the implementation of RCOs

6.2.3.1 RCOs recently implemented

Typical examples of recently introduced RCOs are ESP (Enhanced Survey Programs), and SOLAS chapter XII. In addition to the above, there are some RCOs such as the enforcement of the ISM Code, the application of PSC, etc.

Following its advanced introductions by several classification societies, ESP came into effect by IACS/UR at July 1st 1993; therefore, the comparatively long period of time, after these introductions, is expected to indicate the effect of ESP in the historical casualty data. On the other hand, as SOLAS chapter XII came into effect quite recently at July 1st 1999, it is not considered that the effect of SOLAS chapter XII could be seen in statistical data.

6.2.3.2 Effectiveness of the application of the ESP

Although ESP has been intended to apply to not only cargo hold structures but also ballast tanks, hatch covers, etc, it is considered that the effect of ESP could typically influence the frequency of side shell structure failure of cargo holds. Then, considering ESP as a risk control option against side shell structure failure, it was assumed that the effect of ESP would be reflected in the risk reduction rate in terms of number of casualties. The effectiveness of ISM Code and/or PSC, which are potentially appeared in the historical casualty data, was considered in the block with the effect of ESP application because of difficulty to quantify these risk reduction separating from those of the ESP application. The results are shown in Figures 6.2.9 as the PLL graphs and 6.2.10 as the F-N curve respectively. Except right end data indicated as 'All BC & All Casualties', casualty data related to water ingress was taken into account in Figure 6.2.9.

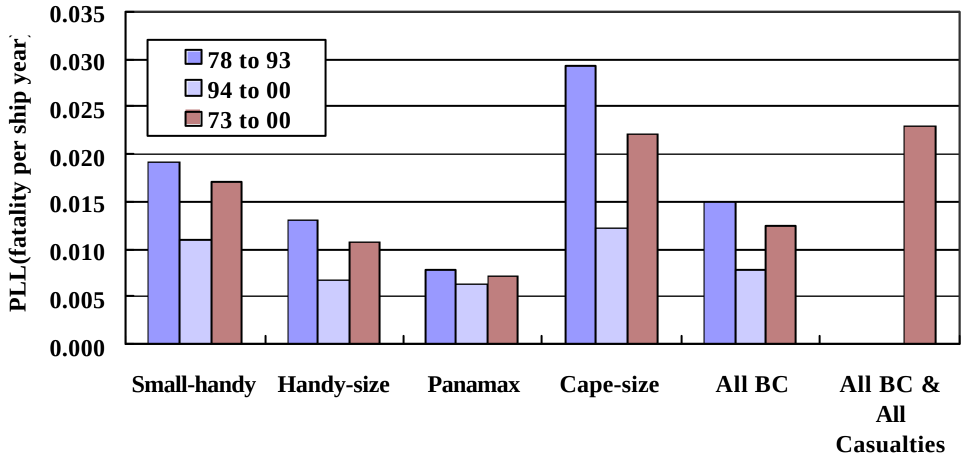


Figure 6.2.9 Effect of ESP in PLL of Bulk Carrier

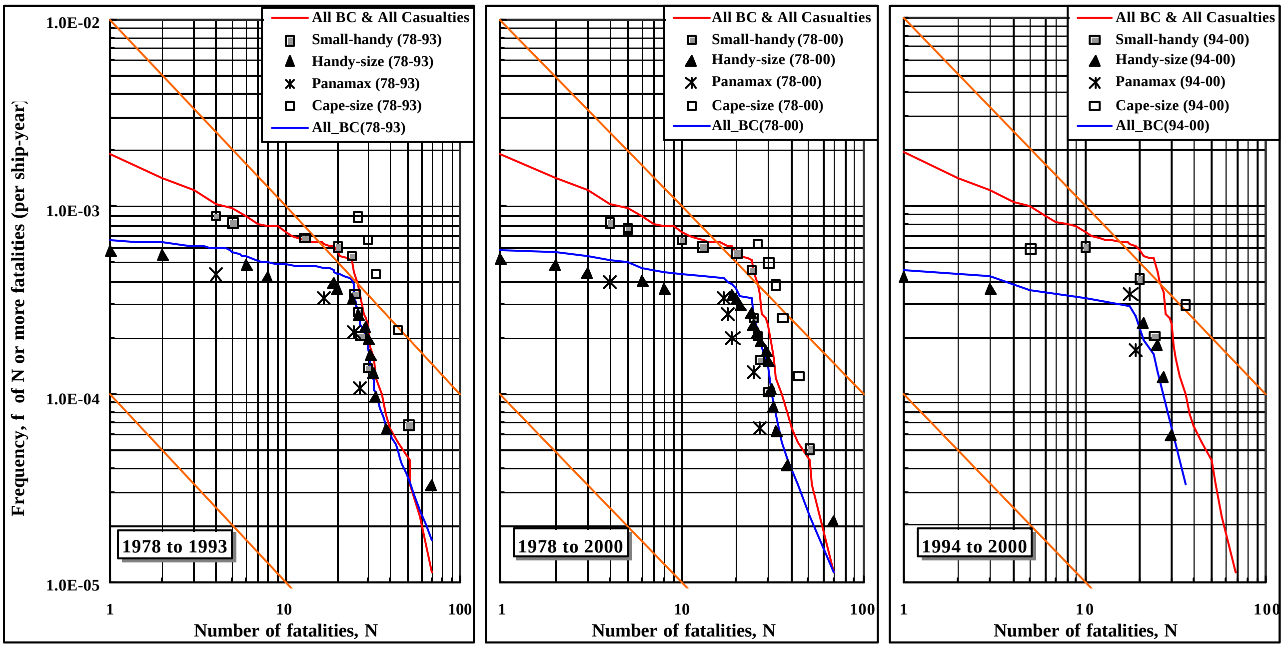


Figure 6.2.10 Effect of ESP in F-N curves of bulk carrier

6.2.3.3 Effectiveness of the application of ESP and SOLAS chapter XII

The effect of the application of the SOLAS chapter XII is conceivable not to appear in the historical casualty data because the years after implementation are short. Thereupon, the possibility of prevention or mitigation of casualty in the historical data was estimated one by one by experts' judgement, according to the criteria shown in Table 6.2.2. According to the assumed casualty data of 20 years passed after the implementation of the SOLAS chapter XII, prepared as the results of above estimation, PLL and F-N curve based on the assumed casualty data were simulated. The simulation of F-N curve was carried out in 2 cases of being effective as a maximum and being not effective as a minimum, because effectiveness of the SOLAS chapter XII on some historical data was hard to be judged due to insufficient information.

Table 6.2.2 Summary of criteria of estimation of risk reduction of the application of the SOLAS chapter XII and UR S21

		Cape-size		Panamax		Handy-size		Small-handy	
		New	Ex.	New	Ex.	New	Ex.	New	Ex.
No.1 C/H Flooding		Y	Y	Y	Y	Y	Y	Y	P
Flooding of C/H other No.1		Y	P	Y	P	Y	P	Y	N*
Flooding of unknown C/H		Y	P	Y	P	Y	P	P	N
Flooding of unknown compartment		P	P	P	P	P	P	P	N
Detail unknown		P	P	P	P	P	P	P	N
Hatch cover structural failure	No.1 C/H	Y	N	Y	N	Y	N	Y	N
	No.2 C/H	P	N	P	N	P	N	P	N
	Other C/H	N	N	N	N	N	N	N	N
Loss of hatch cover, incl. securing failure		N	N	N	N	N	N	N	N
Broken hull girder		P	N	P	N	P	N	P	N

Abbreviations:
New: New buildings
Ex.: Existing ships
Y: Probably effective
P: Sometimes effective
N: Not effective
*: In case of light cargo, evaluated as "P"

The current risk level of bulk carriers has fallen off with the multiplicand effect of the implementation of the SOLAS chapter XII and the ESP. Because the ESP can be effective for prevention of casualty and the SOLAS chapter XII can be effective for mitigation of casualty, the multiplicative effectiveness of the ESP and the SOLAS chapter XII was estimated in the following manner based on simple assumption.

$$PLL_{current} = PLL_{Historical\_data} \times (1 - r_{ESP}) \times (1 - r_{SOLAS\_XII})$$

where $PLL_{current}$: Current potential loss of life (PLL),

$PLL_{Historical\_data}$: PLL obtained from historical data

r_{ESP} : risk reduction rate of the application of ESP

r_{SOLAS_XII} : risk reduction rate of the application of the SOLAS chapter XII

Being premised on these methodology, assumptions, conditions, etc, the imaginary F-N curves and PLL, in which the effect of SOLAS chapter XII are incorporated together with the effect of ESP, are developed as shown in Figure 6.2.11 and Figure 6.2.12 respectively.

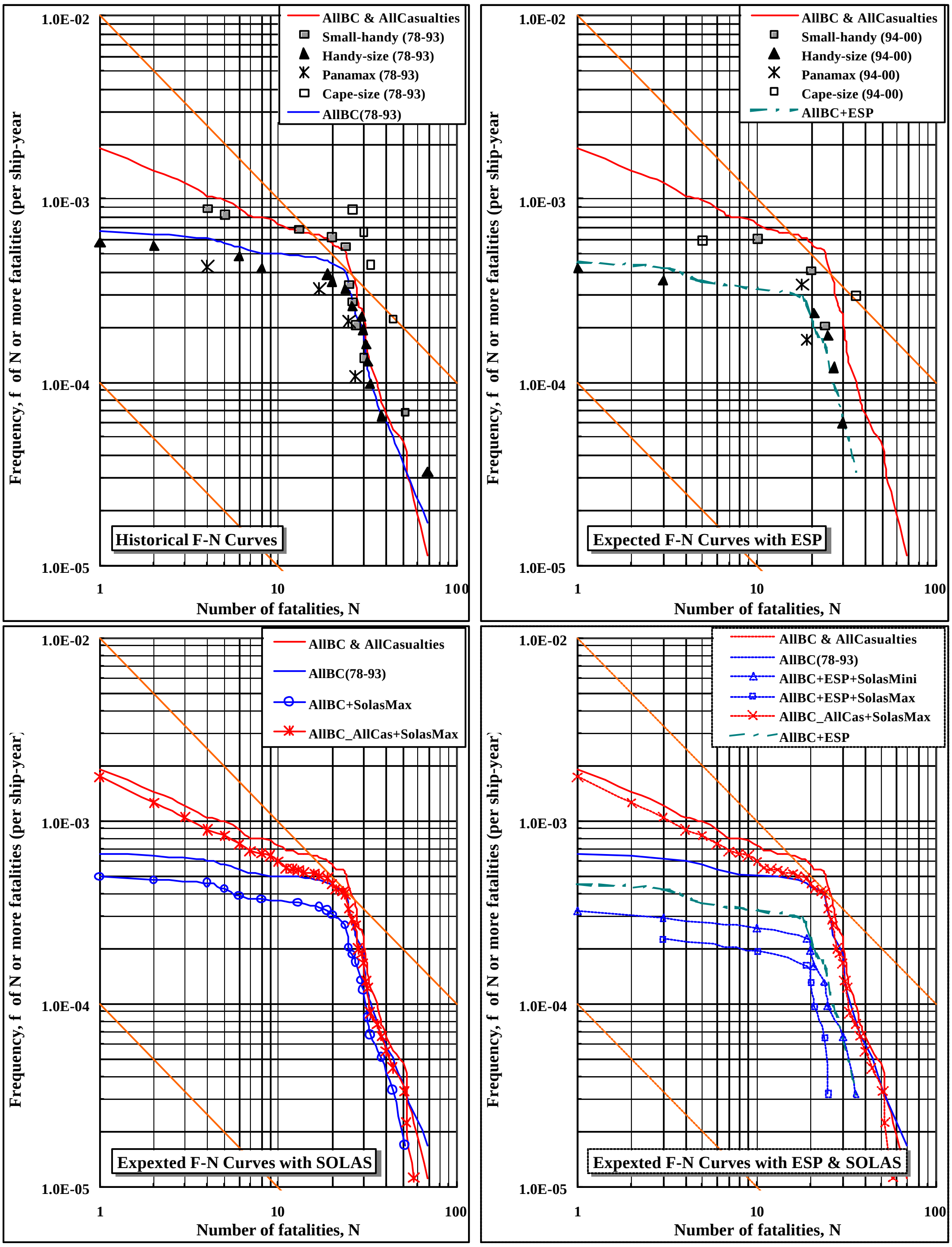


Figure 6.2.11 Effect of SOLAS XII in F-N curve of bulk carrier

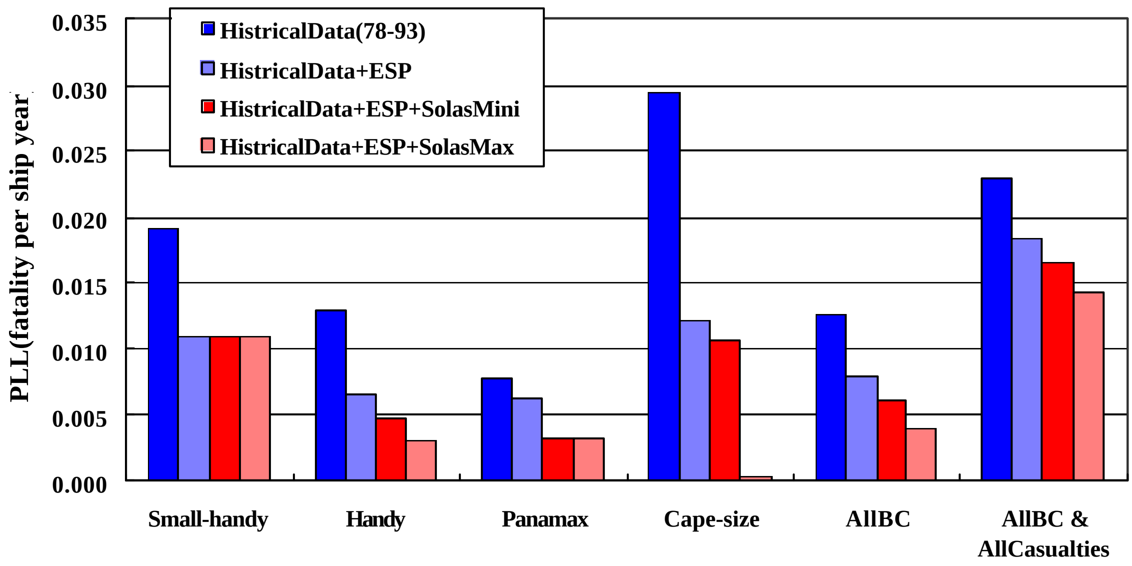


Figure 6.2.12 Effect of SOLAS XII in PLL of bulk carrier

6.2.3.3 Assessment of current risk level

In order to assess the current risk of bulk carriers taking into account recently introduced RCOs such as ESP and SOLAS chapter XII including UR S21, PLL of bulk carriers is compared with those of other type of ships, such as tankers, passengers and general cargoes. For this purpose, all casualties including not only water ingress related casualties but also casualties related to collision, fire, etc. are taken into account. Figure 6.2.13 and 6.2.14 show the results of the comparison of PLL and F-N Curves respectively. It should be noted that the result is based on the simulation of effectiveness of SOLAS chapter XII for 20 years passed after the implementation of the SOLAS chapter XII. The predicted result of F-N Curve for 20 years since the SOLAS chapter XII implementation, F-N Curve of 25 years until the implementation of the SOLAS chapter XII and F-N Curves of other kind of ships are shown in Figure 6.2.14.

Although PLL of bulk carriers would drop considerably by the RCOs already implemented, it would be in relatively higher level in comparison with those of tankers and general cargo carriers. In F-N Diagram, a part of the curve around 20 fatalities with high frequency shows that the risk level would be still in ALARP range close to the Intolerable range, although it would drop considerably by the RCOs already implemented. And also it is conceivable to be in relatively higher level in comparison with other kind of ships. Accordingly, it could be said that RCOs where deemed as possible and reasonable should be examined for the implementation.

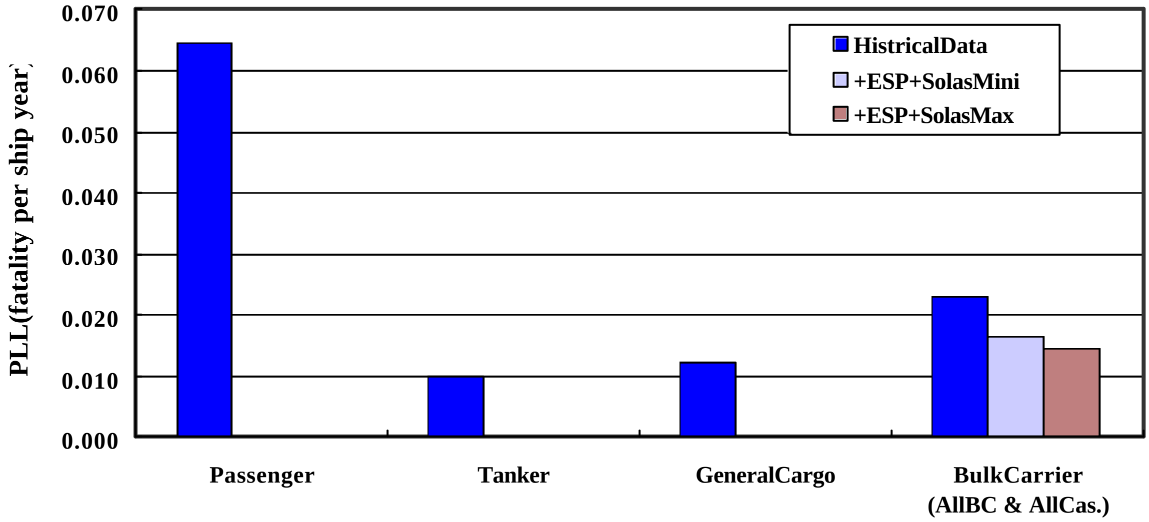


Figure 6.2.13 Comparison of PLL of bulk carrier with other type of ships

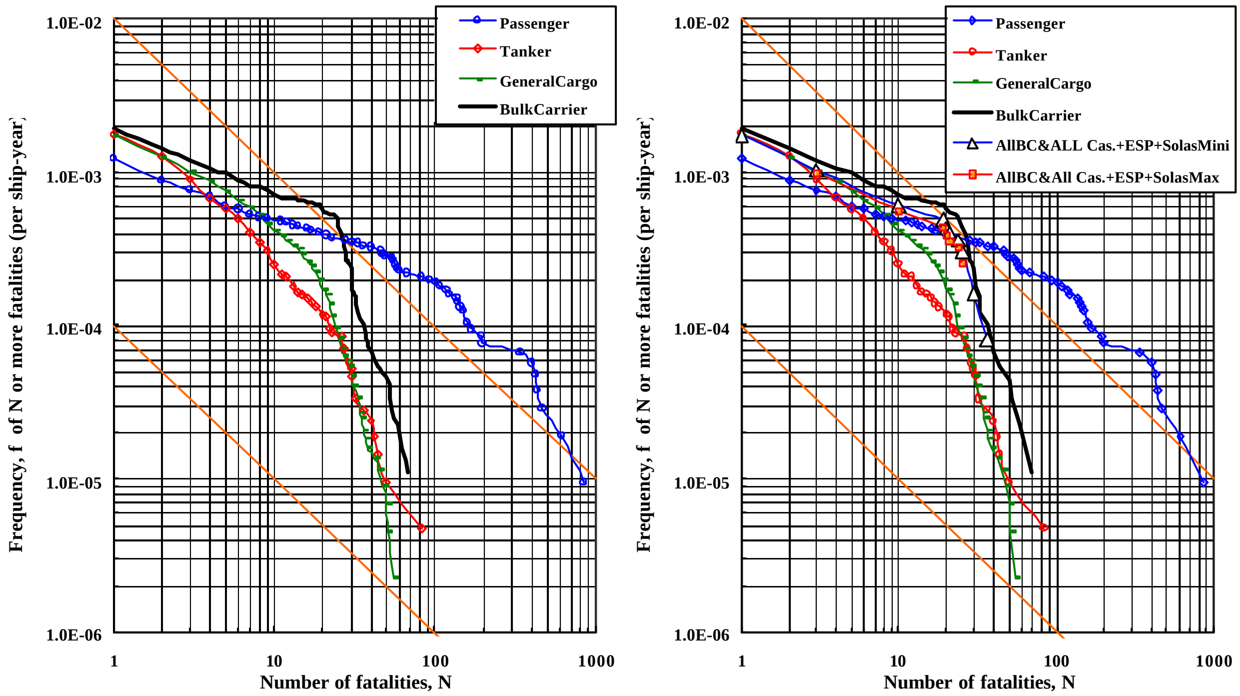


Figure 6.2.14 F-N Curve after the SOLAS chapter XII implementation

6.3 Step 3; Risk Control Options (RCOs)

6.3.1 Method

6.3.1.1 Identification of RCOs

As shown in Table 6.3.1, various Risk Control Measures (RCMs) or Risk Control Options (RCOs) including the SOLAS chapter XII have been implemented to Bulk Carrier so far. However, the various proposals with regard to further RCOs have since been made, because there is the aspect that the effect of RCO is difficult to come into sight immediately.

In these circumstances, the identification of RCOs in this study is carried out with giving priority to the tidying of RCOs already proposed, as shown in the followings:

-1. RCOs that have been already discussed are to be listed by literature survey etc.

-2. Problems and effects etc. on the application of RCOs already proposed, are to be organized in a table.

-3. By a brain storming by the experts and also questionnaire survey, the table listed in above is updated and new RCOs are added as necessity.

Table 6.3.1 List of Risk Control Options Implemented

RCO ID No.	Applied for	Measures	Included RCMs*	Objected hazard ID**	ID in FTA***
ESP	New building	Enhanced Survey Programme (ESP)			
ISM	New building & Existing	ISM Code			
10	New building	SOLAS chapter XII + IACS UR S21	6, 29, 31, 32, 35, 58, 59, 64, 65	1.1.1, 1.1.4.3, 1.1.4.7, 1.1.5.1, 4.2.1	LS120, 220, 320, 322 & 330, BHD000, SSF000 & 200, WIH000, HCF000 & 020
10A		SOLAS chapter XII			
10B		IACS UR S21			
20A 20B	Existing (15years)	SOLAS chapter XII A: BHD replace B: BHD reinforce	32, 35, 58, 59, 64, 65, 70	1.1.1	LS220, 322 & 330, BHD000, SSF000 & 200

* See the Annex 6.
** See the HAZID Worksheet in Annex 4.
*** ID in FTA means ID number of each branch in fault tree shown in Annex 5; Risk Analysis.

6.3.1.2 Estimation of risk reduction of RCOs

The risk reduction by the application of each RCO is estimated by the study of historical data and expert judgment. This is the reason why various damage scenarios are included in the historical data and it is easy to catch the effect of RCOs as probability. Effects of the application of each RCO to the case in the historical data are estimated by the delicate examination of historical data by experts and are, for simplifying, classifying into 3 groups of "effective", "may be effective" and "not effective". The effect of the RCO application is assumed that it is given by the following equation, by setting up each these effects with 100%, 50% and also 0%.

$$r_{Risk\_Reduction} = \frac{N_{probable\_mitigated} + N_{possible\_mitigated} \times 0.5}{N_{total\_loss}}$$

where $r_{Risk\_Reduction}$: Risk reduction rate of RCO
$N_{probably\_mitigated}$: Number of probably mitigated or prevented cases
$N_{posssibley\_mitigated}$: Number of possible mitigated or prevented cases

However, it is difficult to evaluate risk reduction by strengthening structural strength of single side skin construction by this method. Therefore, structural reliability techniques, which could estimate structural failure probability, were used in order to estimate risk reduction when structural strength of side shell is a main parameter. Details are described in annex 7.

By using the aforementioned result, PLL after RCO implemented is given in the following equation assuming that number of fatalities is in proportion to the number of the serious casualties resulting in total loss. This is conceivable that it is adequate assuming that generalize casualty data and obtain the result of the first approximation, although this assumption is not necessarily correct.

$$PLL_{total\_loss}^{RCO} = PLL_{total\_loss} \times (1 - r_{Risk\_Reduction})$$

where $PLL_{total\_loss}^{RCO}$: PLL after RCO implemented, PLL_{total_loss}: PLL before RCO

6.3.2 Literature survey and experts' discussion on RCO

Table 6.3.2 is an example that shows a part of the result of the literature survey and the discussion by the experts regarding RCO screening. As for the whole of the result and details, they are shown in Annex 6.

6.3.3 Results of Step 3

6.3.3.1 Screening and decision of RCO

Among the RCMs collected in 6.3.2, the RCOs, of which the cost benefit assessment of Step 4 should carry out, are nominated by screening in consideration of each features such as expectation of high risk reduction effect, and correspondence to the problem set up in Step 0. The result is shown in Table 6.3.3. Also, regarding a part of the RCOs already implemented (e.g. SOLAS chapter XII etc.), it is included in the objects of the study for the post-evaluation after implementation and also for the comparison with new RCOs. The RCOs regarded as the object of the study are put into simple risk contribution tree as shown in Figure 6.3.1. With regard to the RCOs already implemented, they are distinguished by being underlined.

6.3.3.2 Risk Reduction by RCO

RCOs, which should be examined in Step 4, are decided by the estimation of risk reduction rate and also risk reduction of RCOs listed in Tables 6.3.1 and 6.3.3. They are also shown in Figures 6.3.2 and 6.3.3 showing the estimation result of the risk reduction. The aforesaid method of the estimation of the risk reduction rate from the Historical Data requests the expert's judgement, the premise of which is explained in Annex 7. Although the estimated risk reductions by RCOs shown in these Figures are based on the risk level after the ESP implementation, risk reduction should be estimated based on the risk level after the SOLAS chapter XII application, in case of considering further RCOs after the SOLAS chapter XII application. The supposed risk reduction by major RCOs after the SOLAS chapter XII application which estimated in similar way as above are summarized in comparison with that of after the ESP implementation in Table 6.3.4.

Table 6.3.2 Example of List of RCMs and Discussion

	No.	**RCM**	**Convention/ Standard**	**Discussions** **(A) Current Situation** **(B) Concrete measures or example** **(C) Cost and effectiveness** **(D) Problem in implementation**	**Notes**
Bow height	1	Review of ILLC	ILLC1966	(B) It might be considered with RCM No.2.)	- Under consideration in SLF. - Amendments to rational standards based on ship's motion will be appreciated.
	2	Setting up or enhance- of forecastle	ILLC1966	(B) Newly setting up forecastle of standard superstructure height or enhancement of height of forecastle with another tier of standard superstructure height (C) Design trial is needed. Effectiveness may be evaluated in results of tank tests or numerical simulation. (D) To worsen the navigation bridge visibility. Increase of hull weight in fore part	- ---

Table 6.3.3 List of risk control options used in this analysis

RCO No.	Applied for	Measures	Included RCMs*	Objected hazard ID**	ID in FTA***
11 11A 11B	New building	Application of RCO10 (SOLAS chapter XII for new building ships) to bulk carriers of less than 150 m in length	Same as RCO10	Same as RCO10	Same as RCO10
21A 21B	Existing (15years)	Application of RCO20 (SOLAS chapter XII for existing ships) to bulk carriers of less than 150 m in length	Same as RCO20	Same as RCO20	Same as RCO20
12	New building	Application of RCO10 to bulk carriers carrying cargoes of less than 1.00 t/m^3 in S.G.	Same as RCO10	Same as RCO10	Same as RCO10
22A 22B	Existing (15years)	Application of RCO20 to bulk carriers carrying cargoes of less than 1.78 t/m^3 in S.G.	Same as RCO20	Same as RCO20	Same as RCO20
23 23A	Existing (15years)	Application of UR S21 to existing bulk carriers (A: + RCO20)	6	1.1.4.7, 4.2.1	WIH000, HCF000 & 020
14 14A	New building	Up-grading of securing devices for hatch covers (A: + RCO10)	7, 39	4.2.1	WIH000 & HCF000
24 24A	Existing	Up-grading of securing devices for hatch covers (A: + RCO20)	7, 39	4.2.1	WIH000 & HCF000
15	New building	Application of double side skin construction (All cargo holds)	10, 42	1.1.1.1	COR000, CRK000 & DEF000
25A 25B	Existing (15years)	Application of double side skin construction A: All cargo holds B: Nos. 1&2 cargo holds	10, 42	1.1.1.1	COR000, CRK000 & DEF000
16 ****	New building	Corrosion control of hold frames (Increase of corrosion margin)	9, 41	1.1.1.1, 1.1.4.1	SSF200
51 ****	New building & Existing	Corrosion control of hold frames (Severely control of paint condition)	11, 43	1.1.1.1, 1.1.4.1	COR000
52 ****	New building & Existing	Corrosion control of hold frames (Application of enhanced corrosion allowance)	11, 43	1.1.1.1, 1.1.4.1	COR000

* See Annex 6; risk control options.

** See the HAZID Worksheet in Annex 3.

*** ID in FTA means ID number of each branch in fault tree shown in Annex 5; Risk Analysis.

**** It is needed to examine even the increase of the welding strength in lower end of hold frames concerning an actual application, although it made that corrosion margin is increased for the measure at the time of new building.
Regarding a measure of corrosion progress control of hold frames after delivery, it is conceivable that only daily maintenance/upgrading is able to become the effective measure. It is difficult to be achieved only by the inspection that may be required by rules or regulations etc., considering the paint damage by cargo or cargo handling etc. Here daily maintenance shall be modelled and think periodic repainting. Also, it made, as an alternative means, that hold frames should be replaced in a corrosion early stage (by making the corrosion allowance of small), which is modelled and think a simultaneous replacement when proper time came.

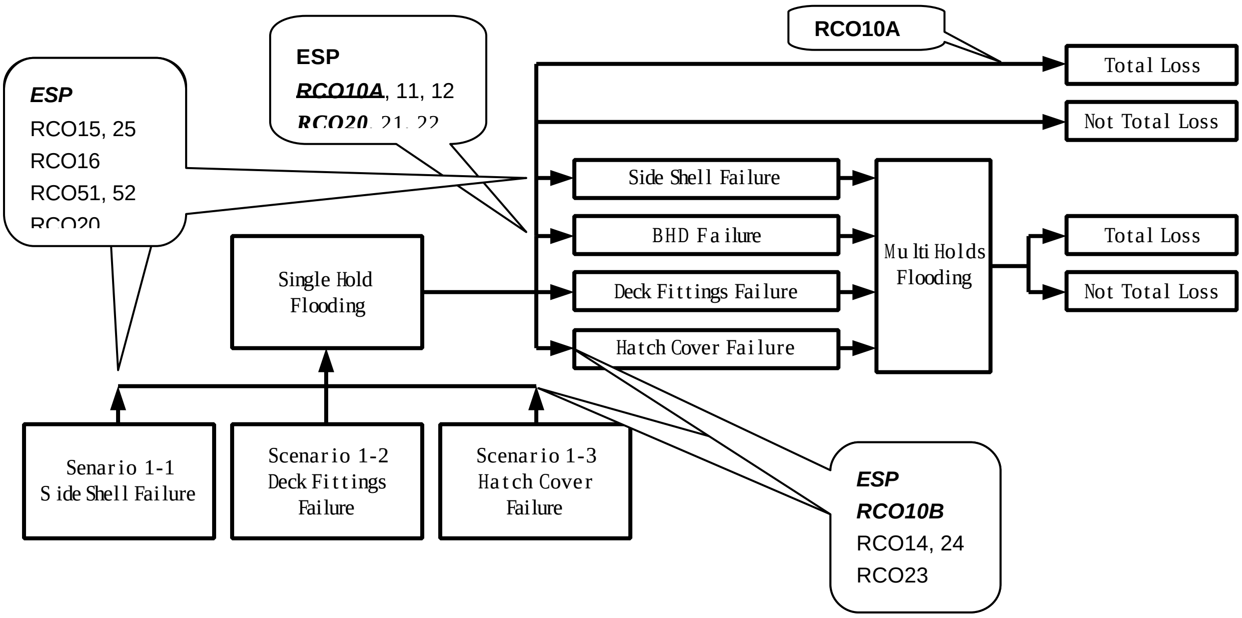


Figure 6.3.1 casual chain and effect of RCOs
(An underline shows RCO already implemented)

Table 6.3.4 Summary of Risk Reduction

RCO ID	After implementation of ESP	After application of SOLAS chapter XII
RCO10: SOLAS chapter XII + UR S 21	1.40×10^{-1}	---
RCO11: RCO10 for small bulk carriers	1.46×10^{-1}	---
RCO15: Double side skin (all C/Hs)	1.47×10^{-1} (2.27×10^{-1})	5.03×10^{-2}
RCO16: Corrosion control of hold frames (Increase of corrosion margin)	8.62×10^{-2} (1.14×10^{-1})	3.07×10^{-2}
RCO51: Corrosion control of hold frames (Severely control of paint condition)	7.46×10^{-2} (9.84×10^{-2})	2.65×10^{-2} / 5.98×10^{-2}
RCO52: Corrosion control of hold frames (Application of enhanced corrosion allowance)	8.31×10^{-2} (1.10×10^{-1})	2.95×10^{-2} / 6.66×10^{-2}
RCO20: SOLAS chapter XII for existing ships	4.70×10^{-2}	---
RCO21: RCO20 for small bulk carriers	8.43×10^{-2}	---
RCO23: Application of UR S21 to existing ships	(5.92×10^{-3})	(4.44×10^{-3})
RCO25A: Application of double side skin construction for existing ships (all C/Hs)	1.08×10^{-1} (1.81×10^{-1})	3.77×10^{-2} / 8.69×10^{-2}
RCO25B: Application of double side skin construction for existing ships (Nos. 1&2 C/Hs)	6.00×10^{-2} (9.69×10^{-2})	2.09×10^{-2} / 4.81×10^{-2}

6.3.3.3 Results of estimation of risk reduction of RCO

Considering the result in Step 2, the RCOs to estimate the cost effectiveness in Step 4 were finally settled not only to the already implemented RCOs with regard to SOLAS chapter XII but also to the following RCOs.

1) Expanded application of the SOLAS chapter XII to the bulk carriers of less than 150 m in length (for new building ships and also existing ships)

2) Compulsory application of double side skin construction (for new building ships and also existing ships)

3) Prevention measure of collapse of single side skin structure (for new building ships and also existing ships)

4) Strengthening of hatch cover design (for existing ships)

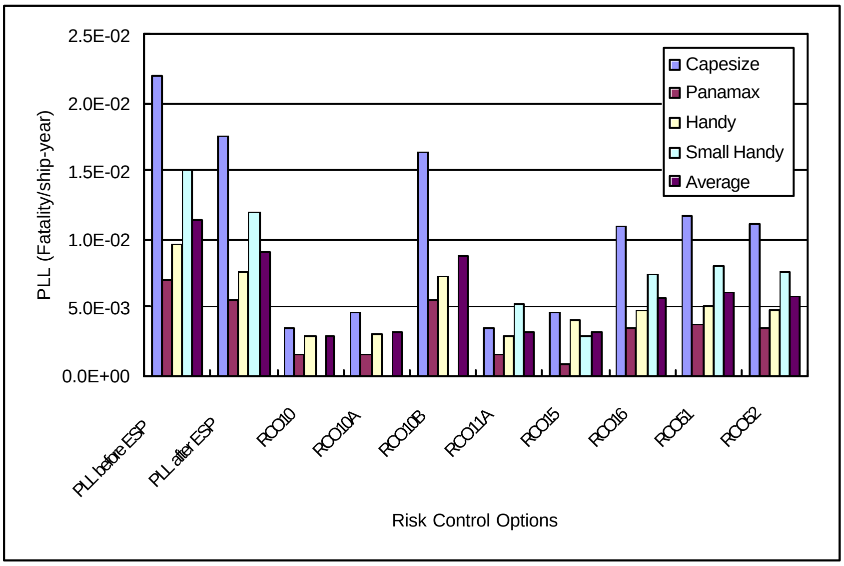


Figure 6.3.2 Summary of risk reduction for new building bulk carriers

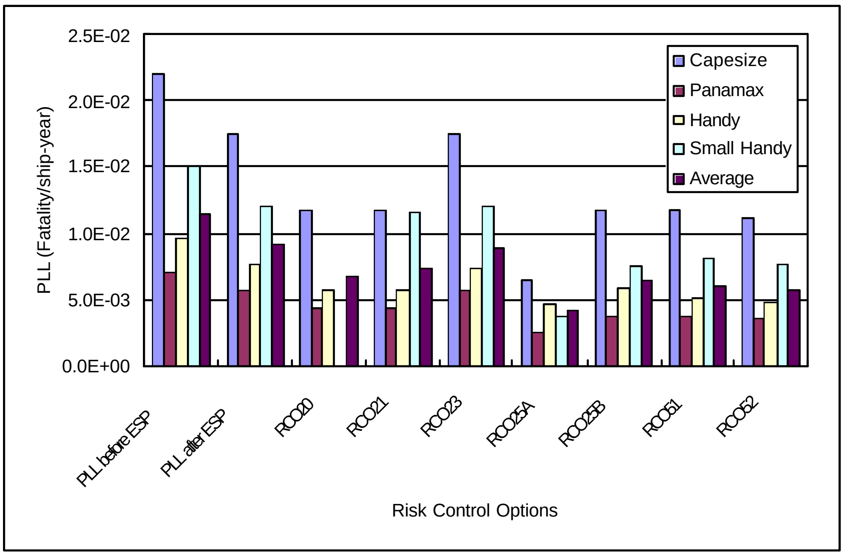


Figure 6.3.3 Summary of risk reduction for existing bulk carriers

6.4 Step 4: Cost benefit assessment

6.4.1 Method

According to the FSA guideline the purpose of Step 4 is made to evaluate the cost effectiveness with regard to the application of each RCO that was selected in Step 3 by cost benefit assessment (CBA) or cost effectiveness analysis (CEA), and compare. Also, "cost per unit risk reduction" (CURR) and "implied cost of averting a fatality" (ICAF) are given in the guidelines as a index showing cost effectiveness.

In this study, the cost effectiveness analysis (CEA) has been tried by referring the index called gross cost of averting a fatality (GrossCAF or GCAF) and net cost of averting a fatality (NetCAF or NCAF). Definitions of these indexes are as given:

$$GrossCAF = \frac{\Delta C}{\Delta R}$$

$$NetCAF = \frac{\Delta C - \Delta B}{\Delta R}$$

where ΔC is the cost of the risk control option

ΔB is the economic benefit resulting from the implementation of the risk control option

ΔR is the risk reduction implied by the risk control option

6.4.2 Cost effectiveness analysis of RCOs already implemented

6.4.2.1 Introduction

In this paragraph, the appropriateness of the application of RCOs already implemented was evaluated by carrying out CBA of the RCOs. The risk level where becomes a premise of CBA is assuming the condition after the ESP implementation as mentioned above.

6.4.2.2 Summary of cost evaluation of RCOs already implemented

Results of cost evaluation of each RCO are shown in annex 7. Tables 6.4.1 and 6.4.2 show the evaluated cost for application of the SOLAS chapter XII to new building ships and existing ships respectively as examples.

Table 6.4.1 Increase of steel weight in new bulk carriers (chapter XII application)

	Cape		Panamax		Handy		Small-Handy	
UR S21	Applied	N.A.	Applied	N.A.	Applied	N.A.	Applied	N.A.
Increased steel weight [ton]	374	340	137	120	53	34	24	14
Material [US$]	224,400	204,000	82,200	72,000	31,800	20,400	14,400	8,400
Work [US$]	112,200	102,000	41,100	36,000	15,900	10,200	7,200	4,200
Facilities [US$]	0	0	0	0	0	0	0	0
Total	336,600	306,000	123,300	108,000	47,700	30,600	21,600	12,600

Table 6.4.2 Cost estimation of the application of SOLAS chapter XII (BHD replacement)

	Cape	Panamax	Handy	Small-Handy
Steel weight [ton] (Increased weight)	111 (22)	56 (11)	31 (6)	11 (2)
Material [US$]	88,800	44,480	24,936	8,840
Work [US$]	205,350	102,860	57,665	20,433
Facilities [US$]	70,072	21,375	15,276	6,384
Total	364,222	168,715	97,877	35,667

6.4.2.3 Economic benefits from the implementation of RCOs

Although it is a moot point what is deemed as economic benefits for the estimation of NetCAF, in this study, the implementation benefits were evaluated by results such that RCO could suppress casualty of total loss as shown in detail:

Economic benefits from the implementation of RCOs: $\Delta B = \int_{y_a}^{25} (R_f - R_a) dy$

Probable loss per ship-year before RCO implemented: $R_f = f_T \times C_T + f_S \times C_S$

Probable loss per ship-year after RCO implemented: $R_a = (1 - r_{RCO}) \times f_T \times C_T + (r_{RCO} \times f_T + f_S) \times C_S$

where

f_T : Rate of incidence of serious casualties from the historical data (1.24×10^{-3})*

f_S : Rate of incidence of total loss casualties from the historical data (7.68×10^{-4})*

C_T : Economical loss by a serious casualty

C_S : Economical loss by a total loss casualty

y_a : Ship age when a RCO is implemented

r_{RCO} : Reduction rate of a RCO

Note: * These values are corrected considering the effect of ESP implementation.

The decrease of serious casualties were not considering it, in consideration of that even RCO includes those different from a preventive measures such like SOLAS chapter XII, although it is considered to be able to reduce occurrence itself of an serious casualty to some degree by introducing RCO in fact. Also, considering the difference by the size of a ship by referring to standard ship price (see annex 7), although it shall depend on the report of IACS in MSC 74 fundamentally about the economic loss by a casualty of total loss, it is doing like Table 6.4.3. Also in consideration of the cost depreciation by a passing year, after construction according to the progress a year an economic loss is assuming that it depends in the following equation and also Table 6.4.3.

Economical loss by a serious casualty on a ship of *n* years in age: $C_T = \dfrac{C_{T0}}{\left(1 + \dfrac{a}{100}\right)^n}$

Economical loss by a total loss casualty on a ship of *n* years in age: $C_S = \dfrac{C_{S0}}{\left(1+\dfrac{a}{100}\right)^n}$

where

C_{T0}: Economical loss by a serious casualty on a new building ship (refer to Table 6.4.2.3)

C_{S0}: Economical loss by a total loss casualty on a new building ship (refer to Table 6.4.2.3)

a: Constant (10 applied in this study)

n: Ship's age

Table 6.4.3 Economical cost by serious casualty and total loss

	Average	Cape Size	Panamax	Handy	Small-Handy
Ship price [US$]	22,700,000	40,200,000	26,200,000	22,500,000	13,600,000
Population ratio	---	8.8 %	16.8 %	52.7 %	21.7 %
Monetary loss by serious casualty [US$]	5,608,000	9,930,000	6,470,000	5,560,000	3,360,000
Monetary loss by total loss [US$]	24,808,000	43,900,000	28,600,000	24,600,000	14,900,000

6.4.2.4 Results

On the basis of the risk level after start of the ESP application but before the SOLAS chapter XII application, GrossCAF of fundamental major RCOs are shown as Figures 6.4.1 and 6.4.2. The post-evaluation of the RCOs already implemented is carried out by comparing the results of CEA of the RCOs on the above-mentioned basis.

With regard to new building bulk carriers, RCO10 is an already introduced RCO for new building bulk carriers. RCO10 consists of 'SOLAS chapter XII (the requirements of damage stability (regulation 4) and structural strength (regulation 5) for new building ships)' and 'IACS UR S21 (the requirements of structural strength for forward Hatch Covers)'. Its GCAF is 0.7 Million US$ and is conceivable as cost effective referring to the criteria proposed by Norway (MSC 72/16). On the other hand, it is the result that RCO10 has some inferiority in a cost effectiveness compared with the increase of corrosion margin of hold frames (RCO16) that may be more cost effective.

For existing ships, RCO20 "SOLAS chapter XII (the requirements of damage stability (regulation 4) and structural strength (regulation 6) for existing ships)" that GCAF is 3.0 (Million US $ per averted fatality), could not be asserted as too cost ineffective to apply, in accordance with the criteria proposed in MSC 72/16. However, it is said that this RCO is in the range that involve the divided opinion regarding the advisability of the introduction. On the stance that introduces preventive and mitigative RCOs in proper balance it is conceivable that the application to existing ships of the SOLAS chapter XII be justified. Also, it is said that the corrosion control (severely control of paint (RCO51)) or application of enhanced corrosion allowance (RCO52)) of hold frames should have been recommended from the point of cost effectiveness according to the analysis result in this time.

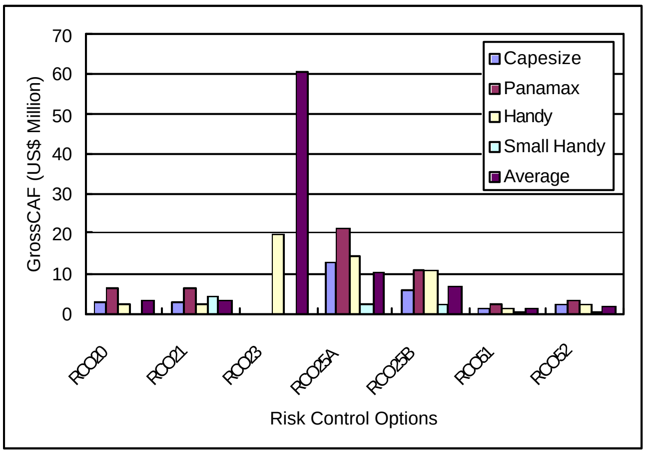


Figure 6.4.1 Gross CAF of RCOs for new building ships

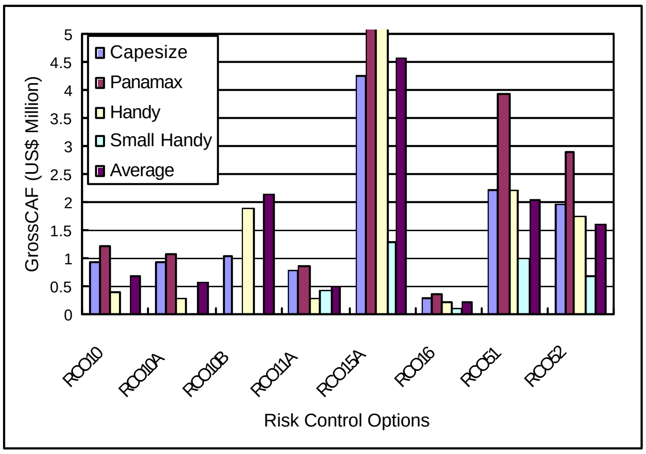


Figure 6.4.2 Gross CAF of RCOs for existing ships

6.4.3 Cost effective analysis of new RCOs

6.4.3.1 Introduction

In this paragraph, the appropriateness of the application of RCOs which may be newly implemented was evaluated by carrying out CBA of the RCOs, on the basis that the risk level where becomes a premise of CBA is assuming the condition after the SOLAS chapter XII application which may drop the risk level to some degree as expressed in 6.2 on the assumption that further implementation of RCOs may be required. Although it is as same method about CEA as those in 6.4.2, examination about NetCAF was not carried out.

6.4.3.2 Summary of cost estimation of new RCOs

The cost estimation of new RCOs are shown in annex 7 for details. For example, rough cost estimation to the application of double side skin construction for new ships (RCO15) and the application of UR S21 (strengthening of hatch covers) to existing ships (RCO23) are shown in Tables 6.4.4 and 6.4.5 respectively.

6.4.3.3 Results

1) For bulk carriers of SOLAS chapter XII applied

For ships complying with the requirements of SOLAS chapter XII, the CEA was carried out assuming that the risk reduction of RCOs is estimated on the basis of the risk level after the SOLAS chapter XII application. For new building ships, it was assumed that the UR S21 also have been already applied. The results of the examination are shown in Table 6.4.6.

2) For bulk carriers of SOLAS chapter XII not applied

.1 For bulk carriers of less than 150 m in length (Lf)

About bulk carriers of less than 150 m in length (It corresponds to “Small Handy” by this study by the classification of the size.), because the application of the

SOLAS chapter XII is excluded, a present risk level can be conceivable to be same as that of before implementation of the SOLAS chapter XII. Therefore, the result of CEA for small handy which shown for the comparison at the post-evaluation of SOLAS chapter XII represents the result of CEA of new RCOs on the basis of present risk level. Table 6.4.7 shows a summary of the results.

.2 For bulk carriers of double side skin construction

With regard to bulk carriers of double side skin construction, the application of the regulation such as structure requirements of the SOLAS chapter XII is exempted (UR S21 is applicable in case of a new ship.). Therefore, on the assumption that the necessity of further safety measure will come out, the evaluation of applicable RCO is carried out in this study. Applying the same method as that in 2.1 above, the result of CEA is obtained as shown in Table 6.4.8. However, it should be considered that the significant GCAF is much greater in actual sense, because the cost for double side skin construction at new building is considerably high in comparison with that of single side skin (for Cape Size, US$ 1.4 million in difference).

Table 6.4.4 Increase of steel weight and cost for double side skin construction (RCO15)

	Capesize	Panamax	Handy	Small-Handy
Steel weight [ton]	805	379	244	109
Paint area [m^2]	15,854	9,093	7,797	4,641
Material [US$]	483,000	227,220	146,160	65,110
Work [US$]	241,500	113,610	73,080	32,550
Paint [US$]	45,707	26,215	22,479	13,380
Paint work [US$]	98,818	56,677	48,599	28,927
Facilities [US$]	0	0	0	0
Sub-total [US$]	869,025	423,722	290,317	139,957
Hold volume loss [m^3]	1,806	972	833	458*
Monetary loss by hold volume loss [US$]	496,500	542,200	251,542	157,032*
Total [US$]	1,365,525	965,922	541,859	296,989

* Where the hold volume loss is considered 3/4 of that for existing vessels instead of 1/3 used in this examination, the following values will be estimated.
Monetary loss: 353,323 $ for hold volume loss of 1,031 m^3

Table 6.4.5 Steel weight and cost for reinforcement of hatch cover

	Capesize (0.087Lf)		Panamax (0.101Lf)		Handy (0.139Lf)		Small-Handy (0.164Lf)	
	59.9 kN/m^2		52.8 kN/m^2		46.1 kN/m^2		44.5 kN/m^2	
	Replace	Reinforce	Replace	Reinforce	Replace	Reinforce	Replace	Reinforce
Steel weight [ton] (Increased weight)	102 (34)	48	66 (17)	24	67 (19)	27	38 (10)	14
Material [US$]	81,600	56,160	52,800	28,080	53,600	31,590	30,400	16,380
Work [US$]	94,350	177,120	61,050	88,560	61,975	99,630	35,150	51,660
Facilities [US$]	5,255	8,759	2,138	3,563	1,528	2,546	638	1,064
Total [US$]	181,205	242,039	115,988	120,203	117,103	133,766	66,188	69,104

Table 6.4.6 Results of CEA of new RCOs for ships of SOLAS chapter XII application

GCAF	RCOs for New building	RCOs for Existing	
(Million US$)		Ships comply with SOALS XII for new ships	Ships comply with SOLAS XII for existing ships
Less than 1	RCO16: Corrosion control of hold frame (increase of corrosion margin) (0.7 M US$)	Nil	Nil
1-3	Nil	Nil	RCO52: Corrosion control of hold frames (application of enhanced corrosion allowance) (2.3 M US$)
	Nil	Nil	RCO51: Corrosion control of hold frames (severely control of paint condition) (2.9 M US$)
3-10	RCO52: Corrosion control of hold frames (application of enhanced corrosion allowance) (5.4 M US$)	RCO52: Corrosion control of hold frames (application of enhanced corrosion allowance) (5.4 M US$)	Nil
	RCO51: Corrosion control of hold frames (severely control of paint condition) (US$ 6.8 million per averted fatality)	RCO51: Corrosion control of hold frames (severely control of paint condition) (US$ 6.8 million per averted fatality)	Nil
Greater than 10	RCO15: Application of double side skin (US$ 15.9 million per averted fatality)	RCO25: Application of double side skin (US$ 53.1 million per averted fatality)	RCO25: Application of double side skin (US$ 22.8 million per averted fatality)
	Nil	Nil	RCO23: Application of UR S21 (US$ 26.3 million per averted fatality)**

Note: ** Figures of GrossCAF of handy bulk carriers

Table 6.4.7 Results of CEA for bulk carriers of less than 150 m in length

GCAF (Million US$)	New building	Existing
Less than 1	RCO16: Corrosion control of hold frames (increase of corrosion margin) (US$ 0.1 million per averted fatality)	Nil
	RCO11: Application of SOLAS XII (US$ 0.1 million per averted fatality)	Nil
	RCO52: Corrosion control of hold frames (application of enhanced corrosion allowance) (US$ 0.7 million per averted fatality)	RCO52: Corrosion control of hold frames (application of enhanced corrosion allowance) (US$ 0.7 million per averted fatality)
	RCO51: Corrosion control of hold frames (severely control of paint condition) (US$ 1.0 million per averted fatality)	RCO51: Corrosion control of hold frames (severely control of paint condition) (US$ 1.0 million per averted fatality)
1-3	RCO15: Application of double side skin (US$ 1.3 million per averted fatality)	Nil
3-10	Nil	RCO25: Application of double side skin (US$ 3.3 million per averted fatality)
	Nil	RCO21: Application of SOLAS XII (US$ 4.3 million per averted fatality)
Greater than 10	Nil	RCO23: Application of UR S21 (US$ --- million per averted fatality)**

Note: ** Figures of GrossCAF of handy bulk carriers

Table 6.4.8 Results of CEA for bulk carriers of double side skin construction

GCAF (Million US$)	New building	Existing
Less than 1	Nill	Nil
1-3	RCO10: Application of the SOLAS XII (2.2 Million US$)	Nil
3-10	Nil	Nil
Greater than 10	Nil	RCO20: Application of the SOLAS XII (US$ 14.0 million per averted fatality)**
	Nil	RCO23: Application of UR S21 (US$ 36.9 million per averted fatality)**

Note: ** Figures of GrossCAF of handy bulk carriers

6.5 STEP 5; Recommendations for decision-making

According to the results of the study obtained so far, following findings and recommendation could be derived.

6.5.1 Risk level of the bulk carrier

With regard to all sizes of bulk carriers and all kinds of casualties, the predicted result of F-N curve for 20 years since the SOLAS chapter XII implementation, which shows that a part of the curve around 20 fatalities is still in 'ALARP region' close to 'Intolerable region'. Of course, it has dropped considerably by the already implemented RCOs. And also it is conceivable to be in relatively higher level in comparison with other kind of ships such as tankers, general cargo carriers, etc. Accordingly, it could be said that RCOs where deemed as possible as reasonably practicable should be examined for the implementation.

Looking into risk level of each size of bulk carriers, current risk level of bulk carriers of less than 150 m in length is judged to be higher than that of other size of bulk carrier. It is for the sake of risk reduction by recently implemented RCOs such as ESP and SOLAS chapter XII. Therefore, bulk carrier of less than 150m in length should be given with high priority.

Although the risk level of bulk carriers of double side skin could not estimated only by historical data analysis directly, it could be considered to be equivalent as the risk level of new building bulk carriers applied to SOLAS chapter XII. Therefore, it is justified that SOLAS chapter XII need not apply to double side skin bulk carriers.

6.5.2 Already implemented RCOs

6.5.2.1 ESP, etc.

The effectiveness of Enhanced Survey Programme (ESP) including ISM-Code etc. is confirmed based on the historical data analysis. More precise quantitative estimation of its effect might be needed not only for bulk carrier FSA study but also for improving ESP etc.

6.5.2.2 RCOs for new building

It is considered that the application of SOLAS chapter XII is a cost effective risk control option (RCO) in general and a combination with SOLAS chapter XII and IACS UR S21 is also a cost effective RCO based on the post estimation of their cost effectiveness.

6.5.2.3 Retrospective RCOs

With regard to retrospective regulations in SOLAS chapter XII for existing bulk carriers, the magnitude of GrossCAF is close to its criterion proposed by Norway (MSC 72/16). Bearing in mind that the requirements largely depend on the location of initial water ingress, parametric study on RCOs similar to SOLAS chapter XII would be beneficial. However preventive RCOs mentioned in 6.5.3.1 and 6.5.3.2 should be focused at this moment.

With regard to retrospection application of the recently introduced hatch cover unified requirement (IACS UR S21) for the bulk carrier of equal and over 15 years old, it is not cost effective and not recommended. (Further discussion on hatch covers is described in 6.5.4.4.)

6.5.3 New RCOs after the implementation of SOLAS chapter XII

6.5.3.1 Single side skin bulk carrier less than 150m in length

With regard to single side skin bulk carriers of less than 150m in length, they have been exempted from SOLAS chapter XII. The necessity of the countermeasure is higher than other sizes of bulk carriers because the magnitude of their risk is relatively higher than other sizes of bulk carrier. And RCOs mitigating consequences after hold flooding as required in SOLAS chapter XII are not considered to be appropriate because one hold flooding itself is fatal if the number of cargo holds is not changed based on the current design practice.

In short, further investigation on following RCOs is recommended:

- Increased corrosion margin (design stage)
- Corrosion control of single side skin (in-service)

6.5.3.2 Single side skin bulk carriers of equal and larger than 150m in length

With regard to single side skin bulk carrier equal and over 150m in length, mitigating safety countermeasure as a secondary barrier after hold flooding has already been implemented in SOLAS chapter XII. Nevertheless preventive measures against water ingress from a breach of side shell structure would be cost effective as further safety countermeasure. According to the cost effectiveness assessment, it is recommended corrosion control requirements such as increase of corrosion margin and preventive coating rather than mandatory requirements of double side skin considering comparison between their cost-effectiveness, i.e., figures of GCAF. In short, further investigation on following RCOs is recommended:

- Increased corrosion margin (design stage)
- Corrosion control of single side skin (in-service)

6.5.3.3 Mandatory requirements of double side skin

Cost effectiveness of double side skin requirements as alternatives to requirements of SOLAS chapter XII is not so different from that of SOLAS chapter XII when ignoring monetary loss due to cargo volume loss. Although there should be so many controversial discussions on pros and cons of double side skin vs. single side skin, it was decided that monetary loss due to cargo volume loss should be taken into account after long discussion among Japanese BC FSA team. As a result, it was found that requirements of SOLAS chapter XII are much more cost effective than double side skin requirements. Therefore double side skin requirements are not recommended as alternatives to SOLAS chapter XII.

6.5.3.4 Additional requirements to double side skin bulk carriers

Ignoring initial cost difference between single side skin and double side skin, extended application of SOLAS chapter XII to double side skin bulk carriers is not so bad in terms of cost-effectiveness. However, Japan believes that such cost difference should not be ignored in the cost effectiveness analysis. Therefore it is not recommended at this moment.

6.5.4 RCOs not covered by cost effectiveness analysis

6.5.4.1 Extended application of SOLAS chapter XII to bulk carriers not carrying heavy cargo

Risk level of bulk carriers carrying heavy bulk cargoes of 1,780 kg/m^3 or more is quite high based on the historical data analysis that shows 70% of serious casualties occurred at the time of carrying heavy cargoes. Hence, it could be said that exemption by low cargo density from application of SOLAS chapter XII was appropriate under the circumstances when Chapter XII was discussed.

6.5.4.2 Mitigating RCOs for bulk carrier with insufficient watertight subdivision

Mitigating RCO for the bulk carriers with insufficient watertight subdivisions is not considered to be a substantial measure and was not given a priority. Preventive RCOs should be examined in line with other type of bulk carriers.

6.5.4.3 Fore end access

Regarding a facility for fore end space access, it seemed not to be useful as RCO because any effective operation may not be done in the space in heavy weather taking into account of the danger to the personnel. So it is not recommended.

6.5.4.4 Hatch cover

Judging from historical data analysis, as the first barrier against hold flooding, the soundness (including both mechanical and human elements) of securing device for hatch cover including hatch coaming seems to be closely related to fatal casualty rather than strength of hatch cover panels. Although it could be said that fatal casualties of detail unknown was caused by hatch cover failures, Japan does not believe so because there are a little number of casualties with clear evidences showing hatch cover failures among casualties those consequences were not so relatively serious. It is recommended that not only hatch cover strength including its design load but also securing system should be considered when hatch cover related casualties are examined.

6.5.4.5 Fore deck fittings

Considering a relatively low risk level of flooding casualties from deck fittings, RCOs for this scenario should be given low priority.

6.5.4.6 Life-saving appliances

Life-saving appliances should be discussed together with recommended RCOs which are described in chapter 7 of this study.

7 FINAL RECOMMENDATIONS FOR DECISION-MAKING

Japan has carried out all five steps of FSA on typical bulk carriers with single deck, topside tank and bilge hopper tank, separated into 4 types, cape size, panamax size, handy size and small handy size. The final recommendations for decision-making from the study are as follows:

7.1 It was judged that the risk level of whole bulk carriers in future would stay at a relatively upper part of the ALARP region even after recently adopted RCOs are implemented and become perfectly effective. Moreover it is higher than other types of ships such as tankers and container carriers. Therefore, IMO should pursue further safety measures that could reduce the risk of bulk carriers, in cost-effective way, as low as reasonably practicable (ALARP) with high priority. The risk level of the bulk carriers under 150m in length is higher than that of the other size of bulk carriers, based on the estimation of the risk of each size of bulk carriers. This means that IMO should give priority to such smaller bulk carriers at first.

7.2 With regard to post-estimation of validity of SOLAS chapter XII, SOLAS chapter XII can be justified based on the comparison of the cost effectiveness of SOLAS chapter XII and that of the other relevant RCOs such as a mandatory requirement of double side skin referring criterion proposed by Norway in MSC 72/16. At the same time, exemption of double side skin bulk carriers from SOLAS chapter XII can be justified based on the same comparison and consideration on the magnitude of risk of double side skin bulk carriers.

7.3 With regard to single side skin bulk carriers of less than 150 m in length, they have been exempted from SOLAS chapter XII. The necessity of the countermeasures for safety of such ships is higher than that of the other sizes of bulk carriers, because the magnitude of the risk of single side skin bulk carriers of less than 150 m is relatively higher than that of the other sizes of bulk carrier. On the other hand, RCOs for mitigating consequences after hold flooding as required in SOLAS chapter XII are not considered to be appropriate, because only one hold flooding is fatal for bulk carriers of less than 150 m in length, if the number of cargo holds of current design practice for such smaller ships can not be changed. Therefore, measures to prevent flooding are much important for such smaller bulk carriers. Then, in short, further investigation on following preventive measures of RCO is recommended:

- Increased corrosion margin (design stage)
- Corrosion control of single side skin (in-service)

7.4 With regard to single side skin bulk carrier of 150m and over in length, the mitigating safety countermeasures as a secondary barrier after hold flooding have already been implemented in SOLAS chapter XII. Nevertheless, preventive measures against water ingress from a breach of side shell structure would be cost effective as a further safety countermeasure. According to the cost effectiveness assessment, it is recommended that corrosion control requirements such as an increase of corrosion margin and preventive coating should be considered, because such measures is much cost-effective than double side skin (see figures of GCAF). In short, further investigation on following RCOs is recommended:

- Increased corrosion margin (design stage)
- Corrosion control of single side skin (in-service)

8. REFERENCES

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