International Association of Classification Societies
(IACS)

FSA of Bulk Carriers
Fore-end Watertight Integrity

Annex 2
Bulk Carrier Risks

Table of Content

1 EXECUTIVE SUMMARY

The present annex is a part of the IACS study *Formal Safety Assessment of Bulk Carriers, Fore end watertight integrity.*

A review of historical casualty data has been conducted for different bulk carriers in order to establish the overall risks, to estimate the contribution from different accident categories, and to compare the results to similar results for other ship types

Standard configuration bulk carriers larger than 20,000 DWT are within the scope of the present study, although a limited number of non-standard configuration bulk carriers may be part of the casualty data, e.g. bulk carriers with double side skin.

The primary data sources used are the LMIS casualty database, April 1999 version, and Lloyd's Statistical Tables.

The average individual risk of fatality to crew, PLL, frequency of serious casualty and total loss on the different bulk carrier categories is shown in the Table 1.

Table 1 Risk measures for bulk carriers larger than 20,000 DWT, period from 1978 to 1998

Bulk carrier category	Average individual risk	PLL	Frequency of serious casualties excluding total losses (per ship year)	Frequency of total losses (per ship year)
Standard bulk carrier larger than 20,000 DWT	3.4E-04	1.7E-02	2.5E-02	3.4E-03

The below figures show the contribution from different accident categories to accident costs and number of fatalities. The accident categories "foundered", "missing", and "machinery" may be attributed to structural failure. The figures show that structural failure contributes with 19% of the economic losses and 74% of the fatalities on bulk carriers larger than 20,000 DWT. The focus given to the structural failure events in the present study hence seems justified.

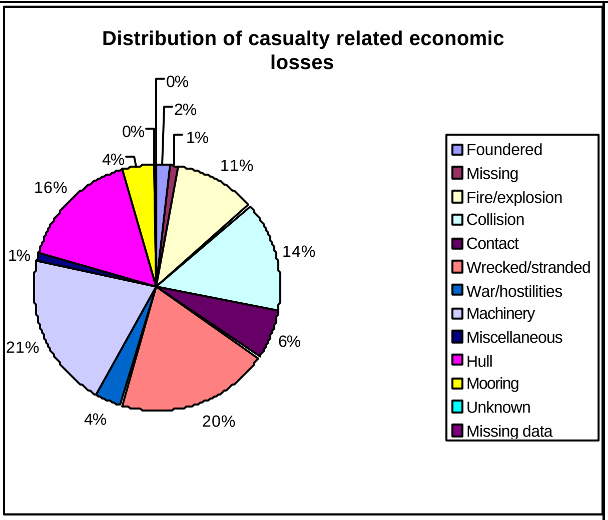

Figure 1 **Distribution of accident costs on accident category.**

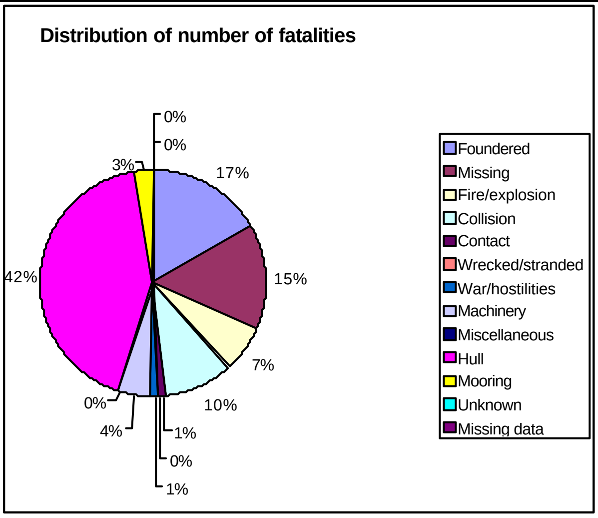

Figure 2 **Distribution of number of fatalities on accident category (personal accidents excluded)**

Aggregated risk results for all the bulk carriers compared to other ship types are shown below. The individual risk to crew (i.e., the annual fatality risk of an average crew member) for different ship types is shown in Figure 3 (MSC72/16). The figure indicates that the difference between bulk carriers (including ore carriers, self dischargers, and other bulk dry) and other ship types is not significant, in fact, other ship types, like general cargo carriers and Ro/Ro cargo carriers, have equally high individual risk levels. In the figure, risk acceptance criteria as suggested in MSC72/16 are included.

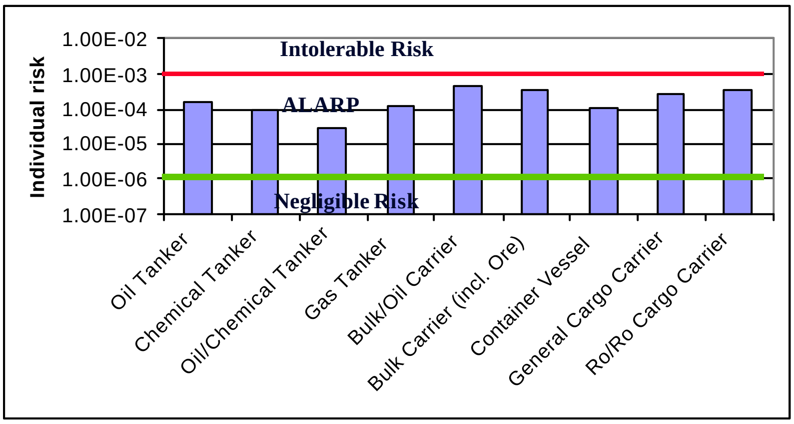

Figure 3 **Individual risk of fatality to crew on different ship types (MSC72/16)**

Figure 4 shows FN curves for different generic ship types (MSC72/16, Eknes, Kvien, 1999). The figure shows that the bulk carriers have relatively high frequencies of accidents involving 10 to 30 fatalities (i.e. the size of the crew) compared to the other generic ship types. Still, the FN curve for the bulk carriers is in the same region as the FN curves for the other ship types.

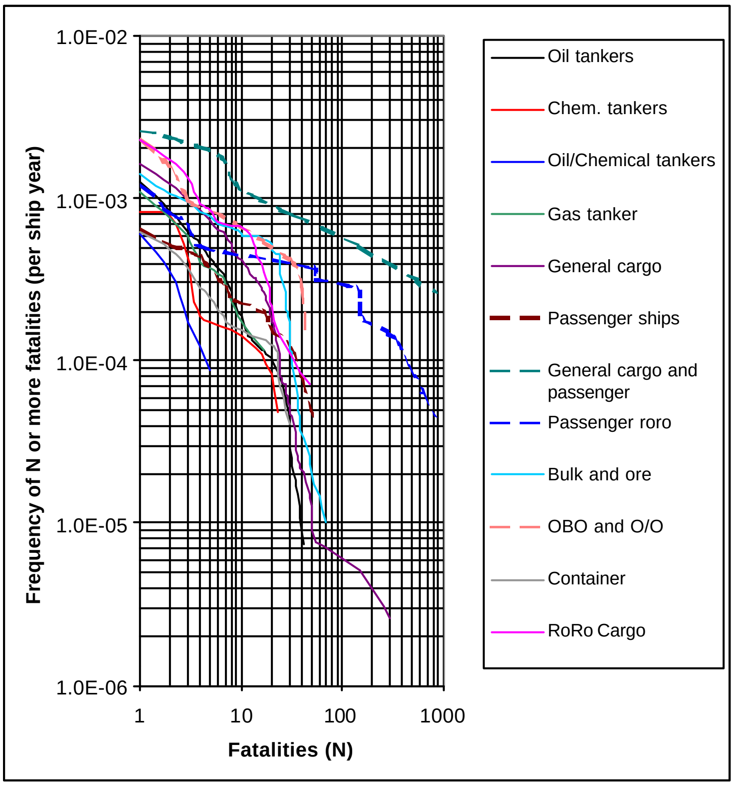

Figure 4 FN curve for different generic ship types

The following scenarios, involving water ingress, have been studied in detail:

- Water ingress due to side shell failure
- Water ingress due to failure of hatch covers and coamings
- Water ingress in the fore end

The reason for selecting these scenarios is that they represent app. 70% of the casualty related fatalities on the bulk carriers. In the following tables, the risk contributions from the different scenarios have been given for the period from 1978 to 1998, together with predictions for the present status for existing bulk carriers (i.e. constructed before the implementation of IACS UR S21 and SOLAS Chapter XII).

Table 2 Risk contribution from water ingress scenarios in the period from 1978 to 1998

Scenario	Potential Loss of Life	Economic Losses (US$)
Water ingress scenarios, overall	0.0115	33,000
Side shell failure scenarios	0.00777	28,400
Hatch cover failure scenarios	0.00334	3,900
Fore end flooding scenarios	0.000598	1,500

Table 3 Present risk contribution from water ingress scenarios, existing bulk carriers

	Potential Loss of Life	Economic Losses (US$)
Water ingress scenarios, overall	0.0085	27,100

Side shell failure scenarios	0.0049	20,400
Hatch cover failure scenarios	0.0026	3,100
Fore end flooding scenarios	0.00047	1,100

Table 4 Present risk contribution from water ingress scenarios, New-buildings

	Potential Loss of Life	**Economic Losses (US$)**
Water ingress scenarios, overall	0.0038	18,300
Side shell failure scenarios	0.0022	14,700
Hatch cover failure scenarios	0.00043	800
Fore end flooding scenarios	0.000077	800

Note that the three water ingress scenarios do not add up to the overall risk contributions from water ingress scenarios. The main reason for this is that some casualties are attributed to several of the scenarios. E.g. accidents involving both fore-end flooding and hatch cover failure may be averted both by preventing the initial water ingress in the fore end and by preventing the escalation by hatch cover collapses.

2 INTRODUCTION

The present annex is a part of the IACS study *Formal Safety Assessment of Bulk Carriers, Fore end watertight integrity.*

The objective of the present report is to establish the risks to form the basis for the evaluation of risk control options, through estimating the overall risks for bulk carriers larger than 20,000 DWT, and the risk contributions from the three scenarios of relevance to the study:

- Water ingress due to side shell failure
- Water ingress due to failure of hatch covers and coamings
- Water ingress in the fore end

The risks are estimated by a reviewing historical casualty data from the period between 1978 and 1998, and by combining casualty data, fleet data, and cost data. The Lloyd's Maritime Information Services (LMIS) casualty database is the primary data source, whereas fleet data have been taken from Lloyd's Statistical Tables and from data provided by Lloyd's Register to a previous DNV study (Eknes et al, 1997).

In Section 3, definitions are given of terms used throughout the study. Section 4 gives some cost data, whereas Section 5 establishes the overall risks for bulk carriers larger than 20,000 DWT, and the results are compared to results from related studies. Section 6 refers the risk contribution from water ingress scenarios in the period from 1978 to 1998, and Section 7 estimates the present status. Finally, Section 7 discusses the findings.

3 DEFINITIONS

Below, some terms used throughout the study are defined.

Serious casualty: Accident resulting in at least one of the following consequences (LMIS, 1995):

- Total loss (see below for further description).
- Breakdown resulting in the ship being towed or requiring assistance from ashore.
- Flooding of any compartment.
- Structural, mechanical or electrical damage requiring repairs before the ship can continue trading.

Total loss: Ship having ceased to exist after a casualty, either due to it being irrecoverable (actual total loss) or due to it being subsequently broken up (constructive total loss) (LMIS, 1995). Constructive total loss occurs when the cost of repair exceeds the insured value of the ship.

The LMIS casualty database divides the accidents into the following 9 accident categories:

1. **Foundered** - includes ships which sank as a result of heavy weather, leaks, breaking in two, etc, and not as a consequence of other categories such as collision etc.
2. **Missing vessel** - includes ships that disappeared without any witnesses knowing exactly what happened in the accident.

3. **Fire/explosion** - includes ships where fire/explosion is the first event reported, or where fire/explosion results from hull/machinery damage, i.e. this category includes fires due to engine damage, but not fires due to collision etc.
4. **Collision** - includes ships striking or being struck by another ship, regardless of whether under way, anchored or moored. This category does not include ships striking underwater wrecks.
5. **Contact** - includes ships striking or being struck by an external object, but not another ship or the sea bottom. This category includes striking drilling rigs/platforms, regardless of whether in fixed position or in tow.
6. **Wrecked/stranded** - includes ships striking the sea bottom, shore or underwater wrecks.
7. **War loss/hostilities** - includes ships damaged from all hostile acts.
8. **Hull/machinery damage** - includes ships where the hull/machinery damage is not due to other categories such as collision etc.
9. **Miscellaneous** - includes lost or damaged ships which cannot be classified into any of the categories 1 through 8 due to not falling into any of the categories above or due to lack of information (e.g. an accident starting by the cargo shifting (not as a consequence of events of any of the categories 1 through 8) would typically be classified as miscellaneous).

In the casualty data analysis below, the category denoted as Hull/machinery damage in the LMIS casualty database has been split into "machinery", "hull", "mooring", and "other" by separating the events according to the component category involved in the casualty.

4 COST DATA

In order to establish loss matrices, costs have been attributed to the casualties. MCA (1996) gives accident related cost data for different ship types. The data given for bulk carriers is shown in Table 5 below.

Table 5 Accident related cost data (MCA, 1996).

Ship size (GT)	Average value of total loss (US$ million, 1993)	Average cargo losses, total loss (US$ million, 1993)	Average cargo losses, partial loss (US$ million, 1993)
< 500			
500 – 4,999	1.4	0.825	0.33
5,000 – 19,999	6.0	2.805	0.99
20,000 – 49,999	14.7	6.435	2.145
50,000 – 99,999	20.5	4.785	1.650
> 100,000		10.395	3.300

If converted into US$ million, 2000, by assuming an average annual inflation of 2%, the accident related cost data will be as given in Table 6.

Table 6 Accident related cost data

Ship size (GT)	Average value of total loss (US$ million, 2000)	Average cargo losses, total loss (US$ million, 2000)	Average cargo losses, partial loss (US$ million, 2000)
< 500			
500 – 4,999	1.6	0.9	0.4

5,000 – 19,999	6.9	3.2	1.1
20,000 – 49,999	16.9	7.4	2.5
50,000 – 99,999	23.5	5.5	1.9
> 100,000		11.9	3.8

Average clean up costs for vessels not carrying oil are also given by MCA (1996). If converted into 2000 US$, the costs are as given in Table 7.

Table 7 Average clean up costs for vessels not carrying oil

Vessel size	**Costs (MCA, 1996)**	**Costs, US$ 2000**
< 5,000 GT	11,000	12,600
> 5,000 GT	329,000	378,000

5 OVERALL RISKS

5.1 Data

The data given below considers bulk carriers of 20,000 DWT or more, intended to carry dry cargo. Not included in the data are ore carriers, self-discharging bulk carriers and other bulk dry carriers like e.g. aggregate bulk carriers, cement carriers, wood chips carriers, limestone carriers, refined sugar carriers, and urea carriers.

For these bulk carriers the LMIS casualty database contains 3058 casualties recorded in the period from 1978 to 1998, of which 978 are recorded as *Non-serious* and 2080 as *Serious* casualties. It turned out that 9 of the casualties classified as Non-serious were fatal. In order to include all fatal accidents in the risk analysis, these 9 Non-serious and fatal accidents were recoded as Serious. All references to Serious and Non-serious casualties in the remaining part of the analysis concerning bulk carriers of 20,000 DWT or more are made to this "new" severity classification. 2089 of the accidents involving bulk carriers larger than 20,000 DWT were thus recorded as Serious and 969 as Non-serious. 248 of the serious casualties were total losses.

Figure 5 shows the number of casualties per year. It is usually anticipated that the number of non-serious events is larger than the number of serious events. This not being the case here indicates that the degree of reporting for the Non-serious casualties is lower than the degree of reporting for the Serious casualties. Hence, the Non-serious casualties have been excluded in the following analyses.

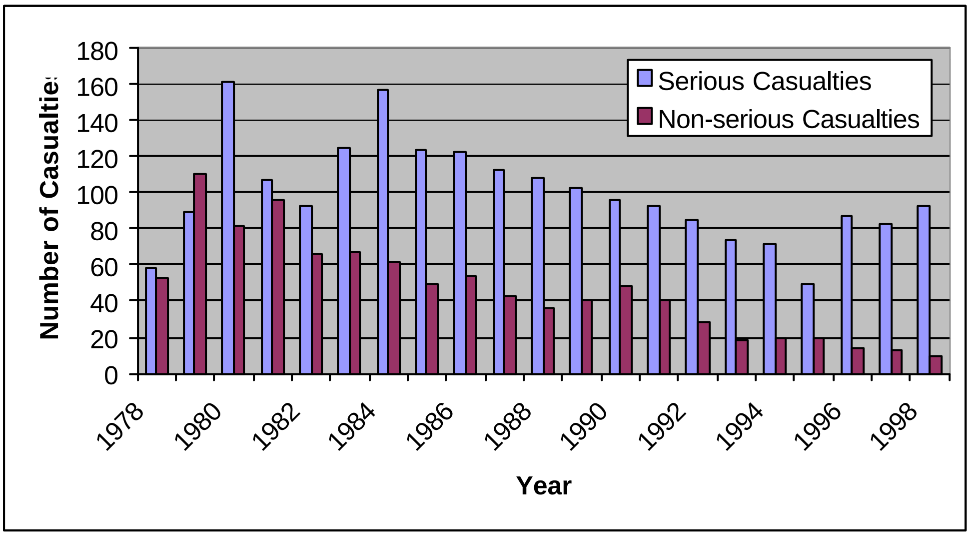

Figure 5 Recorded Non-serious and Serious casualties in the LMIS casualty database per year.

Table 8 indicates the number of bulk carriers per year, which corresponds to the casualty data presented above. An estimate of the total exposure during the time period is hence approximately 73,600 ship years.

Table 8 Fleet numbers for bulk carriers larger than 20,000 DWT. Source: Lloyd's register.

Year	Number of bulk carriers larger than 20,000 DWT	Year	Number of bulk carriers larger than 20,000 DWT
1978	2,500*	1989	3,521
1979	2,500*	1990	3,618
1980	2,705	1991	3,650
1981	2,875	1992	3,685
1982	3,092	1993	3,730
1983	3,251	1994	3,853
1984	3,547	1995	4,007
1985	3,743	1996	4,186
1986	3,743	1997	4,200*
1987	3,556	1998	4,200*
1988	3,454	1978-1998	73,600

* No data was available for these years, and approximate fleet numbers are assumed.

5.2 Loss Matrix

A loss matrix has been established by combining the above cost data with accident frequencies.

The ships constituting the casualty data set vary from 5,125 GT to 154,098 GT, with a mean of 35,860 GT and a standard deviation of 21,150 GT. Hence, cost data for a bulk carrier between 20,000 and 49,999 GT are used to establish the loss matrix. Spouge (1999) estimates the average cost of damage repair and cost of salvage to US$2.6 million and US$130,000, respectively, for oil tankers suffering serious casualties. In absence of better information the same estimates are assumed to apply to bulk carriers greater than 20,000 DWT as given in Table 9.

Table 9 Loss matrix for bulk carrier (US$/generic accident)

Cost item	**Serious casualties (excluding total losses)**	**Total losses**
Cost of total loss		16,900,000
Cost of damage repair	2,600,000	
Cost of lost cargo	2,500,000	7,400,000
Cost of salvage	130,000	130,000
Total damage costs	**5,230,000**	**24,430,000**
Clean-up costs	378,000	378,000
Overall costs (exc. fatalities)	**5,608,000**	**24,808,000**

In Figure 6 the generic losses per accident have been combined with the frequencies of the different accident categories to produce a distribution of economic losses per ship year on the different accident categories. Figure 7 gives the distribution of number of fatalities related on the accident categories. Details are found in Appendix 1.

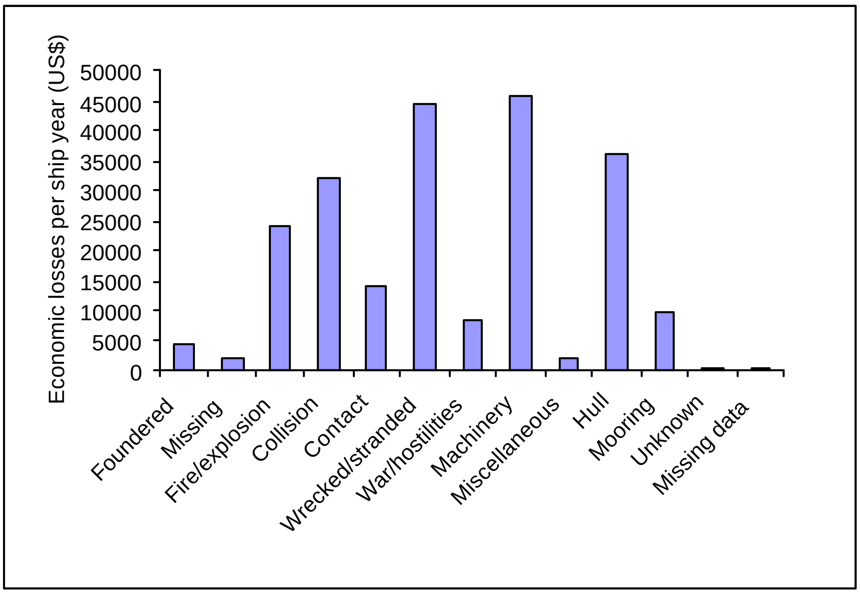

Figure 6 Economic losses distributed on accident category of initial event.

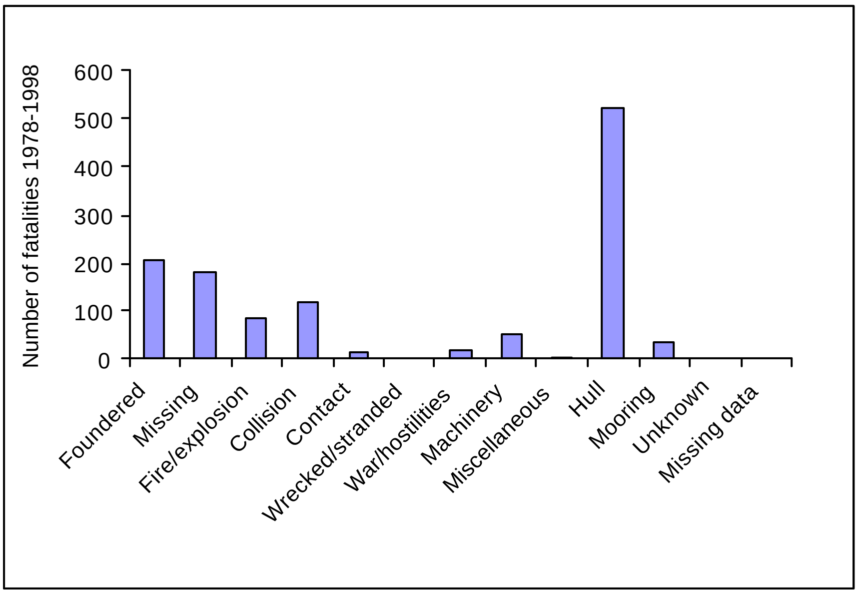

Figure 7 Distribution of number of fatalities between 1978 and 1998 on accident category of initial event.

If the accidents that may be attributed to structural failure are taken as the Foundered, Missing, and Hull categories, the contribution from structural failure to the total economic losses is approximately 19%. This is within the same order of magnitude as the other major contributors to the total economic loss. When considering the number of fatalities, structural failure may account for approximately 73% of the fatalities, which by far is the most significant contribution.

5.3 Individual and societal risk

The individual risk of crew has been calculated as:

$$IR = \frac{n}{N \cdot m} \cdot a$$

where n is the number of fatalities
N is the corresponding number of ship years
m is the average crew size on bulk carriers, taken as 25, and
a is the fraction of a year, which the crew spends onboard, taken as 0.5.

Figure 8 is a graphical representation the estimated individual risk as a function of time. Details are given in Table 17 in Appendix 1.

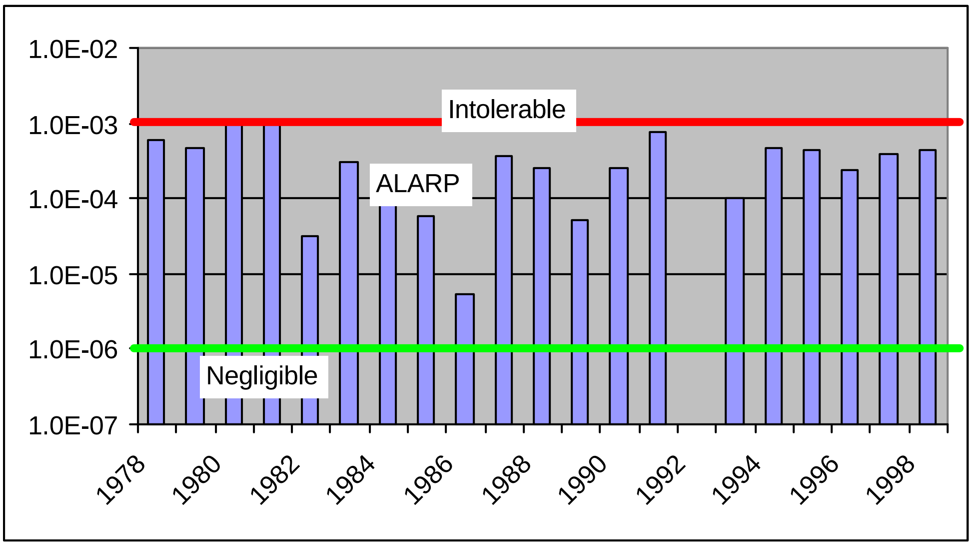

Figure 8 Variation of observed individual risk for bulk carriers larger than 20,000 DWT, all casualties, personal accidents excluded.

There are no obvious time trends in the figure above, and the variation from year to year is large. To investigate whether there is reason to believe that the individual risk of crew on bulk carriers has decreased over the period, the average individual risk from 1980 to 1989 and 1990 to 1998 has been estimated:

1980-1989: $$IR = \frac{\mathrm{n}}{\mathrm{N} \cdot POB} \cdot a = \frac{505}{33487 \cdot 25} \cdot 0.5 = 3.0 \cdot 10^{-4}$$

1990-1998: $$IR = \frac{\mathrm{n}}{\mathrm{N} \cdot POB} \cdot a = \frac{607}{35129 \cdot 25} \cdot 0.5 = 3.5 \cdot 10^{-4}$$

Based on the two estimates, there is no reason to believe that the individual risk has decreased over the two past decades.

If using a risk acceptance criterion as suggested in MSC72/16, as shown in the above figure, the observed individual risk (excluding occupational accidents) for the period mainly is found in the ALARP region. This implies that the overall individual risk is not intolerable, but risk control options should be implemented when found cost effective.

From the given casualty data and fleet data, the average number of fatalities per ship year, the Potential Loss of Life (PLL) for bulk carriers larger than 20,000 DWT over the period from 1978 to 1998 is estimated as:

$$PLL = \frac{1249\ \text{fatalities}}{73600\ \text{shipyears}} = 0.0170\ \text{fatalities} \quad \text{per shipyear}$$

The societal risk as observed in the period is shown in Figure 9, together with risk acceptance criteria as recommended in MSC72/16. The figure shows that the FN curve is found in the upper ALARP region, which may explain the concern for the bulk carriers in recent years.

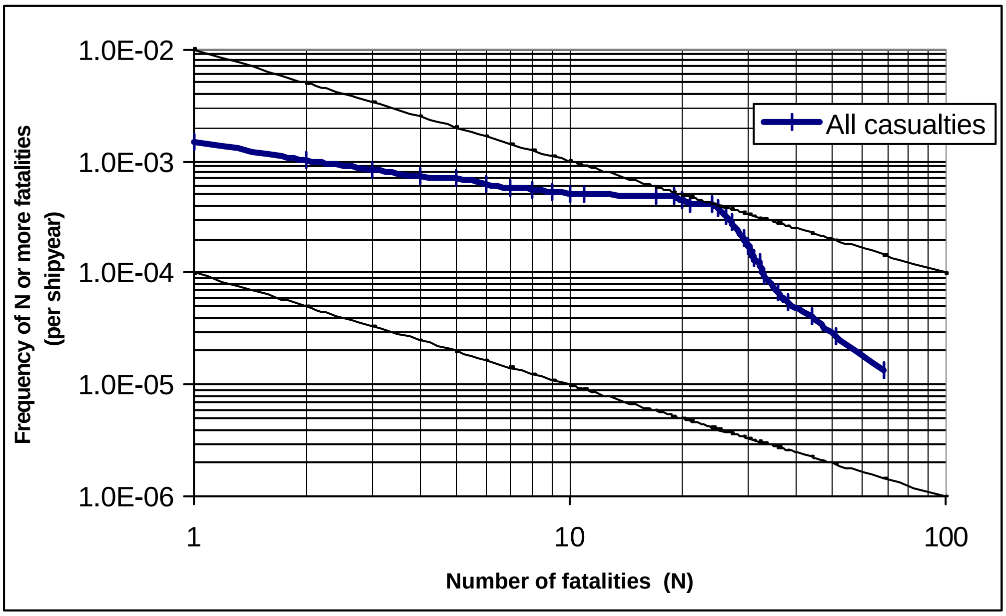

Figure 9 FN curve for bulk carriers larger than 20,000 DWT.

5.4 Dependency of ship age

In order to assess the dependency of the fatality risk of the age of the bulk carriers, the number of fatalities and PLL versus ship age was evaluated. Figure 10 below gives the number of fatalities as a function of ship age and accident category. As only detailed fleet data was available for the period between 1980 and 1996, casualties in this period have been included in the evaluation.

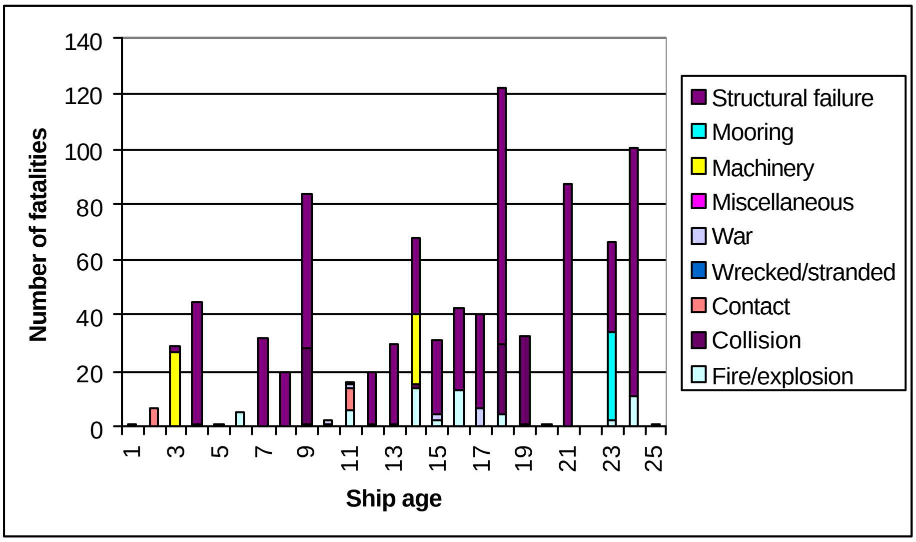

Figure 10 **Number of fatalities as a function of ship age and accident category.**

The casualties that may be related to structural failure have been focussed in the present study, and Figure 11 illustrates the PLL as a function of ship age.

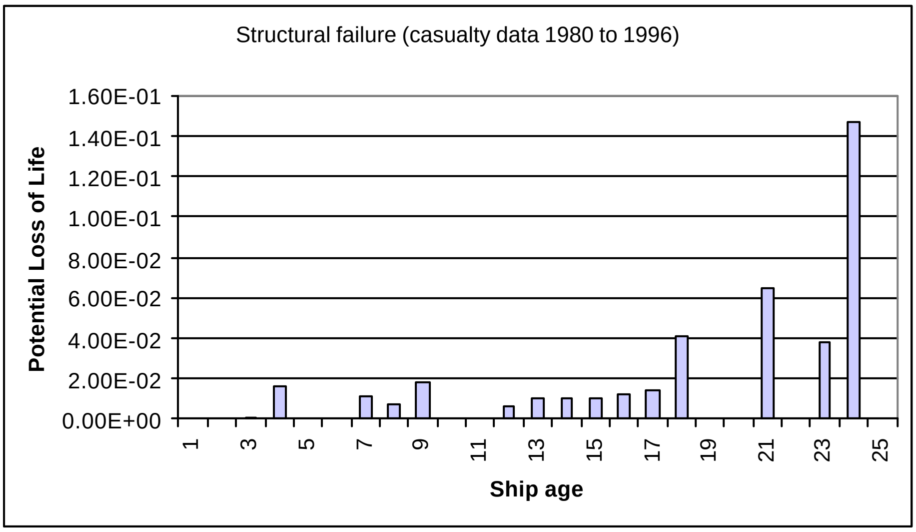

Figure 11 **PLL from structural failure, as a function of ship age.**

Figure 11 shows that the PLL increases significantly as the ship approaches their life expectancy. None of the other accident categories show this clear trend. In this study, 25 years have for simplicity been used as the life expectancy of bulk carriers. In the period from 1980 to 1996, the average life expectancy for bulk carriers was 23.3 years (Eknes et al, 1997).

Figure 12 shows the average age of bulk carriers larger than 20,000 DWT as a function of time. The figure shows that the average age of the fleet has been increasing year by year in the period from 1980 to 1996. Keeping in mind the trend shown in Figure 11, the increasing average ship age implies that the part of the fleet particularly at risk from structural failure have been increasing.

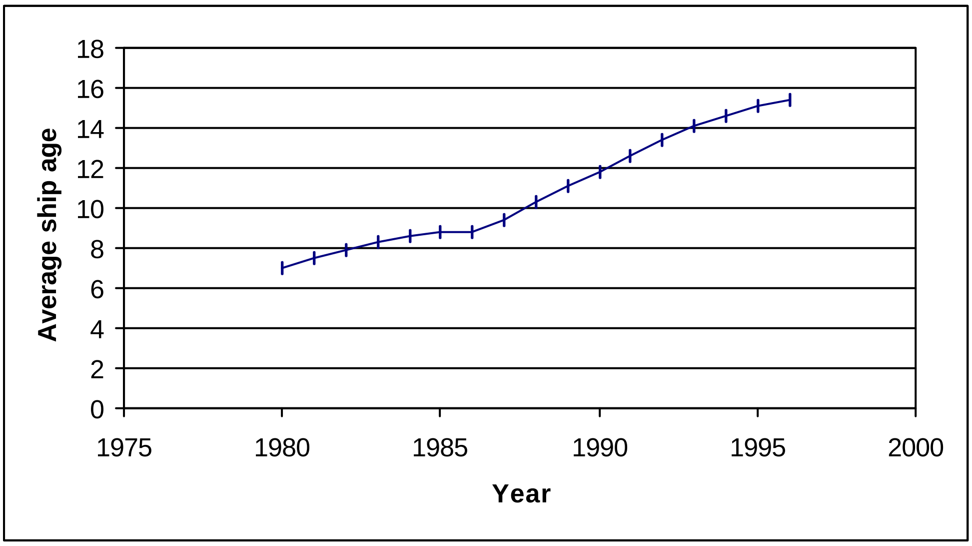

Figure 12 Average age of bulk carriers larger than 20,000 DWT.

5.5 Comparison with related studies

5.5.1 Comparison of risk level for bulk carriers and other generic ships

Figure 13 presents the frequency of serious casualties (per ship year) for different generic ship types (Eknes, Kvien, 1999). The figure indicates that bulk carriers (including ore carriers) is one of the generic ship types with the highest frequency of serious casualties (per ship year).

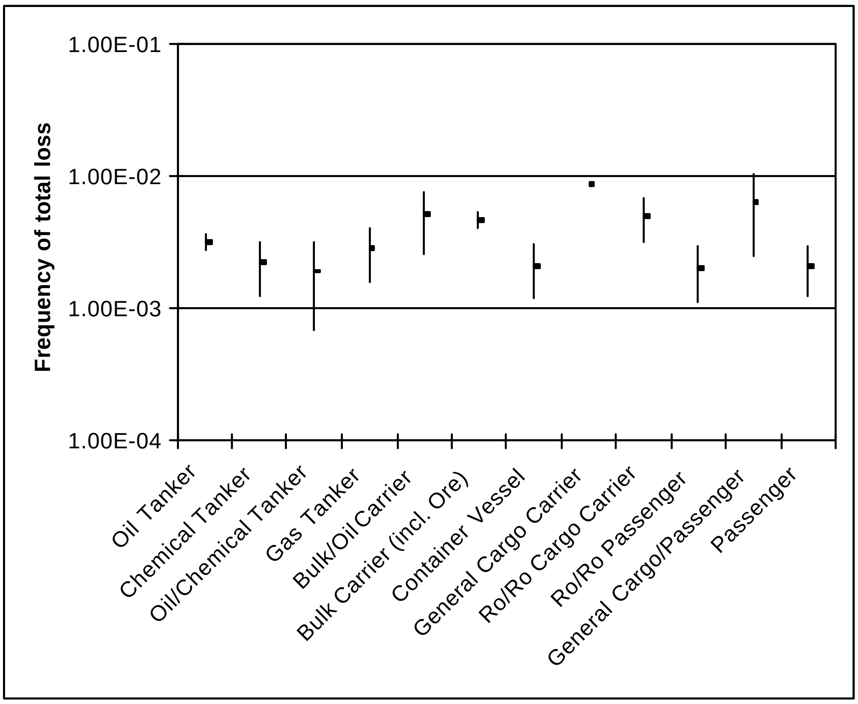

Figure 13 Frequency of serious casualties for different generic ship types, shown as confidence intervals ranging over 6 standard deviations

Figure 14 presents the frequency of total loss (per ship year) for different generic ship types (Eknes, Kvien, 1999). The figure indicates that there is much overlap of the confidence intervals among the different generic ship types. Bulk and ore carriers are among the generic ship types with the highest frequency of total losses together with general cargo carriers, bulk/oil carriers, ro/ro cargo carriers and general cargo/passenger carriers.

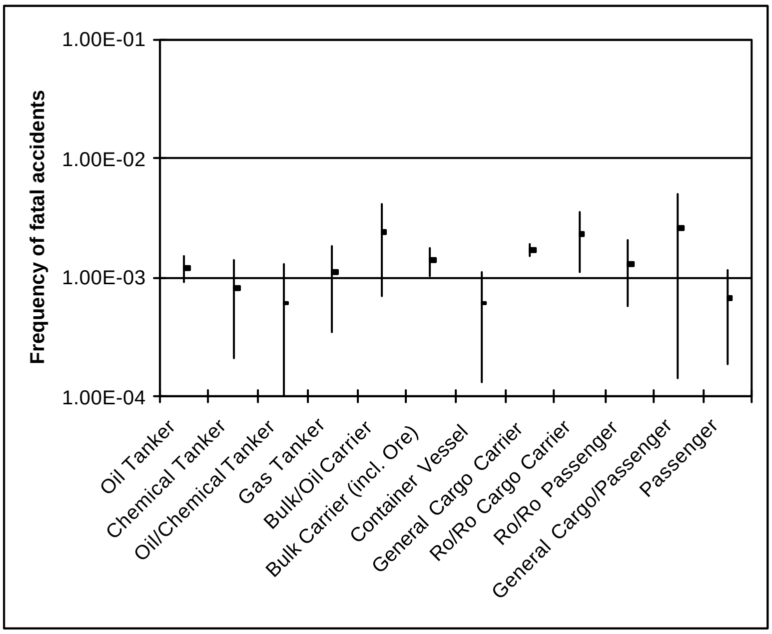

Figure 14 Frequency of total loss for different generic ship types, shown as confidence intervals ranging over 6 standard deviations

The individual risk to crew (i.e., the risk of fatality of an average crew member) for different ship types is shown in Figure 15 (Eknes and Kvien, 1999). The figure shows that the difference between bulk carriers (including ore carriers, self dischargers, and other bulk dry) is not significant, in fact, other ship types, like OBOs, general cargo carriers and Ro/Ro cargo carriers, have equally high individual risk levels. In the figure, risk acceptance criteria as suggested in MSC72/16 are included, which suggests that individual risks on all the shown ship types are in the As Low As Reasonably Practicable (ALARP) region implying that cost effective risk control options should be implemented.

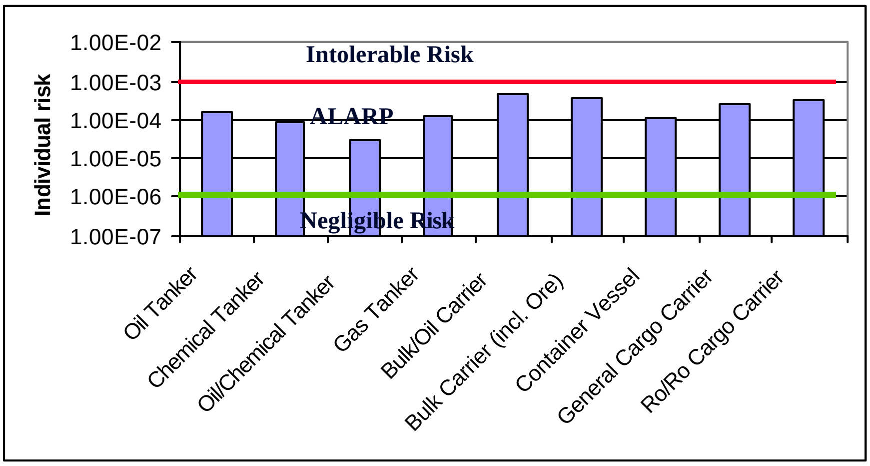

Figure 15 Individual risk of fatality to crew on different ship types (Eknes and Kvien, 1999)

Figure 16 shows FN curves for different generic ship types (Eknes, Kvien, 1999). The figure shows that the bulk carriers have relatively high frequencies of accidents involving 10-30 fatalities (i.e. the size of the crew) compared to the other generic ship types. Still, the FN curve for the bulk carriers is in the same region as the FN curves for the other ship types.

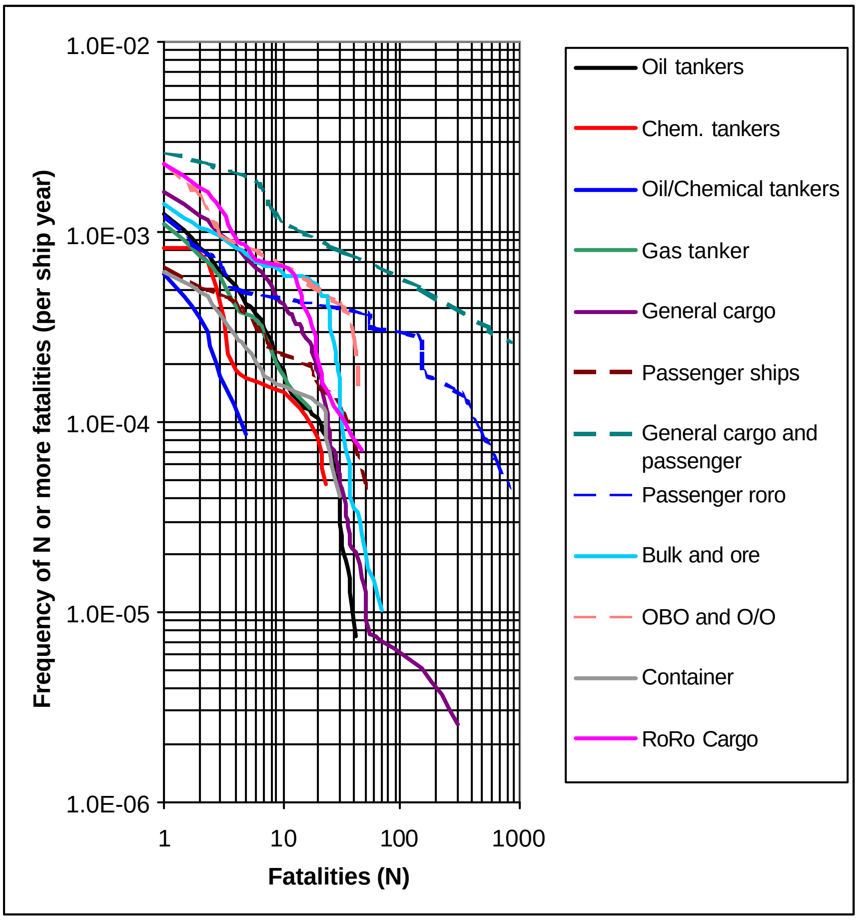

Figure 16 FN curve for different generic ship types

5.5.2 Comparison with Intercargo results

In this section, the data selection from LMIS (1999) and the results are compared with the results given by Intercargo (2000).

Intercargo (2000) lists the number of total losses for bulk carriers exceeding 10,000 DWT for the time period 1990 to 1999. The casualty categorisation differs slightly from the categorisation used by LMIS.

Figure 17 displays the number of total losses distributed on year and size for all bulk and ore carriers exceeding 10,000 DWT. Intercargo (2000) provides a corresponding figure for casualties occurring between 1990 and 1999 involving bulk carriers exceeding 10,000 DWT, see Figure 18. The reason for the discrepancy between the two figures may be the fact that the data foundation of the two analyses is not exactly the same. When adding the number of total losses from 1990 to 1998, the data selection from LMIS gives 140 total losses, while the Intercargo data contains 132 total losses. Hence the two data sets correspond well.

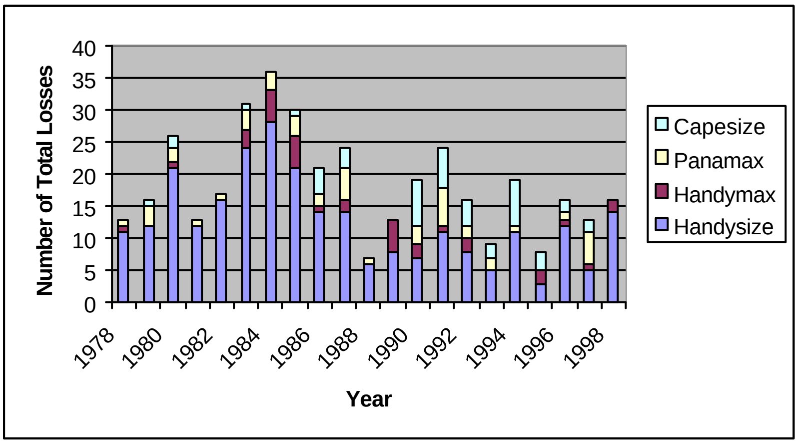

Figure 17 Number of Total Losses by size of vessel, all bulk carriers (1978-1998). (LMIS, 1999)

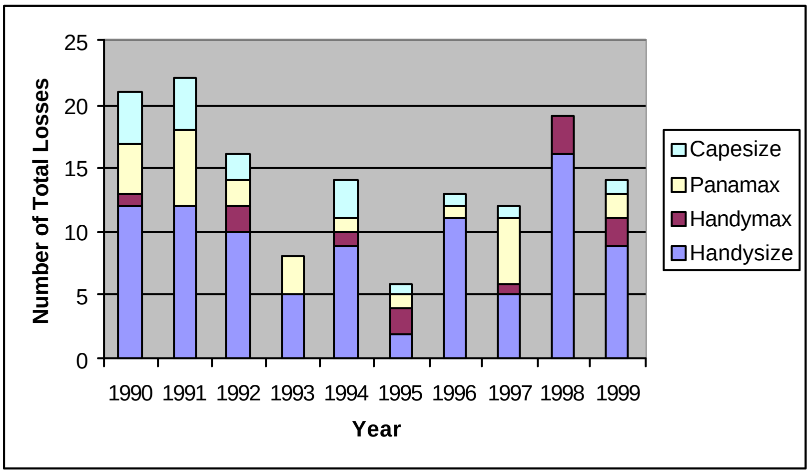

Figure 18 Number of total losses of bulk carriers, 1990 to 1999 (Intercargo, 2000)

LMIS comprises 1809 fatalities related to marine casualties resulting from casualties involving bulk or ore carriers. The number of fatalities resulting from casualties involving bulk and ore carriers each year between 1978 and 1998 for structural failure and other causes is given in Figure 19. The figure indicates that the number of fatalities varies considerably over the years and that a high proportion of the fatalities is related to casualties caused by structural damage. Intercargo (2000) shows a similar figure, see Figure 20. The number of fatalities per year differs somewhat between the data selection used and from Intercargo. While the data selection from LMIS gives 840 fatalities in the period from 1990 to 1998, Intercargo displays approximately 740 fatalities in the same period.

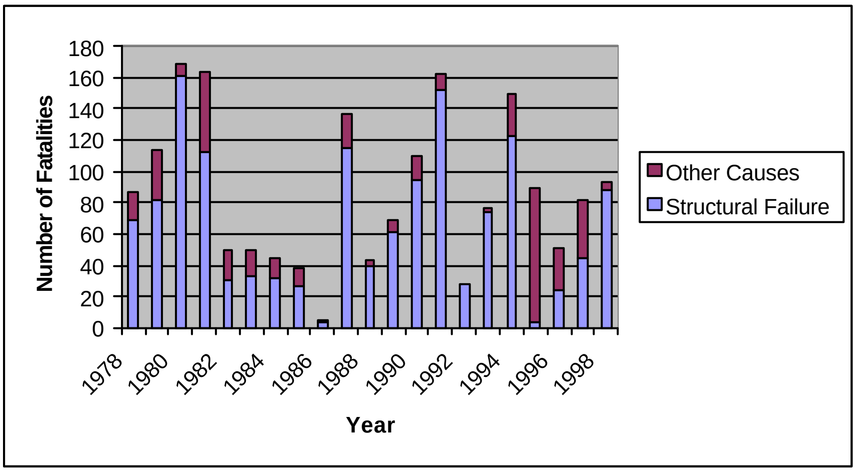

Figure 19 Number of fatalities broken down on year of casualty and failure category (LMIS, 1999)

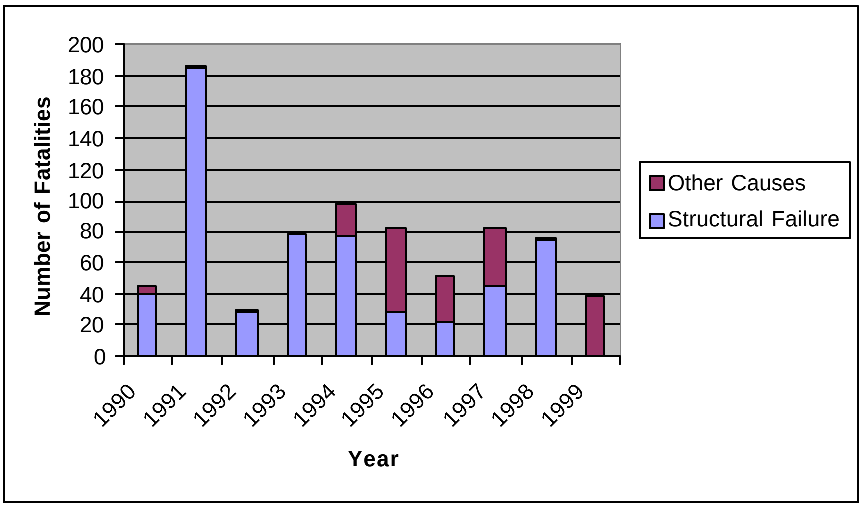

Figure 20 Number of fatalities, 1990 to 1999 (Intercargo, 2000)

The differences between the Intercargo results and the results from the data selection from LMIS may be caused by lack of absolute correspondence between the categorisations used in the two data sets, like ship type categorisations and accident categorisations, i.e. the data foundation used is not completely matching. Although the absolute numbers show some deviations, these are relatively small, and the trends are similar.

5.6 Discussion

The analysis of historical data from 1978 to 1998 revealed that casualties that may be attributed to structural failure accounted for approximately 74 % of all casualty related fatalities on bulk carriers larger than 20,000 DWT. This is by far the major contributor to the fatalities on bulk carriers. The structural failures also appears to be a major contributor to the economic losses related to casualties, although the difference is not significant from accident categories like Wrecked/stranded and Machinery.

Hence, the structural failures may be concluded to have been a major problem to bulk carrier safety, and it appears to be reasonable that this accident category is given focus in the present study.

Individual risks for bulk carriers larger than 20,000 DWT have been found in the ALARP risk region, implying that cost effective risk control options should be implemented. The societal risk is found to be in the upper ALARP risk region, also implying that cost effective risk control options should be implemented.

It should be noted that the Individual risk to crew members on the different bulk carriers are not significantly different than for other ship types, and this to a certain extent also applies to the societal risk and the probability of actual total loss of the ships. However, the facts that a big portion of the fatalities may be associated to structural failure, and that a large portion of the accidents claims the entire or the majority of the crew are strong indications of the traditional bulk carrier design not being sufficiently robust or redundant.

6 RISK CONTRIBUTION FROM WATER INGRESS SCENARIOS, 1978-1998

6.1 Introduction

In the present section, the base risk from water ingress scenarios are estimated, as these constitutes the major contributor to the overall fatality risk from "structural failure". The assessments are based on casualty data alone, whereas under the evaluation of the risk control options, risk models have been established and calibrated towards the casualty data as far as possible, to be able to predict the effect of the risk control options.

The following scenarios leading to water ingress have been assessed to establish base risk levels to be used when evaluating risk control options, see Figure 21:

1. Side shell failure scenarios
2. Fore end flooding scenarios
3. Hatch cover failure scenarios

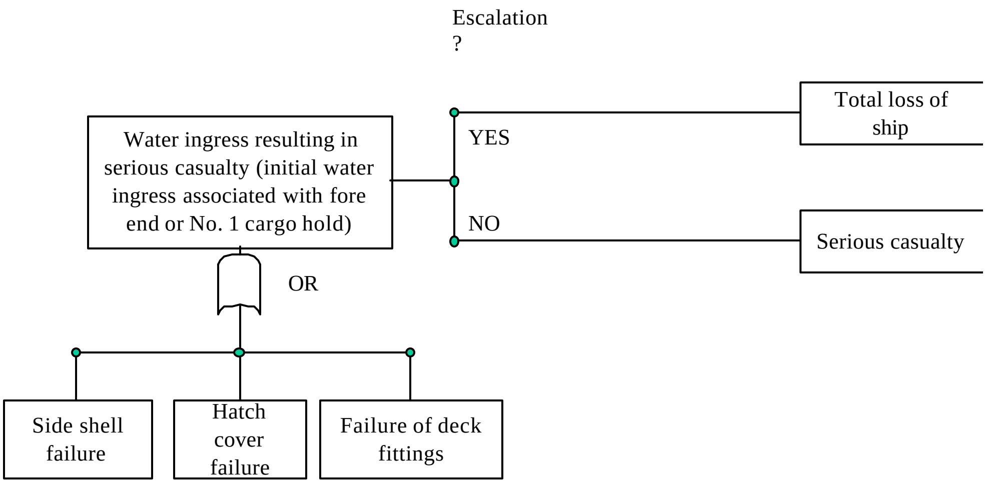

Figure 21 Water ingress scenarios studied.

Given water ingress, escalation or progressive flooding may occur due to one of the following:

- Failure of bulkhead separating a flooded and not flooded cargo hold
- Failure of hull girder

- Failure of hatch cover of not flooded cargo hold
- Cargo liquefaction and loss of stability
- Side shell failure of not flooded cargo hold

6.2 Overall Risk Contribution from Water Ingress Scenarios

6.2.1 Casualty Data

Accidents related to the scenarios might be included in the following accident categories in LMIS database.

- Foundered
- Missing
- Miscellaneous
- Hull

Casualties of the bulk carriers in the above categories were examined and checked one by one if they should be included into the basic data source of the study (Japan, 2001)[1]. As a result, in the LMIS casualty database, April 1999 version, 234 serious casualties including total losses involving water ingress or structural failure with possible water ingress have been found in the period from 1978 to 1998. In the investigation, other data sources such as internal class survey reports and database were referred if necessary and available (e.g. (Japan, 1981), (Intercargo, 2000)). The data foundation represents 73,600 ship years for bulk carriers larger than 20,000 DWT.

When casualties have been categorised in the above scenarios, some casualties have been logged under several of the scenarios. The reason for this is that the scenarios are not mutually exclusive. E.g. an accident involving fore end flooding and progressive flooding by hatch cover failure may be prevented both by preventing the initial flooding of the fore end, but also by preventing the failure of no. 1 hatch cover.

Table 1 shows the summary of the number of casualties. Lists of casualties in each group are given in Annex 6.

In historical casualty data analysis, some total losses, where no indication of flooding was given in LMIS, were judged as “hold flooding due to structural failure” by experts judgement taking into consideration the:

- Age of ship at casualty
- Density of the cargo which loaded at casualty

As a result, among them, there are still remaining 4 casualties where it is not clear whether the casualties involved water ingress or not in the 2nd accident group. They are included in the accident scenario n.1. There are 47 casualties in the 6th accident group where water ingress was confirmed. They were excluded because their causes and sequences were judged to be out of scope of the study.

Table 10 Number of Casualties with regard to water ingress or structural failure

[1] The Japanese Bulk Carrier FSA Project Team that includes members from ClassNK carried out the main part of this task. See MSC74/INF.X (Japan, 2001).

Scenario	Accident Groups	Number of Serious Casualties Total Loss	Others	Sum	Note
n.1	1. Flooding into cargo holds due to structural failure	51	52	103	see Table 1 in Annex 6
	2. Possible water ingress (Detail unknown)	4	0	4	
	(Sub total)	55	52	107	
	3. Flooding not into cargo holds due to structural failure.	7	46	53	see Table 2 in Annex 6
	(Total for Accident Scenario n.1)	62	98	160	
n.2	4. Flooding due to failure of deck fittings, etc.	1	6	7	see Table 3 and 4 in Annex 6
n.3	5. Flooding due to hatch covers or their securing failure	9	11	20	
	(Total for accident scenarios n.2 and 3)	10	17	27	
none	6. Water ingress however excluded from the study	13	34	47	see Table 5 in Annex 6
	Total	85	149	234	

Excluding the second and sixth groups, 183 serious cases and total losses with water ingress reported or with possible water ingress due to structural failure were found. An estimate of the frequency of serious casualty hence is given as:

$f = \frac{g}{m} = \frac{183}{73{,}600} = 2.49 \cdot 10^{-3}$ annual frequency of serious casualty or total loss involving water ingress.

Including the second group, 187 serious cases and total losses were found as upper limit. An estimate of the upper limit of serious casualty hence is given as:

$f_{upper} = \frac{g}{m} = \frac{187}{73{,}600} = 2.54 \cdot 10^{-3}$ annual frequency of serious casualty or total loss involving water ingress.

The deviation between these two estimates is minor, and in the following evaluations the data set forming the upper limit is used.

The numbers of fatalities in each accidents group are shown in Table 11.

Table 11 Number of Fatalities with regard to water ingress or structural failure

Scenario	Accident Groups	Number of Fatalities due to Serious Casualty Total Loss	Others	Sum	Note
n.1	1. Flooding into cargo holds due to structural failure	529	4	533	see Table 1 in Annex 6
	2. Possible water ingress (Detail unknown)	33	0	33	
	(Sub total)	562	4	566	
	3. Flooding not into cargo holds due to structural failure.	6	0	6	see Table 2 in Annex 6
	(Total for Accident Scenario n.1)	568	4	572	
n.2	4. Flooding due to failure of deck fittings, etc.	44	0	44	see Table 3 and 4 in Annex 6
n.3	5. Flooding due to hatch covers or their securing failure	232	2	234	
	(Total for accident scenarios n.2 and 3)	276	2	278	
none	6. Water ingress however excluded from the study	63	0	63	see Table 5 in Annex 6
	Total	907	6	913	

Excluding the sixth group, 850 fatalities are found. The maximum base risk contribution, in terms of PLL, from the water ingress scenarios as deduced from historical data hence is estimated to:

$$PLL_{\text{water ingress}} = \frac{913-63}{73600} = \frac{850}{73600} = 1.15 \cdot 10^{-2} \quad \text{fatalities per ship year}$$

Table 9 above gives a loss matrix for generic bulk carrier accidents. Here, a generic serious casualty is estimated to cost US$ 5,608,000, and a total loss US$ 24,808,000. If these cost estimates are combined with the frequencies for total loss and serious casualty, the maximum risk contribution, in terms of economic losses (*EL*), from serious casualties and total losses due to failure of hatch covers is estimated as:

$$EL_{\text{water ingress}} = \frac{85-13}{73{,}600} \cdot 24{,}808{,}000 + \frac{149-34}{73{,}600} \cdot 5{,}608{,}000 = US\$33{,}000 \text{ per ship year}$$

The above risk measures are mean values applicable for the period between 1978 and 1998. However, during the 1990s, several risk control options were implemented, influencing on the present base risk for bulk carriers. This is explored in the following section.

6.3 Risk Analysis of Side Shell Failure Scenarios

6.3.1 Description of Scenarios

The scenarios considered in the investigation consist of the following events:

1. Significant water ingress through holes due to side shell failure. Under conditions that the holes are opened under or near waterline, the cargo hold may be completely flooded rapidly.
2. In some of the cases there are progressive flooding of cargo holds due to bulkhead failure, leading to total loss of ship and in most cases fatalities.
3. In the remaining cases, the flooding is limited, resulting in serious casualty and not total loss, and few, if any, fatalities.

Different Hazard Identification studies have been conducted, e.g. by IACS, Japan and MCA. The causes of water ingress and major contributors to the risk from side shell failure are represented in Figure 2, as collected by MCA (2000).

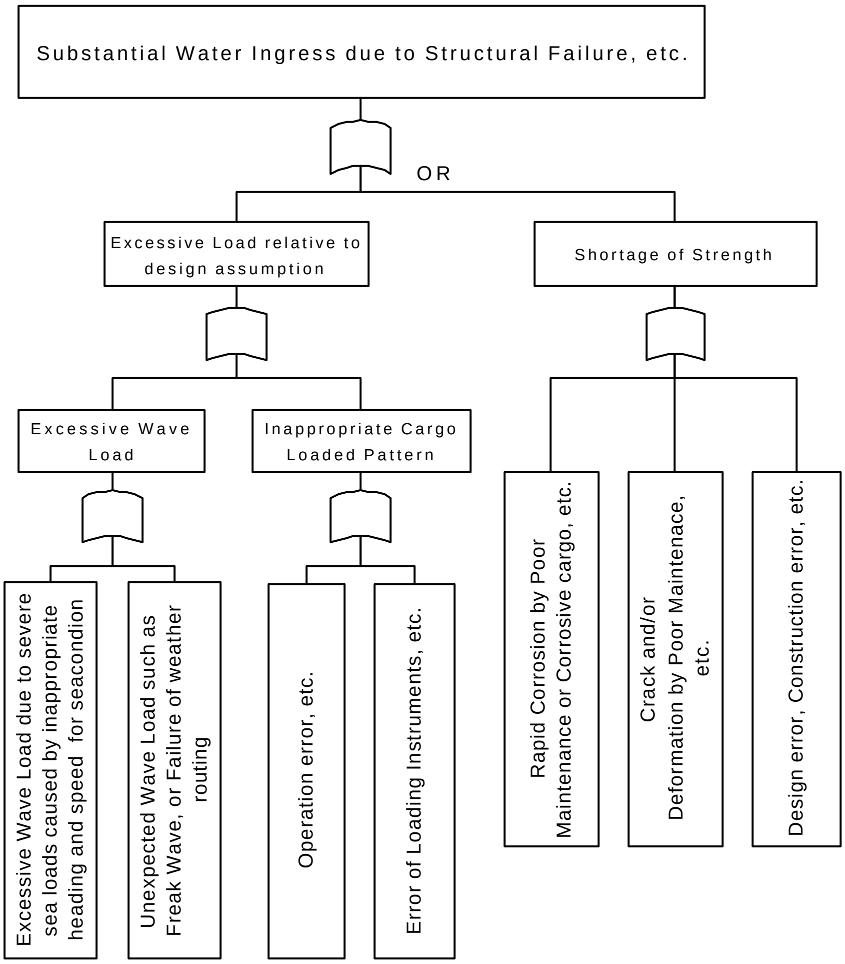

Figure 22 Causes of side shell failure giving substantial water ingress

More precise investigation of causes is required if preventive risk control options are considered.

6.3.2 Base Risk From Casualty Data, 1978 to 1998

In the LMIS casualty database, for bulk carriers of 20,000 DWT and larger, 160 serious cases and total losses with water ingress reported or with possible water ingress were found referring other data sources where necessary. An estimate of the frequency of serious casualty involving water ingress due to structural failure hence is given as:

$$f_1 = \frac{g}{m} = \frac{160}{73{,}600} = 2.17 \cdot 10^{-3} \text{ serious casualties per ship year}$$

In **Figure 23**, the casualties are split on location of event and severity, based on the probabilities and PLLs as obtained in Appendix 3.

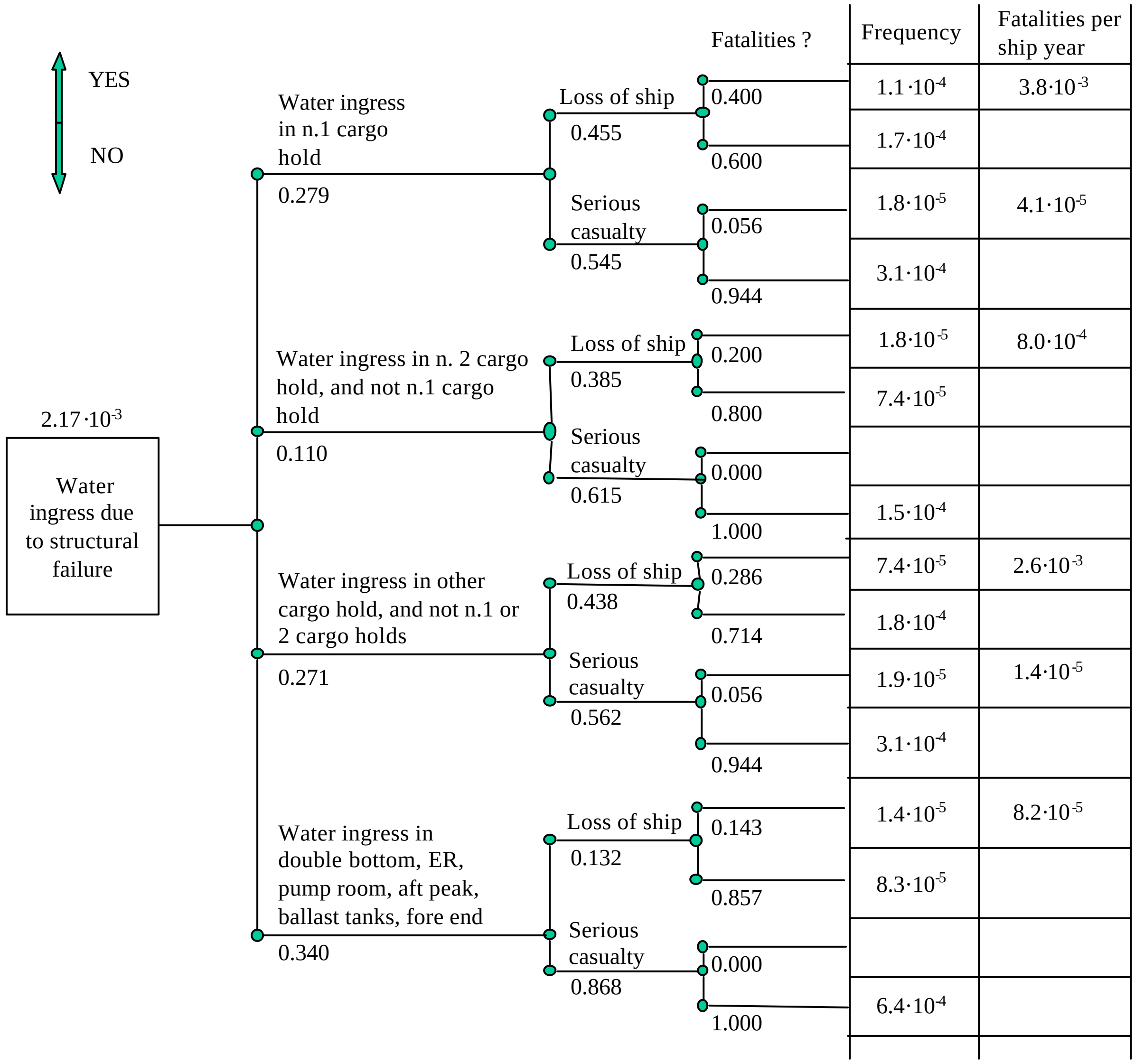

Figure 23 Quantified breakdown of casualty data on water ingress location, loss of ship versus serious casualty, and whether the accidents involved fatalities.

The 160 serious casualties identified for the side shell failure scenarios resulted in 572 fatalities in the period from 1978 to 1998, giving a PLL due to side shell failure of:

$$PLL_{\text{structural\_failure\_(side\_shell)}} = \frac{572 \text{ fatalities}}{73{,}600 \text{ ship years}} = 7.8 \cdot 10^{-3} \text{ fatalities per ship year}$$

If these cost estimates from Table 9 are combined with the frequencies for total loss and serious casualty, the maximum risk contribution, in terms of economic losses (EL), from serious casualties and total losses due to failure of hatch covers is estimated as:

$$EL_{\text{water ingress}} = \frac{62}{73{,}600} \cdot 24{,}808{,}000 + \frac{98}{73{,}600} \cdot 5{,}608{,}000 \approx US\$28{,}400 \text{ per ship year}$$

6.4 Water Ingress due to Hatch Cover Failure

6.4.1 Scenario Description

The hatch cover failure scenarios consist of the following events:
1. Significant water ingress through any hatch cover opening. Given an opening of the size of a hatch cover, the cargo hold may be completely flooded within matter of minutes, see e.g. DETR (1998).
2. In some of the cases there are progressive flooding of cargo holds, leading to total loss of ship and in most cases fatalities.
3. In the remaining cases, the flooding is limited, resulting in serious casualty and not total loss, and few, if any, fatalities.

Further, the scenarios are broken down on cargo hold involved in the initial flooding, and the severity.

Different Hazard Identification studies have been conducted, and Appendix 3 of Annex 4 lists the hazards related to hatch covers and coamings as collected by MCA (2000).

The causes of water ingress and major contributors to the risk are represented in Figure 24.

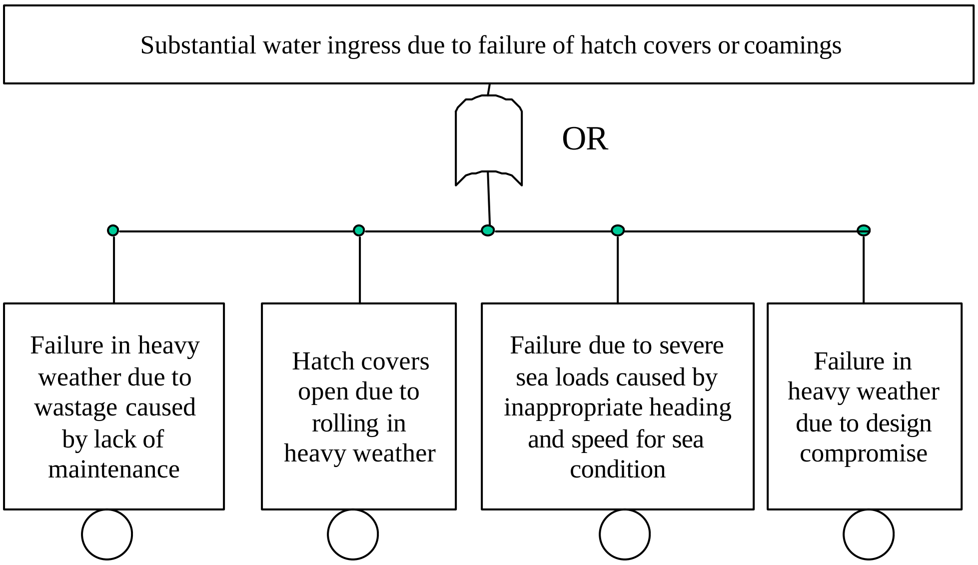

Figure 24 Causes of hatch cover failure giving substantial water ingress

6.4.2 Base risk from casualty data

In the LMIS casualty database, April 1999 version, 195 serious casualties including total losses involving water ingress have been found in the period from 1978 to 1998. The data foundation represents 73,600 ship years for bulk carriers larger than 20,000 DWT. In addition, there are 27 cases where it is not clear whether the casualties involved water ingress or not. In 75 of these 195 water ingress cases, no detailed information has been found regarding the cause of the water ingress to the cargo holds, whereas some of these contain information about which cargo holds suffered from water ingress.

27 cases were found where failure of hatch covers and water ingress or possible water ingress was reported. 20 of the cases were recorded as serious casualties, of which 9 were total losses. 8 accidents involved in total 246 fatalities. 7 cases were recorded as non-serious casualties.

The PLL is taken as the average number of fatalities per ship year. The contribution to the PLL from hatch cover failures is estimated to:

$$PLL_{\text{hatch covers}} = \frac{n}{m} = \frac{246 \text{ fatalities}}{73{,}600 \text{ ship years}} = 3.34 \cdot 10^{-3} \text{ fatalities per ship year}$$

Given 9 total losses due to hatch cover failures and 11 serious casualties not leading to total losses, the economic losses, *EL*, per ship year is estimated to:

$$\begin{aligned} EL_{\text{hatch covers}} &= f_{\text{total loss due to hatch covers}} \cdot C_{\text{total loss}} + f_{\text{serious casualty due to hatch cover}} \cdot C_{\text{serious casualty}} \\ &= \frac{9}{73{,}600} \cdot 24{,}808{,}000 + \frac{11}{73{,}600} \cdot 5{,}608{,}000 = US\$3{,}900 \end{aligned}$$

This constitutes a *lower bound* of the risk contribution from hatch cover failure, as only the cases where this is explicitly stated are included in the data. At the same time, the bound is also considered as a best estimate, since hatch cover failure is one of the failure mechanisms easier to detect and hence more likely to be reported.

Assuming that all 75 cases found, where the source of water ingress was not accounted for, are related to hatch cover failure, an *upper bound* of the frequency of water ingress due to hatch cover failure is found. 37 of the casualties were total losses, and in total the casualties involved 522 fatalities. *Upper bounds* for the risk contribution from hatch covers hence are given as:

$$PLL^{u}_{\text{hatch cover}} = \frac{246 + 522}{73{,}600} = 1.04 \cdot 10^{-2} \text{ fatalities per ship year}$$

The upper bound hence represents an increase of a factor of 3.1 in the PLL due to hatch cover failure.

If cost estimates are combined with the frequencies for total loss and serious casualty, the risk contribution, in terms of economic losses, from serious casualties and total losses due to failure of hatch covers is estimated as:

$$EL^{u}_{\text{hatch cover}} = \frac{9+37}{73{,}600} \cdot 24{,}808{,}000 + \frac{11+38}{73{,}600} \cdot 5{,}608{,}000 = US\$19{,}200 \text{ per ship year}$$

The upper bounds may be used to evaluate the robustness of the recommendations for risk control options considering hatch covers and coamings. However, hatch cover failure is believed to be a failure mechanism relatively easy to detect, and the probability that this is reported is hence believed to be larger than e.g. the probability that side shell failure leading to water ingress being reported. The risk estimates based on the reported cases are thus taken as best estimates.

In Figure 25, an event tree has been quantified as outlined in Appendix 4. The results given in the event tree should be read as a breakdown of the casualty data, giving very strong indications that the majority of the serious casualties and the total losses are related to hatch cover failure and water ingress into (at least) no. 1 cargo hold. Hence, the uncertain branch probabilities taken as 0 and 1, and based on few observations, are not used in the evaluations of the risk control options.

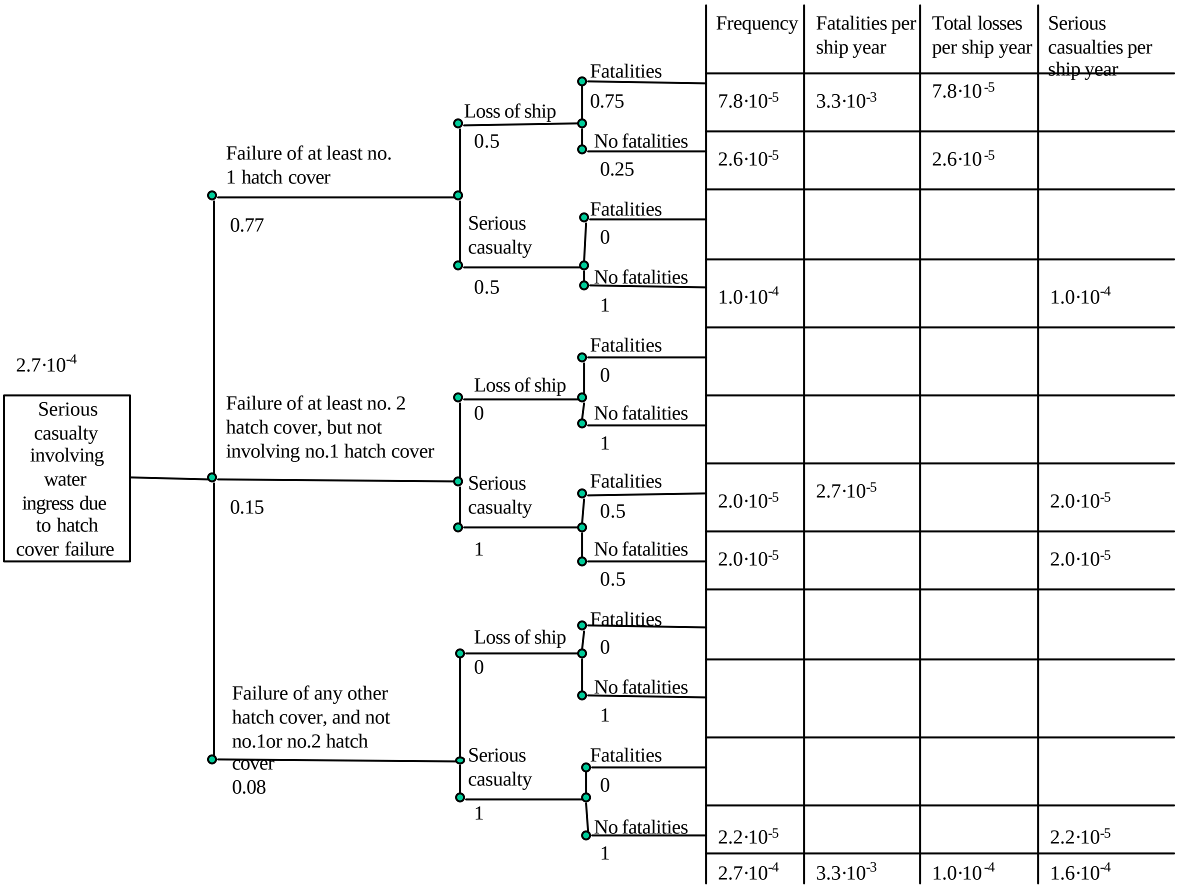

Figure 25 Quantified breakdown of casualty data on water ingress location, loss of ship versus serious casualty, and whether the accidents involved fatalities.

In the below table, the serious casualties (including total losses) are distributed on bulk carrier size.

Table 12 Comparison of different bulk carrier size categories

bulk carrier category	Relative part of fleet	Number of serious casualties and total losses	Expected number of serious casualties if equal underlying frequency	Ratio of observations per expected outcome
handysize	0.48	11	9.6	1.1
handymax	0.24	4	4.8	0.8
panamax	0.19	1	3.8	0.3
capesize	0.09	4	1.8	2.2

Based on this very limited data foundation, it is assumed that the capesize bulk carriers are more at risk than the other size categories, and that the frequency of serious casualty (including total losses) is a factor of 2 higher than the average serious casualty frequency.

6.5 Fore End Flooding Scenarios

Two scenarios of fore-end flooding were investigated:
1. flooding starting from the forepeak (scenario A)
2. flooding starting from the hold n.1 (scenario B)

The two scenarios were represented by means of Event Trees that are basically the same with a different order of the nodes. The ET nodes represent the principal influences that affect the risk. They are described in the following; the same description applies for both ETs.

In scenario A, the following accident escalation is hypothesised in a given sea state:
- due to the loads from water on deck exceeding the collapse load, an opening is generated in the fore peak deck, creating a way for flooding
- a progressive flooding of the fore peak takes place, up to complete filling of the peak
- the ship sails now with a trim by bow: the hatch cover of hold #1 collapses due to actual water head over the deck exceeding the collapse value : a way for flooding is created.
- a progressive flooding of hold #1 takes place up to complete filling.
- the early **(i.e. evacuation of water from the forepeak)** and late (i.e. evacuation of water from hold n.1) corrective actions are unsuccessful.

In scenario B, the following accident escalation is hypothesised in a given sea state:
- due to the loads from water on deck exceeding the collapse load, an opening is generated in the hatch cover n.1, creating a way for flooding
- a progressive flooding of the hold n.1 takes place, up to complete filling of the cargo hold.
- the ship sails now with a trim by bow: a hatch on the forepeak collapses due to actual water head over the deck exceeding the collapse value : a way for flooding is created.
- a progressive flooding of forepeak takes place up to complete filling.
- the early and late corrective actions are unsuccessful.

The ship is assumed lost for any of the following reasons: loss of reserve of buoyancy, capsizing for loss of stability due to free surface effects combined with wave and wind inclining moments, hull girder collapse.

The details of the risk assessment of this scenario may be found in Annex 5.

As a statistical basis, cases have been retrieved from LMIS between 1978 and 1998, by searching for the terms ”fore peak”, ”forecastle”, and ”hawsepipe” in the freetext, in addition to identifying the cases where the event was coded as related to the fore end. The cases constitute the cases we know for a fact involved fore ends of bulk carriers. The data can be used to establish a lower limit for the frequency of flooding of the fore end.

12 cases in the below table involves fore end flooding, of which 2 are characterised as Non Serious (NS), 7 as Serious (S), 2 were Actual Total Losses (ATL), and 1 was a Constructive Total Loss (CTL). The number of corresponding bulk carrier years are 73 600. One of the casualties involved in total 44 fatalities.

The PLL is taken as the average number of fatalities per ship year. The contribution to the PLL from hatch cover failures is estimated to:

$$PLL_{\text{foreend}} = \frac{n}{m} = \frac{44\,\text{fatalities}}{73{,}600\ \text{ship years}} = 5.98 \cdot 10^{-4}\ \text{fatalities per ship year}$$

Given 3 total losses due to hatch cover failures and 7 serious casualties not leading to total losses, the economic losses per ship year is estimated to:

$$EL_{\text{foreend}} = f_{\text{total loss}} \cdot C_{\text{totalloss}} + f_{\text{seriouscasualty}} \cdot C_{\text{seriouscasualty}}$$
$$= \frac{3}{73{,}600} \cdot 24{,}808{,}000 + \frac{7}{73{,}600} \cdot 5{,}608{,}000 = US\$1{,}500$$

The two measures above constitute *lower bounds* of the risk contribution from fore end flooding scenarios, as only the cases where this is explicitly stated are included in the data.

There are 17 cases in the database recorded as Foundered (11 cases) and Missing (6 cases), where the data given does not indicate the location of the initial water ingress. Some of these cases may have been caused by progressive flooding initiated in the fore end of the ships. In total they implied 384 fatalities. Conservatively, it may be assumed that all the casualties were caused by fore end flooding, giving an upper limit for the frequency for total loss of bulk carriers due to fore end flooding:

$$PLL^{upper}{}_{\text{foreend}} = \frac{n}{m} = \frac{(44+384)\text{fatalities}}{73{,}600\text{ ship years}} = 5.82 \cdot 10^{-3} \text{ fatalities per ship year}$$

$$EL^{upper}{}_{\text{foreend}} = f_{\text{totalloss}} \cdot C_{\text{totalloss}} + f_{\text{seriouscasualty}} \cdot C_{\text{seriouscasualty}}$$
$$= \frac{3+17}{73{,}600} \cdot 24{,}808{,}000 + \frac{7}{73{,}600} \cdot 5{,}608{,}000 = US\$7{,}300 \text{ per ship year}$$

The statistical uncertainty in the risk contribution from fore end flooding scenarios hence is considerable.

7 PRESENT BASE RISK CONTRIBUTION FROM WATER INGRESS SCENARIOS

7.1 Introduction

Over the past 10 years, several risk control options have been implemented for bulk carriers:

- the Enhanced Survey Programme (ESP)
- IACS UR S21
- SOLAS chapter XII – applicable to bulk carriers over 150 m

In the present section, the effect of these risk control options is evaluated to establish a base risk contribution from water ingress scenarios relevant for today's situation.

The influences of the different implemented risk control options are schematically shown in the fault and event trees below. In the following sections, the effectiveness of each of these risk control options is discussed.

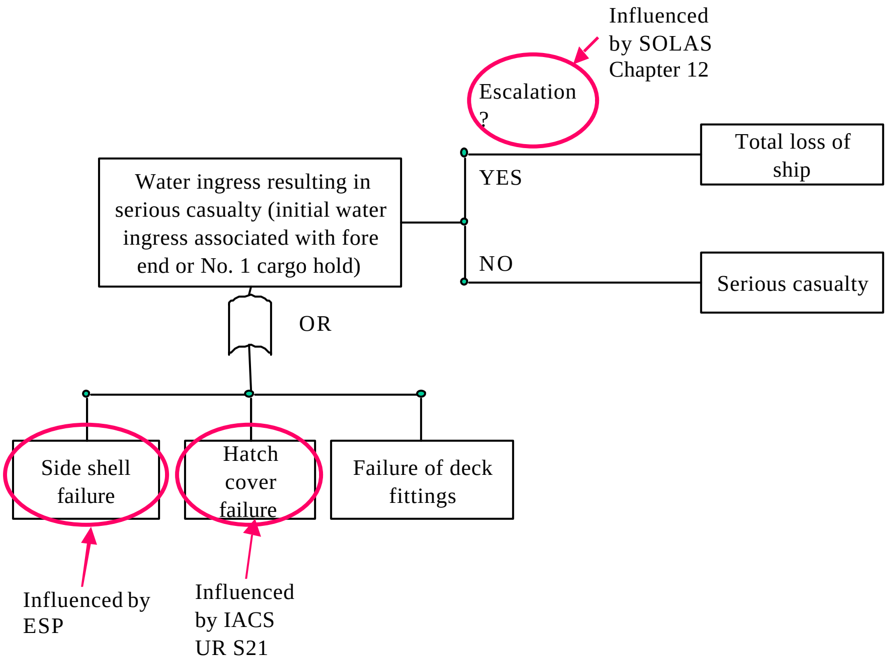

Figure 26 Simple risk model showing the influence of the ESP, IACS UR S21, and SOLAS Chapter 12.

7.1.1 The Enhanced Survey Programme (ESP)

The Enhanced Survey Programme (ESP) was implemented as an IACS Unified Requirement on 1 July 1993 (IACS, 1999).

The risk reduction due to ESP was estimated based on historical casualty data. This risk reduction may include effects from other implemented measures, like the ISM code, but due to lack of detailed information, the entire risk reduction was attributed to ESP.

ESP may prevent side shell failure and hence side shell failure casualties. The number of serious casualties due to side shell failure was found to have declined by app. 19% following the introduction of ESP. For details, see Appendix 5.

7.1.2 IACS UR S21

IACS UR S21 (IACS, 1997) was implemented in July 1998, giving stricter requirements for the design of hatch covers, compared to the International Load Line Convention of 1966 (ILLC 66). Based on structural reliability analyses, IACS UR S21 was estimated to reduce the probability of No. 1 hatch cover collapse by between 90 and 99% compared to ILLC 66. To be conservative, the risk reduction is taken as 90%. The hatch cover collapse failure mode was estimated to account for 70% of serious casualties related to hatch covers. For details, see Annex 4.

7.1.3 SOLAS Chapter XII

The following parts of SOLAS Chapter XII have been evaluated:

- Requirements of structural strength at flooding condition and damage stability for new bulk carrier (Regulation 4 and 5 in SOLAS Chapter XII for new bulk carrier)
- Requirements of structural strength at flooding condition and damage stability for existing bulk carrier (Regulation 4 and 6 in SOLAS Chapter XII for existing bulk carrier)

Casualties between 1978 and 1998 were reviewed in detail to assess whether or not they could have been mitigated if SOLAS Chapter XII had been in force at the time. The risk reduction rates are given in the below tables.

Table 13 Risk reduction rate for New-buildings

RCO1	Number of Total Loss Cases	Number of Probably Mitigated Cases	Number of Possibly Mitigated Cases	Converted Number of Cases	Risk Reduction Rate
Capesize	14	11	0	11	79%
Panamax	14	11	0	11	79%
Handy	38	24	1	24.5	64%
Small Handy	6	0	0	0	0%
ALL	72	46	1	46.5	65%

Table 14 Risk reduction rate for existing bulk carriers

RCO2	Number of Total Loss Cases	Number of Probably Mitigated Cases	Number of Possibly Mitigated Cases	Converted Number of Cases	Risk Reduction Rate
Capesize	14	4	2	5	36%
Panamax	14	4	0	4	29%
Handy	38	1	11	6.5	17%
Small Handy	6	0	0	0	0%
ALL	72	9	13	15.5	22%

7.2 Residual Risk after the Implementation of ESP, UR S21, and SOLAS Chapter XII

7.2.1 Residual risk model

Based on the simple tree given in Figure 26, the risk contribution from structural failure resulting in water ingress is estimated.

The risk contribution from different modes of structural failure, in terms of PLL including the effect of implemented risk control options, is estimated according to the following model:

$$PLL = \left[\left(1 - r_{ESP}^{all}\right)P_{sideshell} + \left(1 - r_{URS21}\right)P_{hatchcovers} + P_{foreend}\right] \cdot \left[\left(1 - r_{SOLASXII}\right) \cdot P_{escalation} \cdot \hat{n}_{TL} + \left(1 - \left(1 - r_{SOLASXII}\right) \cdot P_{escalation}\right)\hat{n}_{SC}\right]$$

where

$r^{all}{}_{ESP}$	is the relative reduction in probability of side shell failure due to ESP
r_{URS21}	is the relative reduction in probability of hatch cover failure due to IACS UR S21
$r_{SOLASXII}$	is the relative reduction in probability of escalation due to SOLAS XII

$P_{sideshell}$	is the annual probability of serious water ingress through side shell
$P_{hatchcovers}$	is the annual probability of serious water ingress through hatch covers
$P_{foreend}$	is the annual probability of substantial water ingress in the fore end
$P_{escalation}$	is the probability of escalation to total loss, given initial flooding
$\hat{n}_{TL}$	is the average number of fatalities per total loss, given detection of water ingress
$\hat{n}_{SC}$	is the average number of fatalities per serious casualty, independent of detection of water ingress

Similarly, the economic losses, *EL*, due to the different modes of structural failure may be estimated by:

$$EL = \left[\left(1 - r_{ESP}^{all}\right)P_{sideshell} + \left(1 - r_{URS21}\right)P_{hatchcovers} + P_{foreend}\right]\cdot$$
$$\left[\left(1 - r_{SOLASXII}\right)\cdot P_{escalation}\cdot C_{TL} + \left(1 - \left(1 - r_{SOLASXII}\right)\cdot P_{escalation}\right)C_{sc}\right]$$

where

C_{TL}	is the estimated cost of a total loss
C_{SC}	is the estimated cost of a serious casualty, excluding total loss

Allowing for no effect of the implemented risk control options the model may be tested against the casualty data from 1978 to 1998 (for the quantification of the different probabilities, see Appendix 2):

$$PLL = \left[P_{sideshell} + P_{hatchcovers} + P_{foreend}\right]\cdot\left(P_{escalation}\cdot\hat{n}_{TL} + \left(1 - P_{escalation}\right)\hat{n}_{SC}\right)$$
$$= \left[2.2\cdot 10^{-3} + 2.7\cdot 10^{-4} + 9.5\cdot 10^{-5}\right]\cdot\left(\left(0.39\cdot 11.7 + \left(1 - 0.39\right)\cdot 0.05\right)\right)$$
$$= 0.0115 \text{ fatalities per ship year}$$

The economic losses, *EL,* associated with structural failure is by assuming the detection of the water ingress does not influence on the economic losses, estimated to:

$$PLL = \left[P_{sideshell} + P_{hatchcovers} + P_{foreend}\right]\cdot\left[P_{escalation}\cdot C_{TL} + \left(1 - P_{escalation}\right)C_{SC}\right]$$
$$= \left[2.2\cdot 10^{-3} + 2.7\cdot 10^{-4} + 9.5\cdot 10^{-5}\right]\cdot\left[0.39\cdot US\$24{,}808{,}000 + \left(1 - 0.39\right)\cdot US\$5{,}608{,}000\right]$$
$$= US\$33{,}000 \text{ per ship year}$$

Hence, the model complies with the casualty statistics as given in the previous section. Below, the different input elements to the risk model have been quantified.

7.2.2 Residual risk results

SOLAS XII has different implications for new-buildings and existing bulk carriers, and IACS UR S21 only applies to new-buildings. Hence, below the evaluation of residual risk therefore has been separated for the two cases.

Existing bulk carriers

For existing bulk carriers, with hatch covers designed according to ILLC66, the relative reductions due to the implemented risk control options are estimated below.

For ESP, the following relative risk reduction was estimated:

$r^{all}_{ESP} = 0.19$

IACS UR S21 did not apply retrospectively, giving:
$r_{URS21} = 0$

For SOLAS XII, 15.5 out of 72 total losses were assessed as expected to be mitigated for existing bulk carriers:

$$r_{SOLASXII} = \frac{15.5 \text{ expected number of mitigated total losses}}{72 \text{ relevant water ingress total losses}} = 0.22$$

Introducing the relative risk reductions into the PLL model gives the following estimate of the PLL after the introduction of ESP, SOLAS XII, and IACS UR S21:

$$\begin{aligned} PLL &= \left[\left(1 - r^{all}_{ESP}\right)P_{sideshell} + \left(1 - r_{URS21}\right)P_{hatch\,covers} + P_{foreend}\right] \cdot \\ &\quad \left[\left(1 - r_{SOLASXII}\right) \cdot P_{escalation} \cdot \hat{n}_{TL} + \left(1 - \left(1 - r_{SOLASXII}\right) \cdot P_{escalation}\right)\hat{n}_{SC}\right] \\ &= \left[\left(1 - 0.19\right) \cdot 2.2 \cdot 10^{-3} + \left(1 - 0\right) \cdot 2.7 \cdot 10^{-4} + 9.5 \cdot 10^{-5}\right] \cdot \\ &\quad \left[\left(1 - 0.22\right) \cdot 0.39 \cdot 11.7 + \left(1 - \left(1 - 0.22\right) \cdot 0.39\right) \cdot 0.05\right] \\ &= 8.5 \cdot 10^{-3} \text{ fatalities per ship year} \end{aligned}$$

$$\begin{aligned} EL &= \left[\left(1 - r^{all}_{ESP}\right)P_{sideshell} + \left(1 - r_{URS21}\right)P_{hatch\,covers} + P_{foreend}\right] \cdot \\ &\quad \left[\left(1 - r_{SOLASXII}\right) \cdot P_{escalation} \cdot C_{TL} + \left(1 - \left(1 - r_{SOLASXII}\right) \cdot P_{escalation}\right)C_{SC}\right] \\ &= \left[\left(1 - 0.19\right) \cdot 2.2 \cdot 10^{-3} + \left(1 - 0\right) \cdot 2.7 \cdot 10^{-4} + 9.5 \cdot 10^{-5}\right] \cdot \\ &\quad \left[\left(1 - 0.22\right) \cdot 0.39 \cdot US\$24{,}808{,}000 + \left(1 - \left(1 - 0.22\right) \cdot 0.39\right) \cdot US\$5{,}608{,}000\right] \\ &= US\$27{,}100 \text{ per ship year} \end{aligned}$$

For existing bulk carriers, to which ESP and SOLAS XII applies, the PLL and economic losses are estimated to have been reduced by approximately 26% and 18% respectively.

New-buildings:

For new-buildings, the estimated relative reductions in the different probabilities are given below.

For ESP, the following relative risk reduction was estimated:
$r^{all}_{ESP} = 0.19$

IACS UR S21, a risk reduction of 90% was estimated for the annual probability of hatch cover failure, estimated to be relevant for 70% of the serious casualties involving hatch covers:
$r_{URS21} = 0.7 \cdot 0.9 = 0.63$

For SOLAS XII, 46.5 out of 72 total losses were assessed as expected to be mitigated for new bulk carriers:

$$r_{SOLASXII} = \frac{46.5 \text{ expected number of mitigated total losses}}{72 \text{ relevant water ingress total losses}} = 0.65$$

Introducing the relative risk reductions into the PLL model gives the following estimate of the PLL after the introduction of ESP, SOLAS XII, and IACS UR S21:

$$PLL = \left[\left(1 - r_{ESP}^{all}\right)P_{sideshell} + \left(1 - r_{URS\,21}\right)P_{hatch\,covers} + P_{foreend}\right] \cdot$$
$$\left[\left(1 - r_{SOLASXII}\right) \cdot P_{escalation} \cdot \hat{n}_{TL} + \left(1 - \left(1 - r_{SOLASXII}\right) \cdot P_{escalation}\right)\hat{n}_{SC}\right]$$
$$= \left[\left(1 - 0.19\right) \cdot 2.2 \cdot 10^{-3} + \left(1 - 0\right) \cdot 2.7 \cdot 10^{-4} + 9.5 \cdot 10^{-5}\right] \cdot$$
$$\left[\left(1 - 0.65\right) \cdot 0.39 \cdot 11.7 + \left(1 - \left(1 - 0.65\right) \cdot 0.39\right) \cdot 0.05\right]$$
$$= 3.8 \cdot 10^{-3} \text{ fatalities per ship year}$$

$$EL = \left[\left(1 - r_{ESP}^{all}\right)P_{sideshell} + \left(1 - r_{URS\,21}\right)P_{hatch\,covers} + P_{foreend}\right] \cdot$$
$$\left[\left(1 - r_{SOLASXII}\right) \cdot P_{escalation} \cdot C_{TL} + \left(1 - \left(1 - r_{SOLASXII}\right) \cdot P_{escalation}\right)C_{SC}\right]$$
$$= \left[\left(1 - 0.19\right) \cdot 2.2 \cdot 10^{-3} + \left(1 - 0\right) \cdot 2.7 \cdot 10^{-4} + 9.5 \cdot 10^{-5}\right] \cdot$$
$$\left[\left(1 - 0.65\right) \cdot 0.39 \cdot US\$24{,}808{,}000 + \left(1 - \left(1 - 0.65\right) \cdot 0.39\right) \cdot US\$5{,}608{,}000\right]$$
$$= US\$18{,}300 \text{ per ship year}$$

The updated PLL and economic losses for new buildings represent a risk reduction of approximately 67% and 45 % respectively compared to the base risk level estimated from the casualties between 1978 and 1998.

7.3 Side Shell Failure Scenarios

Below, the effect of ESP and SOLAS Chapter XII has been incorporated to estimate the present base risk contribution from side shell failure scenarios.

For existing ships, the introduction of ESP and SOLAS Chapter XII is expected to reduce the PLL to:

$$PLL_{\text{structural\_failure\_(side\_shell)}}^{\text{Existingships}} = \left(1 - r_{ESP}^{all}\right)\left(1 - r_{SOLASXII}\right)PLL_{\text{structural\_failure\_(side\_shell)}}^{1978\text{-}1998}$$
$$= \left(1 - 0.19\right)\left(1 - 0.22\right) \cdot 7.8 \cdot 10^{-3} = 4.9 \cdot 10^{-3} \text{ fatalities per ship year}$$

For existing bulk carriers, the economic losses from side shell failure per ship year are estimated to:

$$EL = \left[\left(1 - r_{ESP}^{all}\right)P_{sideshell}\right] \cdot \left[\left(1 - r_{SOLASXII}\right)P_{escalation} \cdot C_{TL} + \left(1 - \left(1 - r_{SOLASXII}\right)P_{escalation}\right)C_{SC}\right]$$
$$= \left[\left(1 - 0.19\right)2.2 \cdot 10^{-3}\right] \cdot \left[\left(1 - 0.22\right)0.39 \cdot US\$24{,}808{,}000 + \left(1 - \left(1 - 0.22\right)0.39\right) \cdot US\$5{,}608{,}000\right]$$
$$= US\$20{,}400 \text{ per ship year}$$

For new-buildings, the base risk in terms of PLL and economic losses are estimated to:

$$PLL_{\text{structural\_failure\_(side\_shell)}}^{\text{New-buildings}} = \left(1 - r_{ESP}^{all}\right)\left(1 - r_{SOLASXII}\right)PLL_{\text{structural\_failure\_(side\_shell)}}^{1978\text{-}1998}$$
$$= \left(1 - 0.19\right)\left(1 - 0.65\right) \cdot 7.8 \cdot 10^{-3} = 2.2 \cdot 10^{-3} \text{ fatalities per ship year}$$

$$EL = \left[\left(1 - r_{ESP}^{all}\right)P_{sideshell}\right] \cdot \left[\left(1 - r_{SOLASXII}\right)P_{escalation} \cdot C_{TL} + \left(1 - \left(1 - r_{SOLASXII}\right)P_{escalation}\right)C_{SC}\right]$$
$$= \left[\left(1 - 0.19\right)2.2 \cdot 10^{-3}\right] \cdot \left[\left(1 - 0.65\right)0.39 \cdot US\$24{,}808{,}000 + \left(1 - \left(1 - 0.65\right)0.39\right) \cdot US\$5{,}608{,}000\right]$$
$$= US\$14{,}700 \text{ per ship year}$$

7.4 Hatch Cover Failure Scenarios

Below, the present base risk contributions from hatch cover failure scenarios are estimated, incorporating the effect from IACS UR S21 and SOLAS Chapter XII.

For existing ships, with hatch covers designed according to the load line convention, the introduction SOLAS Chapter XII is expected to reduce the PLL to:

$$PLL_{\text{hatch covers}}^{\text{Existing ships}} = (1 - r_{SOLAS XII}) PLL_{\text{hatch covers}}^{1978\text{-}1998}$$
$$= (1 - 0.22) \cdot 3.34 \cdot 10^{-3} = 2.6 \cdot 10^{-3} \text{ fatalities per ship year}$$

For existing bulk carriers, the economic losses due to hatch cover casualties are estimated to:

$$EL = P_{hatch\,covers} \cdot \left[(1 - R_{SOLAS XII}) P_{escalation} \cdot C_{TL} + \left(1 - (1 - R_{SOLAS XII}) P_{escalation}\right) C_{SC} \right]$$
$$= 2.7 \cdot 10^{-4} \cdot \left[(1 - 0.22) 0.39 \cdot US\$24{,}808{,}000 + \left(1 - (1 - 0.22) 0.39\right) \cdot US\$5{,}608{,}000 \right]$$
$$= US\$3{,}100 \text{ per ship year}$$

For new-buildings, the base risk contribution from hatch covers, in terms of PLL is estimated to:

$$PLL_{\text{hatch covers}}^{\text{New-buildings}} = (1 - r_{URS21})(1 - r_{SOLAS XII}) PLL_{\text{hatch covers}}^{1978\text{-}1998}$$
$$= (1 - 0.63)(1 - 0.65) \cdot 3.34 \cdot 10^{-3} = 4.3 \cdot 10^{-4} \text{ fatalities per ship year}$$

Similarly, for New-buildings, the economic losses are estimated to:

$$EL = P_{hatch\,covers} (1 - r_{URS21}) \cdot \left[(1 - R_{SOLAS XII}) P_{escalation} \cdot C_{TL} + \left(1 - (1 - R_{SOLAS XII}) P_{escalation}\right) C_{SC} \right]$$
$$= 2.7 \cdot 10^{-4} \cdot (1 - 0.65) \cdot \left[(1 - 0.65) 0.39 \cdot US\$24{,}808{,}000 + \left(1 - (1 - 0.65) 0.39\right) \cdot US\$5{,}608{,}000 \right]$$
$$= US\$800 \text{ per ship year}$$

7.5 Fore-end Flooding Scenarios

The contribution from fore-end flooding scenarios to the PLL after the implementation of SOLAS Chapter XII is for existing bulk carriers estimated to:

$$PLL_{\text{fore end}}^{\text{Existing ships}} = (1 - r_{SOLAS XII}) PLL_{\text{fore-end}}^{1978\text{-}1998}$$
$$= (1 - 0.22) \cdot 5.98 \cdot 10^{-4} = 4.7 \cdot 10^{-4} \text{ fatalities per ship year}$$

The economic losses due to fore-end flooding, for existing bulk carriers are estimated to:

$$EL = P_{foreend} \cdot \left[(1 - r_{SOLAS XII}) P_{escalation} \cdot C_{TL} + \left(1 - (1 - r_{SOLAS XII}) P_{escalation}\right) C_{SC} \right]$$
$$= 9.5 \cdot 10^{-5} \cdot \left[(1 - 0.22) 0.39 \cdot US\$24{,}808{,}000 + \left(1 - (1 - 0.22) 0.39\right) \cdot US\$5{,}608{,}000 \right]$$
$$= US\$1{,}100 \text{ per ship year}$$

For new-buildings, the base risk contribution from hatch covers, in terms of PLL is estimated to:

$$PLL_{\text{fore end}}^{\text{New-buildings}} = (1 - r_{URS21})(1 - r_{SOLASXII})PLL_{\text{fore end}}^{1978\text{-}1998}$$
$$= (1 - 0.63)(1 - 0.65)\cdot 5.98 \cdot 10^{-4} = 7.7 \cdot 10^{-5} \text{ fatalities per ship year}$$

Similarly, for new-buildings, the econimic losses due to fore-end flooding are estimated to:

$$EL = P_{foreend} \cdot [(1 - r_{SOLASXII})P_{escalation} \cdot C_{TL} + (1 - (1 - r_{SOLASXII})P_{escalation})C_{SC}]$$
$$= 9.5 \cdot 10^{-5} \cdot [(1 - 0.65)0.39 \cdot US\$24{,}808{,}000 + (1 - (1 - 0.65)0.39) \cdot US\$5{,}608{,}000]$$
$$= US\$800 \text{ per ship year}$$

8 DISCUSSION

The base risk results as given in the present report are used as input when evaluating the risk control options. The results are based on casualty data and fleet statistics, and are hence subject to statistical uncertainties. However, the database used is evaluated as the best casualty database available, and the degree of reporting is believed to be close to 100% for total losses for the bulk carriers subject for evaluation in the present study. For the serious casualties, excluding the total losses, the degree of reporting is believed to be good, but it should be noted that for bulk carriers, the main risk contributions are from the total losses. Hence, the risk results would not be very sensitive to a degree of reporting of serious casualties, excluding total losses, of less than 100%. The casualty data is therefore believed to give a quite precise estimate of the bulk carrier risks in the time period they cover.

During the 1990s, several risk control options have been implemented, reducing the risks for the bulk carriers. Risk models have been established to try to estimate their effects, partly by assessing casualty data and judging which casualties would have been averted by the risk control option, and partly by using structural reliability methods.

The model used to estimate the risk reductions due to implemented risk control options is based on the following simplifications and assumptions:

- The scenarios are assumed to develop similarly independently of the failure mode leading to the initial water ingress. This is a simplification, as e.g. the probability of escalation, and the number of fatalities might depend on the type of scenario. However, this simplification is not expected to influence significantly on the estimated residual risk.
- The evaluation is based on casualty data and is hence subject to statistical uncertainty.

Based on the simple risk model, reductions in risk contribution from structural failure of 20% for existing bulk carriers and 70% for new-buildings were estimated, due to risk control options implemented during the 1990s. Since the major part of structural failure related casualties occurs to the older part of the bulk carrier fleet, this means that it will take 10 to 15 years before the new-building modifications will show any effect on the casualty statistics.

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Appendix 1 Bulk carrier risk details

This appendix contains the detail for the overall risk assessment presented in Section 5.

In Table 15 the generic losses per accident have been combined with the frequencies of the different accident categories to produce a loss matrix per ship year. Table 15 also includes the total number of fatalities related to each accident category.

Table 15 Loss matrix for bulk carrier accidents (US$/ship year), human costs excluded. Data are from 1978 to 1998.

Accident category	Total economic losses due to serious casualties and total losses (per ship year)	% of total	Total number of fatalities	% of total
All serious casualties and total losses	223,803	100	1,249	100
Foundered	4,273	1.9	206	16.5
Missing	2,022	0.9	182	14.6
Fire/explosion	24,928	11.1	101	8.1
Collision	32,208	14.4	118	9.4
Contact	14,133	6.3	15	1.2
Wrecked/stranded	44,341	19.8	0	0
War/hostilities	8,307	3.7	17	1.4
Hull/machinery_machinery	45,765	20.4	52	4.2
Miscellaneous	1,848	0.8	5	0.4
Hull/machinery_structural	36,100	16.1	520	41.6
Hull/machinery_mooring	9,583	4.3	33	2.6
Hull/machinery_unknown	229	0.1	0	0
Missing data	153	0.1	0	0

Table 16 lists the number of serious casualties and total losses, the number of fatalities and the mean number of fatalities per casualty. Casualties that may be attributed to structural failure are Foundered, Missing, and Hull/machinery_structural. Some of these cases may be due to lost stability.

Table 16 Average frequencies of accidents from 1978 to 1998. The serious casualties exclude the total losses.

Accident category, categorised on initial event	Casualty category	Number of casualties	Frequency (per bulk carrier year)	Fatalities	Mean number of fatalities per casualty
All accident categories	Serious casualties	1841	2.5E-02	138	0.075
	Total losses	248	3.4E-03	1111	4.48
Foundered	Serious casualties	3	4.1E-05	0	0
	Total losses	12	1.6E-04	206	17.17
Missing	Serious casualties	0	0.0E+00	0	0
	Total losses	6	8.2E-05	182	30.33
Fire/explosion	Serious casualties	163	2.2E-03	83	0.51
	Total losses	37	5.0E-04	18	0.49
Collision	Serious casualties	334	4.5E-03	1	0.0030
	Total losses	20	2.7E-04	117	5.85

Contact	Serious casualties	168	2.3E-03	15	0.089
	Total losses	4	5.4E-05	0	0
Grounded/stranded	Serious casualties	374	5.1E-03	0	0
	Total losses	47	6.4E-04	0	0
War/hostilities	Serious casualties	25	3.4E-04	3	0.12
	Total losses	19	2.6E-04	14	0.74
Machinery damage	Serious casualties	508	6.9E-03	25	0.049
	Total losses	21	2.9E-04	27	1.29
Miscellaneous	Serious casualties	11	1.5E-04	4	0.36
	Total losses	3	4.1E-05	1	0.33
Hull/machinery_ structural	Serious casualties	204	2.8E-03	6	0.029
	Total losses	61	8.3E-04	514	8.43
Hull/machinery_ mooring	Serious casualties	46	6.3E-04	1	0.022
	Total losses	18	2.4E-04	32	1.78
Hull/machinery_ unknown	Serious casualties	3	4.1E-05	0	0
	Total losses	0	0.0E+00	0	
Missing data	Serious casualties	2	2.7E-05	0	0

Table 17 gives individual risk estimates per year for the time period from 1978 to 1998.

Table 17 Individual risk from 1978 to 1998.

Year	Fleet size	Fatalities	Individual Risk	Year	Fleet size	Fatalities	Individual Risk
1978	2500	77	6.2E-04	1989	3521	9	5.1E-05
1979	2500	60	4.8E-04	1990	3618	47	2.6E-04
1980	2705	140	1.0E-03	1991	3650	137	7.5E-04
1981	2875	163	1.1E-03	1992	3685	0	0.0E+00
1982	3092	5	3.2E-05	1993	3730	19	1.0E-04
1983	3251	50	3.1E-04	1994	3853	89	4.6E-04
1984	3547	16	9.0E-05	1995	4007	89	4.4E-04
1985	3743	11	5.9E-05	1996	4186	51	2.4E-04
1986	3743	1	5.3E-06	1997	4200	82	3.9E-04
1987	3556	67	3.8E-04	1998	4200	93	4.4E-04
1988	3454	43	2.5E-04	1978-1998	73616	1249	3.4E-04

Table 18 gives the number of fatalities as a function of ship age and accident category. The data is applicable for bulk carriers larger than 20,000 DWT in the period from 1980 to 1996, which was selected due to the data available for the fleet distribution on ship age.

Table 18 Number of fatalities as function of age of ship and accident category.

Age of ship	Number of ship years	Collision	Contact	Wrecked/ stranded	War	Misc.	Machinery	Mooring	Structural failure	Fire/ explosion
1	2442	0	0	0	0	0	0	0	0	1
2	2389	0	7	0	0	0	0	0	0	0
3	2492	0	0	0	0	0	27	0	2	0
4	2618	1	0	0	0	0	0	0	44	0
5	2703	0	0	0	0	0	0	1	0	0
6	2814	0	0	0	0	0	0	0	0	5
7	2903	0	0	0	0	0	0	0	32	0
8	3006	0	0	0	0	0	0	0	20	0
9	3116	27	0	0	0	0	0	0	56	1
10	3157	0	0	0	1	0	0	0	0	1
11	3109	0	8	0	1	1	0	0	0	6

12	2995	0	0	0	0	1	0	0	19	0
13	2802	0	0	0	0	0	0	0	29	1
14	2718	1	0	0	0	0	25	0	28	14
15	2590	0	0	0	2	0	0	0	27	2
16	2416	0	0	0	0	0	0	0	30	13
17	2368	0	0	0	7	0	0	0	33	0
18	2244	26	0	0	0	0	0	0	92	4
19	2005	32	0	0	0	0	0	0	0	1
20	1643	0	0	0	0	0	0	0	0	1
21	1345	0	0	0	0	0	0	0	87	0
22	1105	0	0	0	0	0	0	0	0	0
23	863	0	0	0	0	0	0	32	33	2
24	612	0	0	0	0	0	0	0	90	11
25	395	0	0	0	0	0	0	0	0	1

Appendix 2 Quantification of Residual Risk Model Input

The present appendix contains the quantification of the different probabilities included in the Residual Risk model of Section 7.

The annual probability of serious water ingress due to side shell failure is estimated based on 160 events in 73,600 ship years between 1978 and 1998:

$$P_{sideshell} = \frac{160}{73{,}600} = 2.2 \cdot 10^{-3}$$

Hatch cover failure resulted in 20 serious casualties between 1978 and 1998, giving an annual probability of hatch cover failure resulting in serious casualty (including total loss) of:

$$P_{hatchcovers} = \frac{20}{73{,}600} = 2.7 \cdot 10^{-4} \text{ per year}$$

Fore end flooding is recorded in 7 serious casualties in the time period considered, giving an estimated annual probability of fore end flooding resulting in serious casualty (including total loss):

$$P_{foreend} = \frac{7}{73{,}600} = 9.5 \cdot 10^{-5}$$

72 out of 187 serious casualties resulted in total losses, giving an estimate of the conditional probability of escalation, given water ingress and serious casualty:

$$P_{escalation} = \frac{72}{187} = 0.39$$

The probability of escalation may be dependent on the scenario, hence this probability is below estimated for the three different scenarios. For the side shell scenarios there were 62 total losses in 160 serious casualties (including total losses) giving:

$$P_{escalation}^{\text{side shell}} = \frac{62}{160} = 0.39$$

For hatch covers, 9 total losses were recorded in 20 serious casualties (including total losses):

$$P_{escalation}^{\text{hatch cover}} = \frac{9}{20} = 0.45$$

For fore end flooding, 2 total losses were recorded in 7 events:

$$P_{escalation}^{\text{fore end}} = \frac{2}{7} = 0.29$$

Note that the number of losses used to estimate the probabilities of escalation adds up to 73 and not 72. The reason for this is that the one casualty was included in the data sets for both hatch cover failure and fore end flooding since it involved both.

The difference in the probability of escalation is not very large for the three scenarios, and might be explained by statistical uncertainty due to the limited number of observations.

The 72 total losses between 1978 and 1998 resulted in 844 fatalities, giving an average number of fatalities per total loss of:

$$\hat{n}_{TL} = \frac{844}{72} = 11.7$$ fatalities per total loss on average

In 115 serious casaulties due to water ingress (excluding total losses) there were 6 fatalities, giving:

$$\hat{n}_{SC} = \frac{6}{115} = 0.05$$ fatalities per serious casualty (excluding total loss) on average

Appendix 3 Break down of side shell failure casualty data

Figure 1 illustrates the breakdown of the serious casualties on water ingress location, total losses, and fatal accidents.

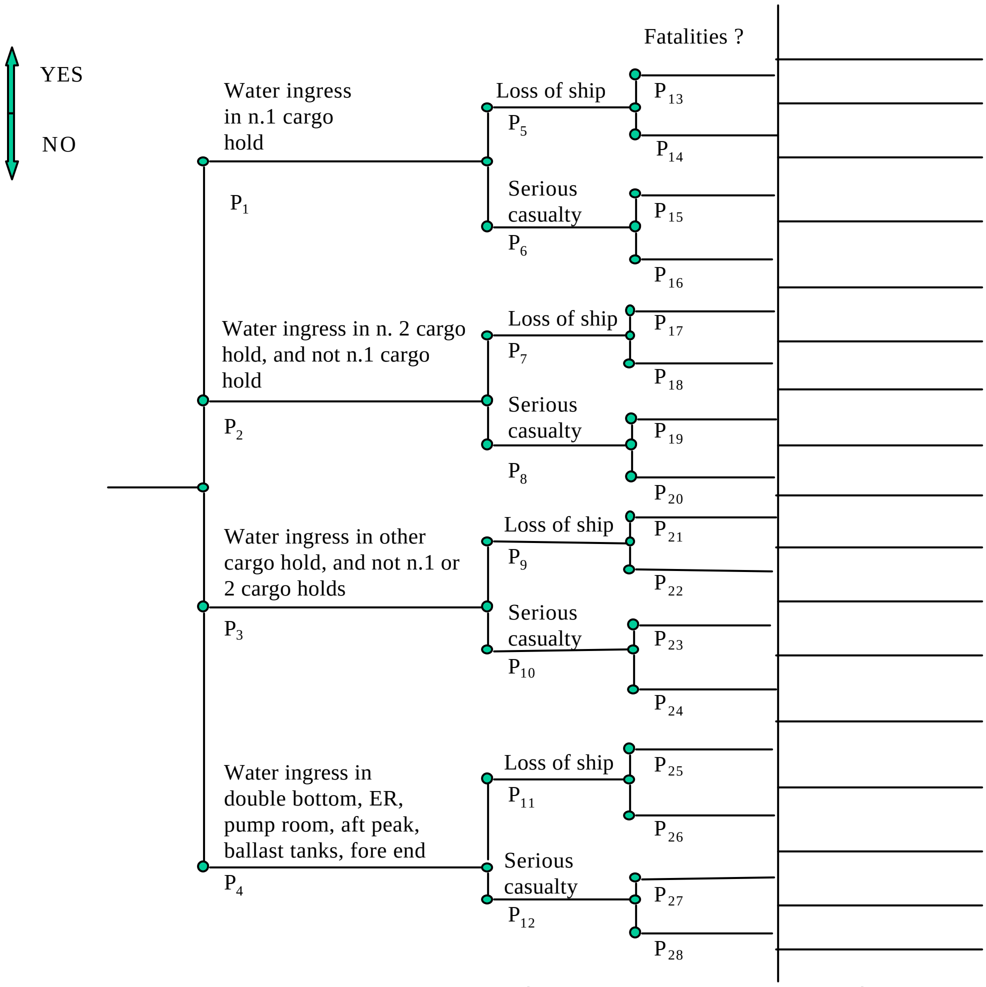

Figure 1 Breakdown of casualties on location of water ingress, and consequences of casualty.

Table 3 shows the results of the investigation on location, severity and fatality in 160 of the reported serious casualties and total losses involving water ingress or possible water ingress. The results were derived from not only LMIS database but also other data sources and experts judgement.

Table 3 Breakdown of casualties due to structural failure on location of water ingress, and consequences of casualty (Bulk carriers larger than 20,000 DWT)

	Serious Casualties excluding total loss			Total Loss			Serious casualties including total loss			Casualty ID (see Tables in Annex 6)
Water ingress location	No. of Casualty	No. of Fatal Case	No. of Fatalities	No. of Casualty	No. of Fatal Case	No. of Fatalities	No. of Casualty	No. of Fatal Case	No. of Fatalities	
n.1 cargo hold	15	1	3	7	3	74	22	4	77	1,2,10,13,16,24,26,31,34,35,48, 49,50,54,55,56,69,71,77,82,83, 86
n.1 and 2 cargo holds	1	0	0	4	1	20	5	1	20	27,38,63,89,95

n.1 and 7 cargo holds	1	0	0	0	0	0	1	0	0	81
n.1, 2 and 3 cargo holds	1	0	0	2	2	30	3	2	30	5,98,100
n.1, 2 ,3and 8 cargo holds	0	0	0	1	0	0	1	0	0	9
n.1 to 6 cargo holds	0	0	0	1	0	0	1	0	0	33
Total n. 1 cargo hold	**18**	**1**	**3**	**15**	**6**	**124**	**33**	**7**	**127**	
n.2 cargo hold	6	0	0	3	0	0	9	0	0	23,47,51,59,75,78,80,84,96
n.2 and 3 cargo holds	1	0	0	1	0	0	2	0	0	12,25
n.2 and 4 cargo holds	0	0	0	1	1	33	1	1	33	22
n.2, 3 and 6 cargo holds	1	0	0	0	0	0	1	0	0	62
Total n. 2 cargo hold	**8**	**0**	**0**	**5**	**1**	**33**	**13**	**1**	**33**	
n.3 cargo hold	3	1	1	2	0	0	5	1	1	14,21,36,79,104
n.4 cargo hold	1	0	0	1	0	0	2	0	0	37,39
n.5 cargo hold	5	0	0	5	3	88	10	3	88	7,15,42,43,61,76,85,92, 101,103
n.6 cargo hold	1	0	0	0	0	0	1	0	0	41
n.7 cargo hold	4	0	0	1	0	0	5	0	0	4,30,46,67,68
n.8 cargo hold	3	0	0	0	0	0	3	0	0	8,18,44
n.4 and 5 cargo holds	0	0	0	1	0	0	1	0	0	87
n.4 and 7 cargo holds	1	0	0	0	0	0	1	0	0	53
n.5 and 6 cargo holds	0	0	0	1	0	0	1	0	0	73
n.3, 4 and 5 cargo holds	0	0	0	1	1	3	1	1	3	58
n.5, 6 and 7 cargo holds	0	0	0	1	0	0	1	0	0	28
n.3, 5, 6 and 7 cargo holds	0	0	0	1	0	0	1	0	0	11
Total other cargo holds	**18**	**1**	**1**	**14**	**4**	**91**	**32**	**5**	**92**	
Unknown cargo holds	**8**	**0**	**0**	**17**	**11**	**281**	**25**	**11**	**281**	3,6,17,19,20,29,32,40,45,52,57, 60,64,65,66,70,72,88,90,91,93,97,102, 105,106
fore end	7	0	0	2	1	6	9	1	6	O12,O15,O23,O30,O31,O35,O36,O42,O53
engine room	18	0	0	5	0	0	23	0	0	O1,O4,O7,O8,O10,O11,O14,O16,O18,O19,O20,O21,O22,O24, O25,O29,O34,O39,O40,O41,O44,O47,O52
pump room	3	0	0	0	0	0	3	0	0	O3,O5,O13
aft peak	2	0	0	0	0	0	2	0	0	O45,O49
fuel oil tanks	2	0	0	0	0	0	2	0	0	O9,O26
ballast tanks	14	0	0	0	0	0	14	0	0	O2,O6,O17,O27,O28, O32,O33,O37,O38,O43,O46,O48,O50,O51
Total water ingress to other spaces	**46**	**0**	**0**	**7**	**1**	**6**	**53**	**1**	**6**	
Suspected water ingress (detail unknown)	**0**	**0**	**0**	**4**	**2**	**33**	**4**	**2**	**33**	74,94,99,107
Total	**98**	**2**	**4**	**62**	**25**	**568**	**160**	**27**	**572**	

Probabilities of Water Ingress by locations

Based on the above table, 103 cases are related to cargo hold flooding and 53 cases are not. The remaining 4 cases suspected water ingress (detail unknown) are considered to be neglected.

The probability of the water ingress being related to n.1 cargo hold is taken as:

$$P_1 = \frac{g}{m} = \frac{33+13+32+25}{160-4} \bullet \frac{33}{33+13+32} = 0.279$$

The probability of the water ingress involving n.2 cargo hold and not n.1 is taken as:

$$P_2 = \frac{g}{m} = \frac{33+13+32+25}{160-4} \bullet \frac{13}{33+13+32} = 0.110$$

The probability of the water ingress involving any other cargo hold, but not n.1 or n.2 is taken as:

$$P_3 = \frac{g}{m} = \frac{33+13+32+25}{160-4} \bullet \frac{32}{33+13+32} = 0.271$$

Finally, the probability that the water ingress occurred in other spaces is estimated as:

$$P_4 = \frac{g}{m} = \frac{53}{160-4} = 0.340$$

Probabilities of total loss or serious casualty

Given water ingress in n.1 cargo hold, the probability of total loss is, based on historical data, estimated as:

$$P_5 = \frac{g}{m} = \frac{15}{33} = 0.455$$

The probability of serious casualty, given water ingress in n.1 cargo hold is estimated to:

$$P_6 = \frac{g}{m} = \frac{33-15}{33} = 0.545$$

For water ingress in n.2 cargo hold and not n.1, the probabilities of total loss based on the casualty data are estimated to:

$$P_7 = \frac{g}{m} = \frac{5}{13} = 0.385$$

Consequently, the probabilities of serious casualty given water ingress in n.2 cargo hold and not n.1 is estimated to:

$$P_8 = \frac{g}{m} = \frac{13-5}{13} = 0.615$$

For water ingress in other cargo holds and not n.1 or 2, the probability of total loss based on the casualty data are estimated to:

$$P_9 = \frac{g}{m} = \frac{14}{32} = 0.438$$

Consequently, the probability of serious casualty given water ingress in n.2 cargo hold and not n.1 is estimated to:

$$P_{10} = \frac{g}{m} = \frac{32-14}{32} = 0.562$$

For water ingress in other spaces, the probability of total loss based on the casualty data is estimated to:

$$P_{11} = \frac{g}{m} = \frac{7}{53} = 0.132$$

Consequently, the probability of serious casualty water ingress in other spaces and not in n. 1 or 2 cargo hold is estimated to:

$$P_{12} = \frac{g}{m} = \frac{53-7}{53} = 0.868$$

The introduction of SOLAS Chapter XII is estimated to reduce the probability of escalation, and hence total loss, given flooding of no. 1 cargo hold by 10% for existing ships, whereas the other probabilities of escalation will be unaffected. Thus, for existing ships:

$$P_5^{\text{Existingships}} = (1-r_{SOLASXII})P_5 = (1-0.1)\cdot 0.455 = 0.41$$

$$P_6^{\text{Existingships}} = \left(1-P_5^{\text{Existingships}}\right) = 0.59$$

$$P_7^{\text{Existingships}} = P_7 = \frac{g}{m} = \frac{5}{13} = 0.385$$

$$P_8^{\text{Existingships}} = P_8 = \frac{g}{m} = \frac{13-5}{13} = 0.615$$

$$P_9^{\text{Existingships}} = P_9 = \frac{g}{m} = \frac{14}{32} = 0.438$$

$$P_{10}^{\text{Existingships}} = P_{10} = \frac{g}{m} = \frac{32-14}{32} = 0.562$$

$$P_{11}^{\text{Existingships}} = P_{11} = \frac{g}{m} = \frac{7}{53} = 0.132$$

$$P_{12}^{\text{Existingships}} = P_{12} = \frac{g}{m} = \frac{53-7}{53} = 0.868$$

For new ships, SOLAS Chapter XII has been estimated to reduce the probability of escalation by 69%, independently of cargo hold flooded:

$$P_5^{\text{New-buildings}} = (1-r_{SOLASXII})P_5 = (1-0.69)\cdot 0.455 = 0.14$$

$$P_6^{\text{New-buildings}} = 1-P_5^{\text{New-buildings}} = 1-0.14 = 0.0.86$$

$$P_7^{\text{New-buildings}} = (1-r_{SOLASXII})P_7 = (1-0.69)\cdot 0.385 = 0.12$$

$$P_8^{\text{New-buildings}} = 1-P_7^{\text{New-buildings}} = 1-0.12 = 0.88$$

$$P_9^{\text{New-buildings}} = (1-r_{SOLASXII})P_9 = (1-0.69)\cdot 0.438 = 0.14$$

$$P_{10}^{\text{New-buildings}} = 1-P_9^{\text{New-buildings}} = 1-0.14 = 0.86$$

$$P_{11}^{\text{New-building}} = P_{11} = \frac{g}{m} = \frac{7}{53} = 0.132$$

$$P_{12}^{\text{New-building}} = P_{12} = \frac{g}{m} = \frac{53-7}{53} = 0.868$$

Probability of fatal cases

In total, there are 62 total losses and 98 serious casualties where the location of the water ingress is given in Table 3.

There were 6 reported fatal accidents among the total losses reported involving n. 1 cargo hold, involving 124 fatalities in total. The probability of fatal accident given total loss due to water ingress in n.1 cargo hold is estimated as:

$$P_{13} = \frac{g}{m} = \frac{6}{15} = 0.400$$

The probability of non-fatal accident given total loss due to water ingress in n.1 cargo is estimated to:

$$P_{14} = \frac{g}{m} = \frac{15-6}{15} = 0.600$$

Among the serious casualties due to water ingress in n. 1 cargo hold, there were 1 fatal accident involving 3 fatalities, and 17 casualties with no fatalities giving:

$$P_{15} = \frac{g}{m} = \frac{1}{1+17} = 0.056$$

$$P_{16} = \frac{g}{m} = \frac{17}{1+17} = 0.944$$

Related to n. 2 cargo hold, there was no recorded fatal accident involving fatalities among the serious casualties and one fatal accident involving 33 fatalities among the total losses. This gives the following probability estimates:

$$P_{17} = \frac{g}{m} = \frac{1}{5} = 0.20$$

$$P_{18} = \frac{g}{m} = \frac{5-1}{5} = 0.80$$

$$P_{19} = \frac{g}{m} = \frac{0}{8} = 0$$

$$P_{20} = \frac{g}{m} = \frac{8}{8} = 1.0$$

For water ingress in other cargo holds than n. 1 or 2, there were recorded 4 fatal accidents in 14 total losses giving 91 fatalities in total, and 1 fatal accident in 18 serious casualties, involving 1 fatality. Hence the probability estimates are:

$$P_{21} = \frac{g}{m} = \frac{4}{14} = 0.286$$

$$P_{22} = \frac{g}{m} = \frac{14-4}{14} = 0.714$$

$$P_{23} = \frac{g}{m} = \frac{1}{18} = 0.056$$

$$P_{24} = \frac{g}{m} = \frac{18-1}{18} = 0.944$$

Water ingress in other spaces led to one fatal accident among the 7 total losses, involving 6 fatalities, and none among 46 serious casualties. The probability estimates are:

$$P_{25} = \frac{g}{m} = \frac{1}{7} = 0.143$$

$$P_{26} = \frac{g}{m} = \frac{7-1}{7} = 0.857$$

$$P_{27} = \frac{g}{m} = \frac{0}{46} = 0.0$$

$$P_{28} = \frac{g}{m} = \frac{46}{46} = 1.0$$

Quantification of Frequency

Estimation of PLLs

In 25 cases, there are reports involving 281 fatalities where the location of water ingress is not logged. The distribution is shown in Table 3.

In the following investigation, it is assumed that the number of fatalities where water ingress location is unknown could be distributed to those of n.1 cargo hold, n.2 cargo hold and other cargo hold according to their ratio of the numbers of fatal cases in total loss, 6:1:4.

Then number of fatalities where water ingress location is in n.1 cargo hold is estimated as follows:

$$n_{est} = 124 + \frac{6}{6+1+4} \times 281 = 124 + \frac{6}{11} \times 281 \approx 277$$

Number of fatalities where water ingress location is in n.2 cargo hold is estimated as follows:

$$n_{est} = 33 + \frac{1}{6+1+4} \times 281 = 33 + \frac{1}{11} \times 281 \approx 59$$

Number of fatalities where water ingress location is in other cargo holds is estimated as follows:

$$n_{est} = 91 + \frac{4}{6+1+4} \times 281 = 91 + \frac{4}{11} \times 281 \approx 193$$

The summary of the estimation is shown in Table 4.

Table 4 Summary Table of number of fatalities and estimated number of fatalities on location of water ingress, and consequence of casualty due to structural failure

water ingress location	Number of fatalities		
	Serious casualties excluding total loss	Total losses	
		Reported	Estimated
n. 1 cargo hold	3	124	277
n. 2 cargo hold	0	33	59
other cargo holds	1	91	193
unknown hold	0	281	N.A.
other spaces	0	6	6
possible water ingress (no detail)	0	33	33
Total	4	568	568

Taking into consideration the above assumption, PLLs are estimated as shown in the following Table 5.

Table 5 PLL distributed on location of water ingress, and consequence of casualty due to structural failure

water ingress location	Serious casualties excluding total loss		Total loss	
	Number of fatalities (Reported)	PLL	Estimated number of fatalities	PLL
n. 1 cargo hold	3	$4.1 \cdot 10^{-5}$	277	$3.8 \cdot 10^{-3}$

n. 2 cargo hold	0	0	59	$8.0 \cdot 10^{-4}$
other cargo holds	1	$1.4 \cdot 10^{-5}$	193	$2.6 \cdot 10^{-3}$
other spaces	0	0	6	$8.2 \cdot 10^{-5}$
Total	4	$5.4 \cdot 10^{-5}$	535	$7.3 \cdot 10^{-3}$

Putting probabilities and PLL obtained in the above into the tree of Figure 1, the event tree of Figure 3 is given.

After all, in total, number of serious casualties excluding total loss is 98, number of total loss is 62 and number of fatalities is 572.

The base risk contribution from structural failure such as side shell failure as deduced from historical data hence is estimated to:

$$PLL_{\text{structural\_failure\_(side\_shell)}} = \frac{572}{73600} = 7.8 \cdot 10^{-3} \text{ fatalities per ship year}$$

According to the table 9 in Annex 2 of MSC74/INF.X submitted by IACS (IACS, 2001), the loss matrix for generic bulk carrier accidents was proposed. Here, a generic serious casualty is estimated to cost US$ 5,608,000, and a total loss US$ 24,808,000. If these cost estimates are combined with the frequencies for total loss and serious casualty, the maximum risk contribution from serious casualties and total losses due to failure of hatch covers is estimated as:

$$EL_{\text{water ingress}} = \frac{62}{73,600} \cdot 24,808,000 + \frac{98}{73,600} \cdot 5,608,000 \approx USD\,28,400 \text{ per ship year}$$

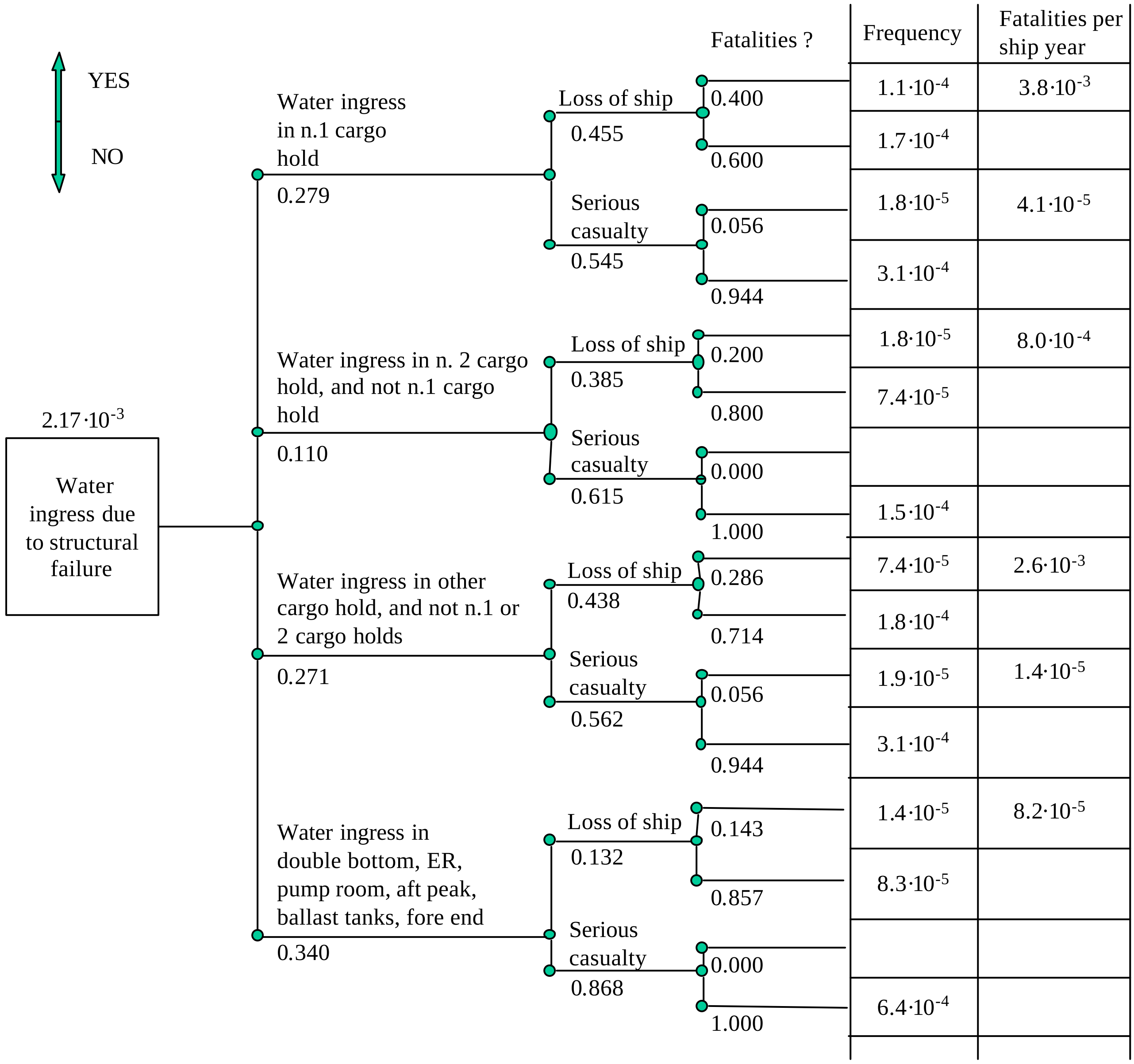

Figure 3 Quantified breakdown of casualty data on water ingress location, loss of ship versus serious casualty, and whether the accidents involved fatalities.

Appendix 4 Break-down of Hatch Cover Casualty Data

Below the hatch cover casualty data are further investigated, in order detect trends and to attribute the casualties to different circumstances.

The tree below illustrates the breakdown of 20 serious casualties on water ingress location, total losses, and fatal accidents.

When trying to quantify the different branches of the tree, in many cases there are only 1 or perhaps 0 observations. This is of course not sufficient to make any reliable estimates for the different branch probabilities. The results from the tree is mainly used to estimate the risk contribution from no. 1 and 2 hatch covers, and this is also the branches to which the majority of the cases relate.

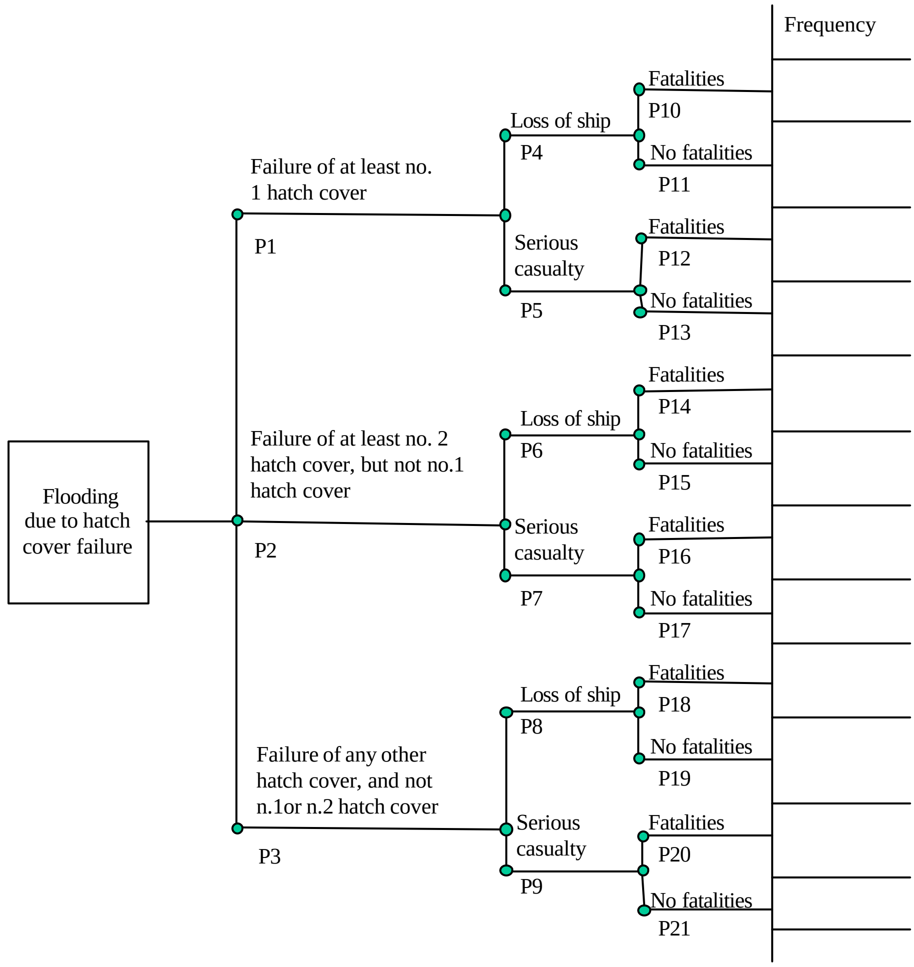

Figure 27 Breakdown of casualties on location of failed hatch cover, and consequences of casualty.

Frequency of flooding due to hatch cover failure

In the LMIS casualty database, for bulk carriers of 20,000 DWT and larger, 20 cases were found involving failure of hatch cover and water ingress. In 19 of the cases, water ingress was reported, while one case probably involved water ingress although not specified. An estimate of the frequency of serious casualty involving water ingress due to hatch cover failure hence is given as:

$f_1 = \frac{g}{m} = \frac{20}{73{,}600} = 2.7 \cdot 10^{-4}$ annual frequency of serious casualty or total loss involving water ingress due to hatch cover failure.

Location of water ingress

In 13 of the 20 serious casualties and total losses involving water ingress and hatch cover failure events, the location for the water ingress is given. The results are shown in the below table.

Table 19 Number of casualties split on reported location of water ingress

Location of water ingress	Number of occurrences	% of total
no. 1 cargo hold	7	54
n. 1 and 2 cargo holds	3	23
n. 2 cargo hold	1	7.7
n. 2 and 7 cargo holds	1	7.7
n. 4 cargo hold	1	7.7
Total reported	13	100
unknown cases	7	
Total	20	

Based on the above table, the probability of the water ingress being related to no. 1 cargo hold is taken as:

$$P_1 = \frac{g}{m} = \frac{7+3}{13} = 0.77$$

The probability of the water ingress involving n.2 cargo hold and not no. 1 is taken as:

$$P_2 = \frac{g}{m} = \frac{1+1}{13} = 0.15$$

Finally, the probability of the water ingress involving any other cargo hold, but not no. 1 or n.2 is taken as:

$$P_3 = \frac{g}{m} = \frac{1}{13} = 0.08$$

Probability of total loss given water ingress location

Out of the 13 cases where the location of the water ingress was recorded, 5 were total losses while 8 were serious casualties. The table below gives the distribution between total losses and serious casualties.

Table 20 Number of casualties split on serious casualties and total losses.

Location of water ingress	Serious casualties	Total losses
no. 1 cargo hold	3	4
n. 1 and 2 cargo holds	2	1

n. 2 cargo hold	1	0
n. 2 and 7 cargo holds	1	0
n. 4 cargo hold	1	0
Total known cases	**8**	**5**
Unknown	4	3
Total	**12**	**8**

Given water ingress in no. 1 cargo hold, the probability of total loss is taken as:

$$P_4 = \frac{g}{m} = \frac{4+1}{3+2+4+1} = 0.5$$

Based on the information extracted, it also seems that all the total losses may be attributed to water ingress in no. 1 cargo hold.

The probability of serious casualty, given water ingress in no. 1 cargo hold is estimated to:

$$P_5 = \frac{g}{m} = \frac{3+2}{3+2+4+1} = 0.5$$

For water ingress in other cargo holds than no. 1, the probabilities of total loss based on the casualty data are estimated to:

$$P_6 = P_8 = \frac{g}{m} = \frac{0}{1} = 0$$

Consequently, the probabilities of serious casualty given water ingress in other cargo holds than no. 1 are estimated to:

$$P_7 = P_9 = \frac{g}{m} = \frac{1}{1} = 1$$

Probability of fatalities given water ingress location and casualty severity

In total, there are 8 total losses among the identified relevant cases. 7 of the identified hatch cover and water ingress casualties involved fatalities. In 6 of these cases, the location of the water ingress was recorded. Table 12 below gives the distribution of fatal and non-fatal casualties.

Table 21 Number of fatalities split on serious casualties and total losses

Location of water ingress	Number of fatal accidents among the serious casualties	Number of fatal accidents among the total losses
n. 1 cargo hold	0	4
n. 1 and 2 cargo holds	0	1
n. 2 cargo hold	1	0
n. 2 and 7 cargo holds	0	0
n. 4 cargo hold	0	0
Unknown	0	1
Total	1	6

If assuming that the remaining accident, which is the sixth fatal accident with no details regarding water ingress location, involved flooding of no. 1 cargo hold, the probability of fatal accident given total loss due to water ingress in no. 1 cargo hold caused by hatch cover failure is to:

$$P_{10} = \frac{g}{m} = \frac{6}{8} = 0.75$$

It is also assumed that the 2 remaining total losses with no information about water ingress location follow the pattern of the 5 reported cases, hence involving water ingress in no. 1 cargo hold. In total there were 227 fatalities in the 6 total losses involving fatalities.

The probability of non-fatal accident given total loss due to water ingress in no. 1 cargo is estimated to:

$$P_{11} = \frac{g}{m} = \frac{2}{8} = 0.25$$

One of the serious casualties related to no. 2 cargo hold involved 2 crew members being swept over board, and the probability of fatal accident given serious casualty due to water ingress in no. 2 cargo hold is estimated to:

$$P_{16} = \frac{g}{m} = \frac{1}{2} = 0.5$$

Similarly, the probability of non-fatal accident given serious casualty due to water ingress in n.2 cargo hold is estimated to:

$$P_{17} = \frac{g}{m} = \frac{1}{2} = 0.5$$

For the remaining scenarios, no fatal accidents are recorded giving:

$$P_{12} = P_{14} = P_{18} = P_{20} = 0$$

and

$$P_{13} = P_{15} = P_{19} = P_{21} = 1$$

The above estimates based on very few or no observations are obviously encumbered with large uncertainties. However, this does not influence on the evaluations of the risk control options, since these are directed at no. 1 and 2 hatch covers, and the majority of the cases may be related to no. 1 hatch cover.

Appendix 5 Estimation of Risk Reduction Rate of ESP

In order to estimate risk reduction rate of Enhance Survey Program (ESP), historical casualty data were revisited. Table 22 shows the number of bulk carrier by year and number of serious casualties. Considering the ESP is preventive risk control option against side shell failure, the effectiveness is assumed to be judged by the risk reduction rate of ESP by number of serious casualties.

ESP was introduced at 1st July 1993 and several class societies introduced it earlier than that date.

As shown in Table 22, casualty rate after 1994 is 0.00108 (number of serious casualties / ship year) while that before 1993 is 0.0016 (number of serious casualties / ship year). An estimate of the risk reduction rate by ESP r_{ESP} was calculated using these two figures as follow.

$$r_{ESP} = \frac{0.0016 - 0.00108}{0.0016} = 0.325$$

ESP can not cover all of 187 serious casualties under consideration. It is assumed that ESP can cover 107 serious casualties related to hold flooding due to structural failure such as side shell failure. Hence, risk reduction rate r_{ESP}^{all} to all casualties under consideration by ESP is calculated as follows.

$$r_{ESP}^{all} = r_{ESP} \times \frac{107}{187} = 0.325 \times \frac{107}{187} \approx 0.19$$

Table 22 Rough estimation of ESP-effectiveness

Year	Fleet Number of Bulk Carriers	No. of serious casualties related hold flooding due to structural failure
1978	2500	1
1979	2500	3
1980	2705	8
1981	2875	2
1982	3092	2
1983	3251	1
1984	3547	5
1985	3743	5
1986	3743	1
1987	3556	7
1988	3454	3
1989	3521	10
1990	3618	14
1991	3650	16
1992	3685	2
1993	3730	5
Sub total	**53170**	**85**
Casualty rate 1978-1993 (per ship-year)		**0.00160**
1994	3853	8
1995	4007	2
1996	4186	4
1997	4200	3
1998	4200	5
Sub total	**20446**	**22**
Casualty rate 1994-1998 (per ship-year)		**0.00108**
Effectiveness of ESP based on casualty rate (reduction rate of serious casualty)		**33%**
Total No. of serious casualties related hold flooding due to structural failure		107
Total No. of all serious casualties related water ingress		187
Percentage of ESP related		**57%**
Effectiveness of ESP in general		**19%**

*ESP came into effect by IACS/UR: 1993/7/1