ANNEX 5 Risk Analysis

1 Method of Risk Analysis

In order to obtain statistical and quantified risk data, risk analysis was conducted through the following process:

1) Investigate bulk carrier world fleet statistics by year and each ship-size;
2) Analyze historical data such as LMIS casualty database;
3) Establish risk contribution diagrams such as Event Tree, Fault Tree, etc., based upon the casualty data; and
4) Estimate and evaluate risk of bulk carrier by each accident category for each ship size.

Taking the background information and the result of hazard identification meetings into consideration, accidents under concern are segmented into the following 4 accident scenario groups:

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

In analyzing the historical casualty data, they were grouped into 4 groups by ship-size: i.e. *Cape-size* bulk carrier, *Panamax* bulk carrier, *Handy-size* bulk carrier and *Small-handy* bulk carrier. The classification of each bulk carrier group is referred to Table 3.3.1and Table 3.3.2 in MSC75/5/2 ANNEX. Furthermore, the risks of bulk carrier were calculated in the following 2 stages of risk analysis:

1) Assuming that recently introduced measures such as ESP, SOLAS Chapter XII, etc. have little effected the past casualty data, the risk level, before these measures were introduced, was estimated at the 1st stage of analysis.
2) Examining the potential effect of these measures to each accident case, the historical data was simulated, as if sufficient years have passed after these measures came into effect, and imaginary risk levels, supposed to be improved by these measures, were estimated.

2 Estimation of Risk Levels before the Introduction of these Risk Control Measures

2.1 Results of Historical Data Analysis

2.1.1 Investigation of Casualties by Accident Scenario and Ship Type

Table 2.1 summarizes the number of casualties by accident group and ship type. The lists of casualties in each accident groups are attached as Appendix 1.

In the historical data, there are some total loss casualties, which are not clearly specified with any involvement of flooding or water ingress. However, the experts in the working group judged some of them to group into “Accident group-1: hold flooding due to structural failure”, taking the following factors into consideration.

- ✓ Age of ship at the time of casualty
- ✓ Density of the cargo which was loaded at the time of casualty

However, in spite of applying the above-mentioned expert judgment as a rule, there are 6 casualties that should be left in "Accident group-2: presumed water ingress (detail unknown)".

Table 2.1 Number of casualties by accident group and ship type

Scenario		Accident group	Number of casualties					Note (See Appendix 1)
			Cape-size	Pana-max	Handy-size	Small-handy	*Sum*	
1	-1	1. Flooding into cargo holds due to structural failure	25 (13)	21 (15)	67 (28)	33 (21)	*146 (77)*	Table B1 of Annex 3
		2. Presumed water ingress (detail unknown)	0 (0)	0 (0)	1 (1)	5 (5)	*6 (6)*	
		(Sub-total)	*25 (13)*	*21 (15)*	*68 (29)*	*38 (26)*	*152 (83)*	
		3. Flooding into other compartments due to structural failure	7 (1)	8 (0)	32 (6)	9 (5)	56 (12)	Table B2 of Annex 3
		(Total for Scenario-1-1)	***32 (14)***	***29 (15)***	***100 (35)***	***47 (31)***	***208 (95)***	
	-2	4. Flooding into Fore Peak due to failure of deck fittings, etc.	1 (1)	2 (0)	5 (0)	1 (0)	*9 (1)*	Table B4 of Annex 3
	-3	5. Water ingress due to hatch covers failure or their securing failure	4 (0)	1 (1)	14 (7)	1 (0)	*20 (8)*	
		(Total for Scenarios-1-2 and -1-3)	***5 (1)***	***3 (1)***	***19 (7)***	***2 (0)***	***29 (9)***	
		(Total for Scenario-1-1 to -1-3)	***37 (15)***	***32 (16)***	***119 (42)***	***49 (31)***	***237 (104)***	
2		6. Structural failure without water ingress in heavy weather	20 (2)	8 (0)	17 (0)	7 (1)	*52 (3)*	Table B3 of Annex 3
3		7. Structural failure during loading operation	2 (1)	2 (1)	5 (0)	3 (1)	*12 (3)*	Table B6 of Annex 3
4		8. Accident due to cargo shift at sea	0 (0)	0 (0)	8 (2)	11 (5)	*19 (7)*	Table B5 of Annex 3
none		9. Water ingress in moderate sea condition or through piping; then, excluded from the study	4 (0)	11 (2)	13 (2)	12 (4)	*40 (8)*	Table B6 of Annex 3
		Total	***63 (18)***	***53 (19)***	***162 (46)***	***82 (42)***	***360 (125)***	

Note: Figures in parenthesis show number of total loss included.

According to the analysis summarized in Table 2.1 above, the following findings are achieved.

1) On Each Accident Scenario:
- ✓ 208 casualties are found in "Scenario-1-1: Flooding due to hull structural failure such as side shell failure" and about half of them (95 casualties) are resulted in total loss;
- ✓ On the other hand, 52 casualties in "Scenario-2: Structural failure without water ingress in heavy weather" indicate that even if hull structure is damaged in heavy weather, ships can survive unless being flooded;
- ✓ As for "Scenario-3: Structural failure during loading operation" and "Scenario-4: Accident due to cargo shift at sea", the probabilities of accidents are relatively low in comparison with other accident scenarios; and
- ✓ In spite of clear statement of water ingress in 40 casualties in "Accident group-9: Water ingress in moderate sea condition or through piping", the experts in the working group judged that it is reasonable to exclude the type of accident from the scope of this study, because of their causes and sequences.

2) On *Small-handy* Bulk Carrier:
- ✓ The total loss ratio of *Small-handy* bulk carrier group is about 34% of all total losses. This percentage seems relatively high in comparison with its fleet ratio of 22%; and

- ✓ The *Small-handy* group result in high total loss ratio in every scenario except "Scenario-2: Structural failure without water ingress in heavy weather", which resulted in no total loss casualty.

3) On *Cape-size* Bulk Carrier:
   - ✓ The total loss ratio of *Cape-size* bulk carrier group is about 14% of all total losses. This percentage seems relatively high in comparison with its fleet ratio of 8.8%; and
   - ✓ Although the casualty ratio on "Scenario-2: Structural failure without water ingress in heavy weather" of *Cape-size* bulk carrier group also shows high figure of about 38% of all casualties, only 2 total loss cases (eventual broken up and scuttle) were reported.

Even excluding "Accident groups –2: Presumed water ingress (detail unknown)" from "Scenario-1", total 231 casualties are relating to eventual flooding. An estimate of the frequency of casualty hence is given as:

$$f = \frac{g}{m} = \frac{231}{89,900} = 2.57 \cdot 10^{-3}$$ annual frequency of casualty including total loss involving water ingress

With adding **6** casualties in "Accident group-2: Presumed water ingress (detail unknown)", 237 casualties including total loss were found as upper side frequency. An estimate of the upper side frequency of casualty hence is given as:

$$f_{upper} = \frac{g}{m} = \frac{237}{89,900} = 2.64 \cdot 10^{-3}$$ annual frequency of casualty including total loss involving water ingress

As there is not any significant difference between these two figures, we assume that casualties in "Accident group-2" could be categorized into "Scenario-1-1" as shown in Table 2.1.

2.1.2 Investigation of Fatalities by Accident Scenario and Ship Type

Table 2.2 and Table 2.3 summarize the number of fatal cases by accident group and ship type, and the number of fatalities by accident group and ship type, respectively. Lists of casualties in each accident group are also attached as Appendix 1. Figures 2.1 and 2.2 are the F-N Curves of bulk carrier and PLL (Potential Loss of Life) of bulk carrier respectively. In these figures, "All BC & All casualties" comprises all accident groups in Table 2.3 and all other casualties, which are basically excluded from this study, such as fire, collision, etc, derived from LMIS database.

According to the analysis summarized in Table 2.2, Table 2.3, Figure 2.1 and Figure 2.2, the following findings are achieved.

1) From Table 2.2 (in relation with Table 2.1 in the paragraph 2.1.1):
   - ✓ It is found that 40% of all total loss cases in Table 2.1 is resulted in fatal cases (50 fatal cases to 125 total loss cases);
   - ✓ As for "Scenario-1: progressive flooding after the following initial failures/flooding", about 42% of total loss cases in Table 2.1 is resulted in fatal cases (44 fatal cases to 104 total loss cases);
   - ✓ As for "Scenario-1-1", about 39% of total loss cases in Table 2.1 is resulted in fatal cases (37 fatal cases to 95 total loss cases);
   - ✓ Therefore, as a whole, it is found that around 40 % of total loss cases are resulted in fatal cases; and
   - ✓ Although there is no particular difference of fatal case ratio among ship size, *Handy-size* shows slightly higher fatal case ratio. According to this historical data analysis, this is contributed by

the high fatal case ratio in "Scenario 1-3: water ingress due to hatch covers failure or their securing failure" (5 fatal loss cases to 7 total loss cases).

2) From Table 2.3:
- ✓ As for cause of accidents, it is found that about 92% of these fatalities relate to "Scenario-1: progressive flooding after the following initial failures/flooding" and that about 76% of them are in "Scenario-1-1: structural failure such as side shell failure";
- ✓ As for ship type, about 73% of these fatalities in "Scenario-1" are of *Handy-size* and *Small-handy* bulk carrier groups;
- ✓ As for fatalities due to scenarios other than "Scenaio-1" (8 % of total fatalities), more than half of them are relating to "Scenario-4: accident due to cargo shift at sea" and are concentrated into accidents of *Handy-size* and *Small-handy* bulk carrier groups; and
- ✓ Therefore, it could be concluded that the most important accident scenario to fatal casualty of bulk carriers would be "Scenario-1" in which total 1,031 fatalities are counted.

3) From Figure 2.1 & Figure 2.2:
- ✓ PLL of "All BC", which relates to structural failure, is lower than PLL of "All BC & All Casualties"; and
- ✓ *Cape-size* and *Small-handy* bulk carrier groups indicate relatively high PLL. This tendency can be seen in Figure 2.1 F-N Curves of bulk carrier.

Then, the maximum base risk contribution PLL of "Scenario-1", from the water ingress scenarios as deduced from historical data hence, is estimated to:

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

Table 2.2 Number of fatal cases by accident group and ship type

Scenario		Accident group	Number of casualties					Note (See Appendix 1)
			Cape-size	Pana-max	Handy-size	Small-handy	*Sum*	
1	-1	1. Flooding into cargo holds due to structural failure	5 (5)	4 (4)	15 (13)	9 (9)	*33 (31)*	Table B1 of Annex 3
		2. Presumed water ingress (detail unknown)	0 (0)	0 (0)	1 (1)	2 (2)	*3 (3)*	
		(Sub-total)	*5 (5)*	*4 (4)*	*16 (14)*	*11 (11)*	*36 (34)*	
		3. Flooding into other compartments due to structural failure	0 (0)	0 (0)	1 (1)	2 (2)	3 (3)	Table B2 of Annex 3
		(Total for Scenario-1-1)	***5 (5)***	***4 (4)***	***17 (15)***	***13 (13)***	***39 (37)***	
	-2	4. Flooding into Fore Peak due to failure of deck fittings, etc.	1 (1)	0 (0)	0 (0)	0 (0)	*1 (1)*	Table B4 of Annex 3
	-3	5. Water ingress due to hatch covers failure or their securing failure	0 (0)	1 (1)	6 (5)	0 (0)	*7 (6)*	
		(Total for Scenarios-1-2 and -1-3)	***1 (1)***	***1 (1)***	***6 (5)***	***0 (0)***	***8 (7)***	
		(Total for Scenario-1-1 to -1-3)	***6 (6)***	***5 (5)***	***23 (20)***	***13 (13)***	***47 (44)***	
2		6. Structural failure without water ingress in heavy weather	0 (0)	0 (0)	0 (0)	0 (0)	*0 (0)*	Table B3 of Annex 3
3		7. Structural failure during loading operation	0 (0)	0 (0)	0 (0)	0 (0)	*0 (0)*	Table B6 of Annex 3
4		8. Accident due to cargo shift at sea	0 (0)	0 (0)	1 (1)	2 (2)	*3 (3)*	Table B5 of Annex 3
none		9. Water ingress in moderate sea condition or through piping; then, excluded from the study	0 (0)	1 (1)	1 (1)	1 (1)	*3 (3)*	Table B6 of Annex 3
Total			***6 (6)***	***6 (6)***	***25 (22)***	***16 (16)***	***53 (50)***	

Note: Figures in parenthesis show number of total loss included.

Figure 2.3 Number of fatalities by accident group and ship type

Scenario		Accident group	Number of fatalities: Cape-size	Panamax	Handy-size	Small-handy	*Sum*	Note
1	-1	1. Flooding into cargo holds due to structural failure	130 (130)	89 (89)	261 (257)	211 (211)	*691 (687)*	Table B1 of Annex 3
		2. Presumed water ingress (detail unknown)	0 (0)	0 (0)	6 (6)	51 (51)	*57 (57)*	
		(Sub-total)	*130 (130)*	*89 (89)*	*267 (263)*	*262 (262)*	*748 (744)*	
		3. Flooding into other compartments due to structural failure	0 (0)	0 (0)	6 (6)	31 (31)	*37 (37)*	Table B2 of Annex 3
		(Total for Scenario-1-1)	***130 (130)***	***89 (89)***	***273 (269)***	***293 (293)***	***785 (781)***	
	-2	4. Flooding into Fore Peak due to failure of deck fittings, etc.	44 (44)	0 (0)	0 (0)	0 (0)	*44 (44)*	Table B4 of Annex 3
	-3	5. Water Ingress due to hatch covers failure or their securing failure	0 (0)	17 (17)	185 (183)	0 (0)	*202 (200)*	
		(Total for Scenarios-1-2 and -1-3)	***44 (44)***	***17 (17)***	***185 (183)***	***0 (0)***	***246 (244)***	
		(Total for Scenario-1-1 to -1-3)	***174 (174)***	***106 (106)***	***458 (452)***	***293 (293)***	***1,031 (1,025)***	
2		6. Structural failure without water ingress in heavy weather	0 (0)	0 (0)	0 (0)	0 (0)	*0 (0)*	Table B3 of Annex 3
3		7. Structural failure during loading operation	0 (0)	0 (0)	0 (0)	0 (0)	*0 (0)*	Table B6 of Annex 3
4		8. Accident due to cargo shift at sea	0 (0)	0 (0)	20 (20)	34 (34)	*54 (54)*	Table B5 of Annex 3
none		9. Water ingress in moderate sea condition or through piping; then, excluded from the study	0 (0)	4 (4)	32 (32)	5 (5)	*41 (41)*	Table B6 of Annex 3
Total			***174 (174)***	***110 (110)***	***510 (504)***	***332 (332)***	***1,126 (1,120)***	

Note: Figures in parenthesis show number of fatalities in case of total loss of ship.

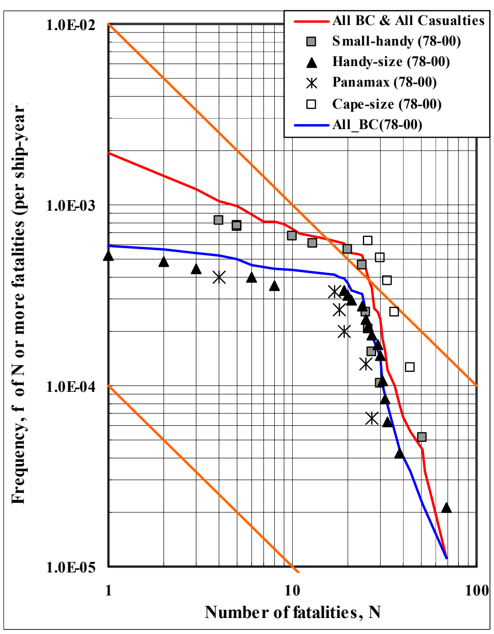


Figure 2.1 F-N curves of bulk carrier

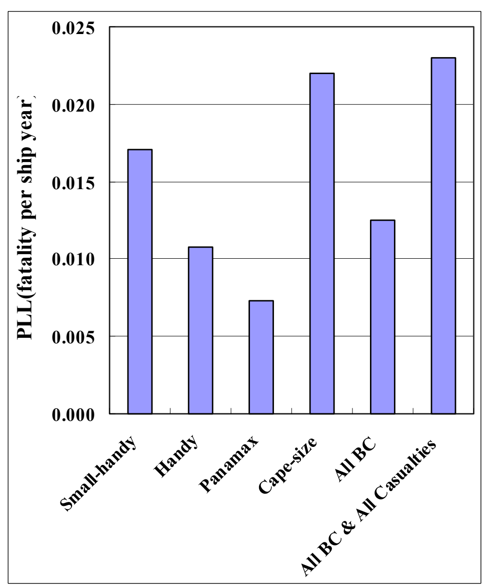


Figure 2.2 PLL of bulk carrier

2.2 Risk Contribution Tree

2.2.1 Event Tree derived from Historical Data

As a result of the investigation of historical data, typical accident sequences or link of events, which caused serious casualties concerned, are focused on as follows:

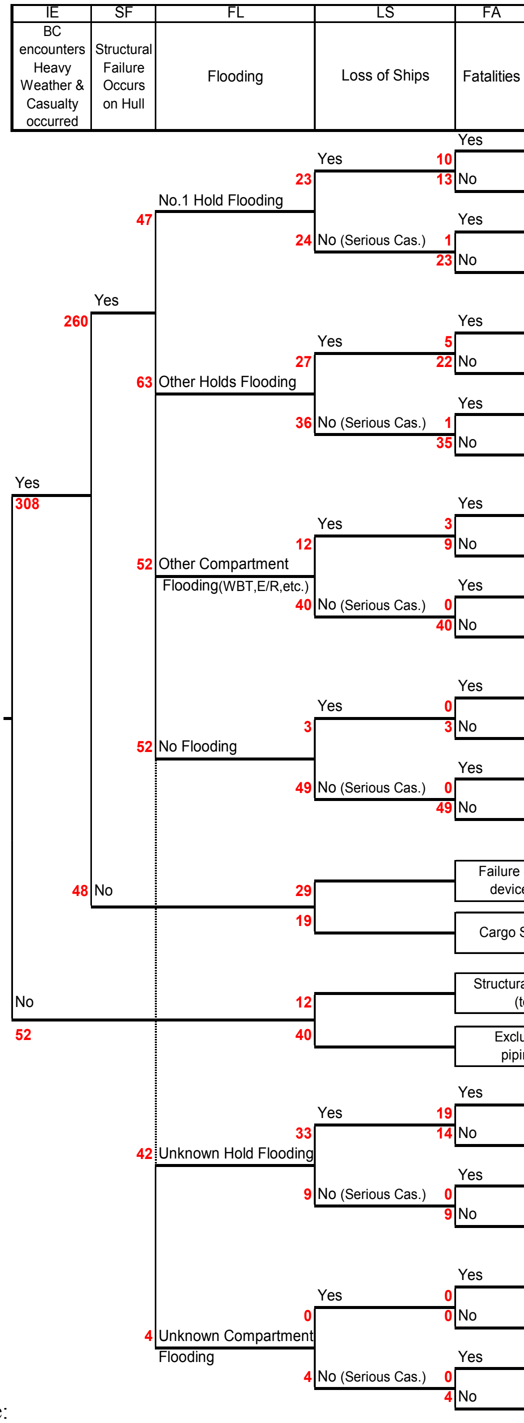
.1 Flooding due to structural failure;
  .1.1 Flooding to cargo holds due to structural failure;
    .1.1.1 Significant water ingress through fractures due to side shell failure. Providing that such fractures are below or near waterline, cargo holds can be rapidly flooded;
    .1.1.2 In some cases, progressive flooding to other cargo holds leads to total loss of ship and inevitable fatalities; and
    .1.1.3 In other cases, flooding is limited to such a level of seriousness as no total loss and no fatality.
  .1.2 Flooding to other compartments;
  .1.3 Flooding due to failure of deck fittings, etc; and
  .1.4 Water Ingress due to hatch cover failure or securing failure.
.2 Structural failure without water ingress in heavy weather;
.3 Accident during loading operation; and
.4 Accident due to cargo shift at sea.

Event tree diagrams were developed according to these accident scenarios. Figure 2.3 shows an event tree diagram with casualty breakdown on structural failures of bulk carrier of 10,000 DWT and over. As for 40 casualty cases in “Scenario-none: Water ingress in moderate sea condition or through piping; then, excluded from the study”, are grouped into either event number 39) or 40) in Figure 2.3, and their breakdown, by cause of accident, is illustrated in Figure 2.4.

Figure 2.4 also shows an event tree diagram with regard to accidents due to “structural failure of hatch cover”, “securing or tightening failure of hatch cover” and “failure of small hatch, ventilator, etc”. Detailed event tree diagrams for each ship size are referred to in a separate report of the FSA study.

It is obvious that frequency of casualty can be estimated using historical data of casualties and statistical fleet data of world bulk carriers. From these diagrams, following findings were obtained:

- ✓ Although these estimations are quite rough, the fatality rate with regard to No.1 cargo hold flooding seems to be relatively high among the casualties on bulk carriers. This tendency is more noticeable in hatch cover related casualties. (See Figure 2.3 and Figure 2.5)
- ✓ Frequency of serious casualty leading from securing failure/tightening failure of hatch cover is same as that of structural failure of hatch cover. However, while the serious casualties due to hatch cover failure did not result in any fatality, the number of fatalities in securing/tightening failure category is extremely large. (See Figure 2.5)
- ✓ As the reason of this, it is supposed that the securing failure (including structural failure of closing device, human element, etc) causes the cargo hold exposed widely to sea at once by hatch cover being opened or washed away. It seems that such many fatalities as 200 were probably resulted under situations like this. (See Figure 2.5)
- ✓ Judging only from the historical data analysis, the soundness (including both mechanical and human elements) of securing device for hatch cover including hatch coaming, as the first barrier against hold flooding, seems to be closely related to fatal casualty rather than strength of hatch cover panels. (See Figure 2.5)



Outcome: Consequence after Structural Failure	Frequency (per ship-year)	Fatalities per ship-year	Average Ship Age	Ratio of High Density Cargo Loaded	Total Number of Fatalities	Event No.
No.1 Hold Flooding, Total Loss, Fatalities	1.1E-04	2.2E-03	17.6	90.0%	169 / 30	1) 2)
No.1 Hold Flooding, Total Loss, No Fatality	1.4E-04	0.0E+00	19.8	53.8%	0 / 0	3) 4)
No.1 Hold Flooding, Returned, Fatalities	1.1E-05	3.3E-05	22.0	0.0%	0 / 3	5) 6)
No.1 Hold Flooding, Returned, No Fatality	2.6E-04	0.0E+00	15.2	47.8%	0 / 0	7) 8)
						Σ
Other Holds Flooding, Total Loss, Fatalities	5.6E-05	1.3E-03	21.2	80.0%	103 / 18	9) 10)
Other Holds Flooding, Total Loss, No Fatality	2.4E-04	0.0E+00	17.7	68.2%	0 / 0	11) 12)
Other Holds Flooding, Returned, Fatalities	1.1E-05	1.1E-05	14.0	0.0%	0 / 1	13) 14)
Other Holds Flooding, Returned, No Fatality	3.9E-04	0.0E+00	16.5	45.7%	0 / 0	15) 16)
						Σ
Other Compartment Flooding, Total Loss, Fatalities	3.3E-05	4.1E-04	19.3	0.0%	0 / 37	17) 18)
Other Compartment Flooding, Total Loss, No Fatality	1.0E-04	0.0E+00	20.6	44.4%	0 / 0	19) 20)
Other Compartment Flooding, Returned, Fatalities	0.0E+00	0.0E+00	0.0	0.0%	0 / 0	21) 22)
Other Compartment Flooding, Returned, No Fatality	4.4E-04	0.0E+00	16.0	12.5%	0 / 0	23) 24)
						Σ
No Flooding, Total Loss, Fatalities	0.0E+00	0.0E+00	0.0	0.0%	0 / 0	25) 26)
No Flooding, Total Loss, No Fatality	3.3E-05	0.0E+00	18.7	66.7%	0 / 0	27) 28)
No Flooding, Returned, Fatalities	0.0E+00	0.0E+00	0.0	0.0%	0 / 0	29) 30)
No Flooding, Returned, No Fatality	5.5E-04	0.0E+00	13.4	14.3%	0 / 0	31) 32)
Failure of Hatch Covers or other closing devices (to be assessed separately)	3.2E-04	2.7E-03	14.1	24.1%	101 / 145	33) 34)
Cargo Shift (to be assessed separately)	2.1E-04	6.0E-04	10.4	36.8%	30 / 24	35) 36)
Structural failure during loading operation (to be assessed separately)	1.3E-04	0.0E+00	20.7	33.3%	0 / 0	37) 38)
Excluded case from the study, e.g. piping failure, etc. (out of scope)	4.4E-04	4.6E-04	16.2	10.0%	32 / 9	39) 40)
Unknown Hold Flooding, Total Loss, Fatalities	2.1E-04	4.7E-03	18.9	78.9%	365 / 59	41) 42)
Unknown Hold Flooding, Total Loss, No Fatality	1.6E-04	0.0E+00	21.0	42.9%	0 / 0	43) 44)
Unknown Hold Flooding, Returned, Fatalities	0.0E+00	0.0E+00	#DIV/0!	0.0%	0 / 0	45) 46)
Unknown Hold Flooding, Returned, No Fatality	1.0E-04	0.0E+00	16.9	11.1%	0 / 0	47) 48)
						Σ
Unknown Compartment Flooding, Total Loss, Fatalities	0.0E+00	0.0E+00	#DIV/0!	0.0%	0 / 0	49) 50)
Unknown Compartment Flooding, Total Loss, No Fatality	0.0E+00	0.0E+00	#DIV/0!	0.0%	0 / 0	51) 52)
Unknown Compartment Flooding, Returned, Fatalities	0.0E+00	0.0E+00	#DIV/0!	0.0%	0 / 0	53) 54)
Unknown Compartment Flooding, Returned, No Fatality	4.4E-05	0.0E+00	20.5	0.0%	0 / 0	55) 56)

Note:

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

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

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

Figure 2.3 Event tree diagram with casualty breakdown (10,000dwt+)

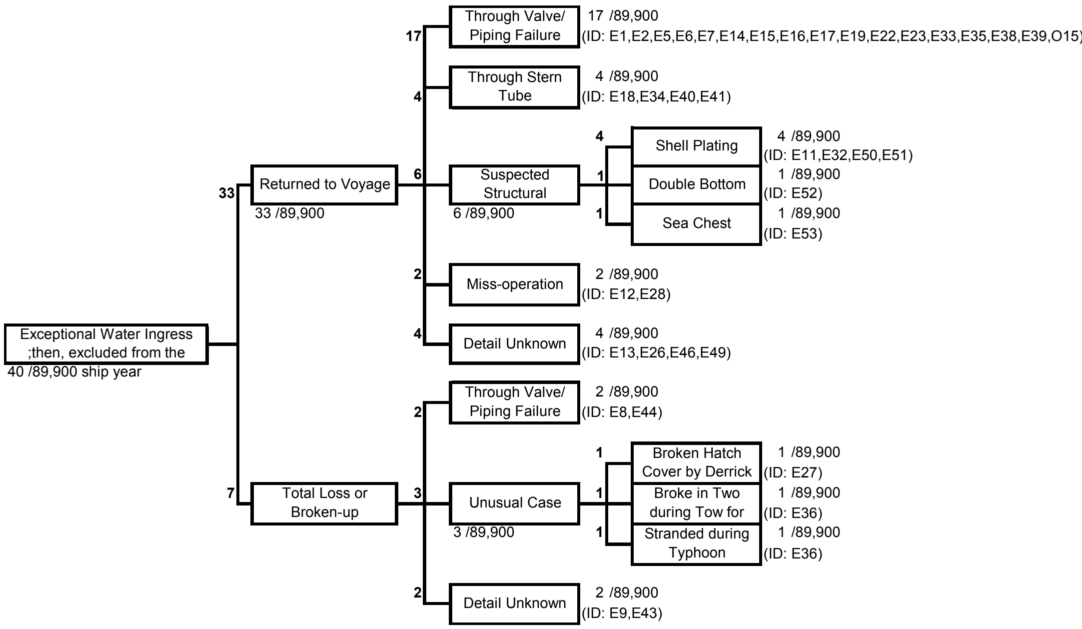


Figure 2.4 Break down diagram with regard to Scenario-none (Cases excluded from this study)

IE: BC encounters Heavy Weather & Casualty occurred	HCF: Failure occurs on Hatch Cover or other closing device	FL: Flooding	LS: Loss of Ships	FA: Fatalities	Outcome: Sequence of Casualty	Probability: Frequency (per ship-year)	Probability: Fatalities per ship year	Note: Average Ship Age	Note: Ratio concerning Fore End or No.1 Hold	Note: Total Number of Fatalities	Event No.
	9 Structural Failure of Hatch Cover	6 Yes	2 Yes	0 Yes	HC Structural Failure-Flooding-Sank-Fatalities	0.0E+00	0.0E+00	0.0	0.0%	0 / 0	1) / 2)
				2 No	HC Structural Failure-Flooding-Sank-No Fatality	2.2E-05	0.0E+00	15.5	50.0%	0 / 0	3) / 4)
			4 No (Serious Cas.)	1 Yes	HC Structural Failure-Flooding-Returned-Fatalities	1.1E-05	2.2E-05	3.0	0.0%	0 / 2	5) / 6)
				3 No	HC Structural Failure-Flooding-Returned-No Fatality	3.3E-05	0.0E+00	18.0	100.0%	0 / 0	7) / 8)
		3 No			HC Structural Failure-No Flooding-Returned	3.3E-05	0.0E+00	11.3	33.3%	0 / 0	9) / 10)
											Σ
	11 Securing or Tightening Failure of Hatch Cover	10 Yes	6 Yes	6 Yes	HC Securing or Tightening Failure-Flooding-Sank-Fatalities	6.7E-05	2.2E-03	21.5	100.0%	200 / 0	11) / 12)
				0 No	HC Securing or Tightening Failure-Flooding-Sank-No Fatality	0.0E+00	0.0E+00	0.0	0.0%	0 / 0	13) / 14)
			4 No (Serious Cas.)	0 Yes	HC Securing or Tightening Failure-Flooding-Returned-Fatalities	0.0E+00	0.0E+00	0.0	0.0%	0 / 0	15) / 16)
				4 No	HC Securing or Tightening Failure-Flooding-Returned-No Fatality	4.4E-05	0.0E+00	20.5	50.0%	0 / 0	17) / 18)
		1 No			HC Securing or Tightening Failure-No Flooding-Returned	1.1E-05	0.0E+00	17.0	0.0%	0 / 0	19) / 20)
											Σ
	9 Failure of Small Hatch, Ventilator, etc.	9 Yes	1 Yes	1 Yes	Miscellaneous Closing Device Failure-Flooding-Sank-Fatalities	1.1E-05	4.9E-04	4.0	100.0%	44 / 0	21) / 22)
				0 No	Miscellaneous Closing Device Failure-Flooding-Sank-No Fatality	0.0E+00	0.0E+00	0.0	0.0%	0 / 0	23) / 24)
			8 No (Serious Cas.)	0 Yes	Miscellaneous Closing Device Failure-Flooding-Returned-Fatalities	0.0E+00	0.0E+00	0.0	0.0%	0 / 0	25) / 26)
				8 No	Miscellaneous Closing Device Failure-Flooding-Returned-No Fatality	8.9E-05	0.0E+00	8.4	100.0%	0 / 0	27) / 28)
		0 No			Miscellaneous Closing Device Failure-No Flooding-Returned	0.0E+00	0.0E+00	0.0	0.0%	0 / 0	29) / 30)

Note:

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

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

Figure 2.5 Event tree diagram with casualty breakdown (Failure of hatch cover or other closing device)

2.2.2 Fault Tree derived from Historical Data

In order to establish effective RCOs, fault tree analysis was conducted separately specifying initial events and consequences, which can cause each event in the above-described event tree diagrams. In addition to analysis of the LMIS casualty database, reference was made with Class NK damage database, brainstorming by experts, etc.

The causes of total loss of ship and major contributors to the risk are represented in Figure 2.6. In addition, Figure 2.7 and Figure 2.8 are considered to represent the cause of flooding and cause of structural failure with their major contributors, respectively. In considering the cause of structural failure, it is mainly focused on side shell failure according to the historical casualty data.

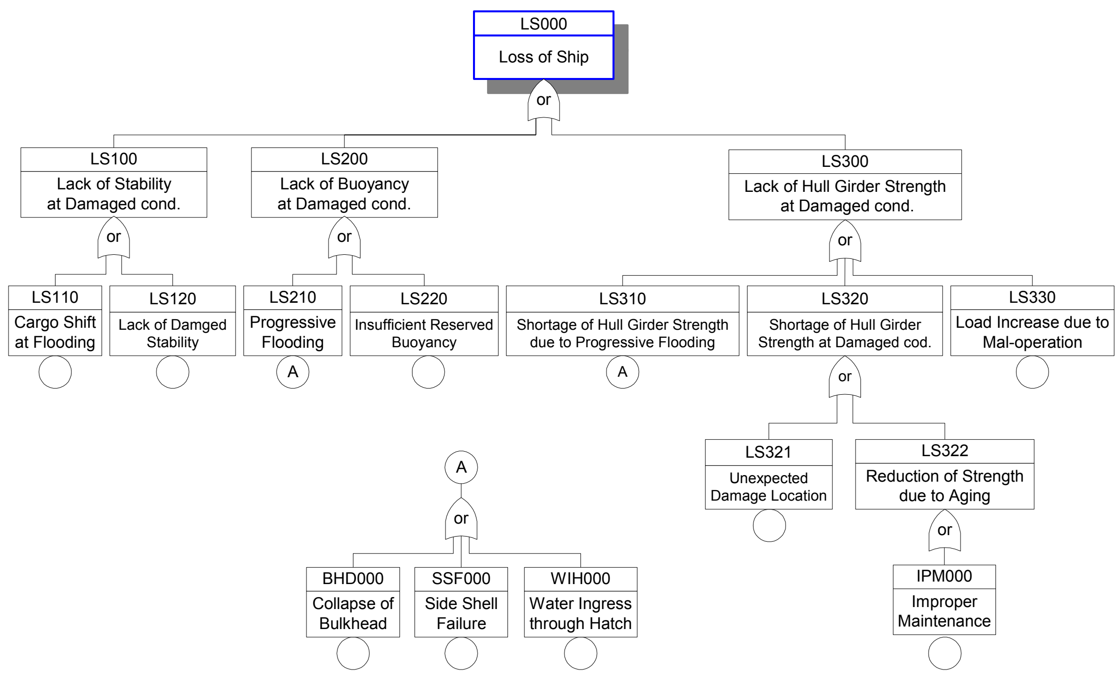


Figure 2.6 Fault tree to loss of ship (corresponding to "LS" in the event trees)

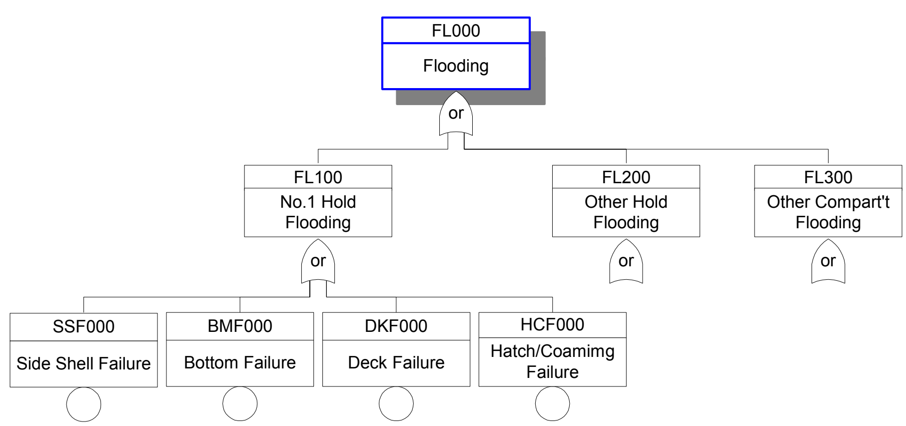


Figure 2.7 Fault tree to flooding (corresponding to "FL" in the event trees)

2.2.3 Progressive Flooding

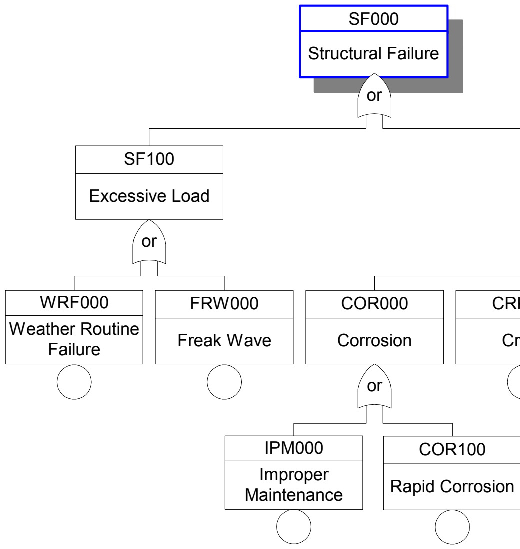


Figure 2.8 Fault tree to structure failure (corresponding to "SF" in the event trees)

The causes of progressive hold flooding is assumed to be one of the following:

- ✓ Failure of bulkhead between flooded cargo hold and adjacent cargo hold;
- ✓ Failure of hull girder;
- ✓ Failure of hatch cover of other cargo hold;
- ✓ Cargo liquefaction and loss of stability; and
- ✓ Another side shell failure of other cargo hold.

Figure 2.9 is the break down of progressive hold flooding led to total loss upon investigation of historical data. All casualties in "Scenario-1-1", except "Accident group-3", are allocated in Figure 2.9, according to location of failure.

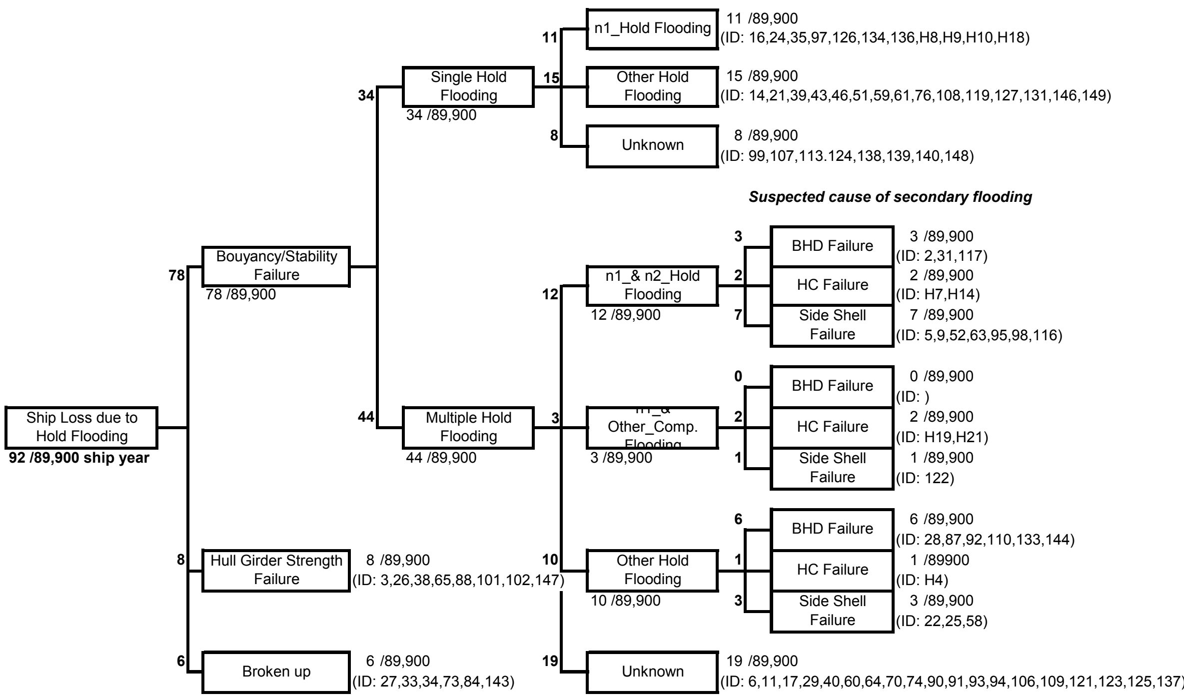


Figure 2.9 Break down diagram with regard to ship loss due to hold flooding

2.3 Evaluation of Risk before Introduction of Recent RCOs

2.3.1 Estimation of PLL (Potential Loss of Life)

In the investigations after this section, it is assumed that the number of fatalities, where water ingress location is unknown, could distribute to those of No.1 cargo hold, No.2 cargo hold and other cargo holds according to their ratio of number of fatal cases. For example, in the case of Cape-size bulk carrier, using the identified fatality ratio between No.1 hold: No.2 hold: Other holds = 35:33:0, the number of fatalities of the unknown hold flooding cases were distributed.

Then, the number of fatalities, where water ingress location is in No.1 cargo hold, is estimated as follows:

$$n_{est} = 35 + \frac{35}{35+33+0} \times 62 = 35 + \frac{35}{68} \times 62 \approx 67$$

The number of fatalities, where water ingress location is in No.2 cargo hold, is estimated as follows:

$$n_{est} = 33 + \frac{33}{35+33+0} \times 62 = 33 + \frac{33}{68} \times 62 \approx 63$$

The number of fatalities, where water ingress location is in other cargo holds, is estimated as follows:

$$n_{est} = 0 + \frac{0}{35+33+0} \times 62 = 0 + \frac{0}{68} \times 62 \approx 0$$

The results of these estimations are summarized in Table 2.4 with their Potential Loss of Life (PLL) indexes by location of water ingress. In addition, PLL of total loss case is illustrated in Figure 2.10.

Table 2.4 Summary of number of fatalities, estimated number of fatalities and PLL (Potential Loss of Life) by location of water ingress in the initial event and consequence of accident

Location of initial water ingress	Serious casualty case excluding total loss		Total loss case										
			Number of fatalities (reported)					Number of fatalities (estimated)					
	Number of fatalities	PLL	Cape-size	Panamax	Handy-size	Small-handy	*Sum*	Cape-size	Panamax	Handy-size	Small-handy	*Sum*	PLL
No.1 cargo hold	3	$3.3 \cdot 10^{-5}$	35	44	8	112	*199*	67	63	26	211	*367*	$4.1 \cdot 10^{-3}$
No.2 cargo hold	0	0	33	0	0	0	*33*	63	0	0	0	*63*	$7.0 \cdot 10^{-4}$
Other cargo holds	1	$1.1 \cdot 10^{-5}$	0	18	70	0	*85*	0	26	231	0	*257*	$2.9 \cdot 10^{-3}$
(Sub-total of identified holds)	***4***	***$4.4 \cdot 10^{-5}$***	***68***	***62***	***78***	***112***	***320***	***130***	***89***	***257***	***211***	***687***	***$7.6 \cdot 10^{-3}$***
Unknown cargo hold	0	0	62	27	179	99	*367*	0	0	0	0	*0*	0
Total cargo holds	***4***	***$4.4 \cdot 10^{-5}$***	***130***	***89***	***257***	***211***	***687***	***130***	***89***	***257***	***211***	***687***	***$7.6 \cdot 10^{-3}$***
Other spaces	0	0	0	0	6	31	*37*	0	0	6	31	*37*	$4.1 \cdot 10^{-3}$
Presumed water ingress (no detail)	0	0	0	0	6	51	*57*	0	0	6	51	*57*	$6.3 \cdot 10^{-4}$
Sub Total	***4***	***$4.4 \cdot 10^{-5}$***	***130***	***89***	***269***	***293***	***781***	***130***	***89***	***269***	***293***	***781***	***$8.7 \cdot 10^{-3}$***
Failure of deck fittings, etc	0	0	44	0	0	0	*44*	44	0	0	0	*44*	$4.9 \cdot 10^{-4}$
Hatch cover structural failure	2	$2.2 \cdot 10^{-5}$	0	0	0	0	*0*	0	0	0	0	*0*	0
Hatch cover securing failure	0	0	0	17	183	0	*200*	0	17	183	0	*200*	$2.2 \cdot 10^{-3}$
Exceptional case in HC failure	0	0	0	0	0	0	*0*	0	0	0	0	*0*	0
Accident due to cargo shift at sea	0	0	0	0	20	34	*54*	0	0	20	34	*54*	$6.0 \cdot 10^{-4}$
Total	***6***	***$6.7 \cdot 10^{-5}$***	***174***	***106***	***472***	***327***	***1,079***	***174***	***106***	***472***	***327***	***1,079***	***$1.2 \cdot 10^{-2}$***
Cases excluded from the study	0	0	0	4	32	5	41	0	4	32	5	41	$4.6 \cdot 10^{-4}$
Grand Total	***6***	***$6.7 \cdot 10^{-5}$***	***174***	***110***	***504***	***332***	***1,120***	***174***	***110***	***504***	***332***	***1,120***	***$1.2 \cdot 10^{-2}$***

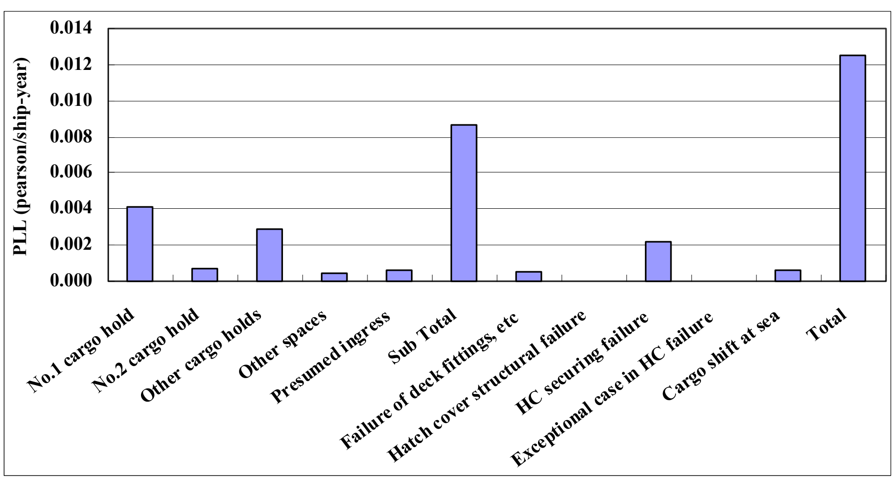


Figure 2.10 PLL of total loss case by location of water ingress

3 Evaluation of Reduced Risk after Introduction of Recent RCOs

3.1 Recently Introduced RCOs

Typical examples of recently introduced RCOs are ESP (Enhanced Survey Programs), SOLAS Chapter XII, etc.

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

3.2 Estimation of Effect of ESP

In order to estimate the effect of ESP, the historical data were revisited. Although ESP has been intended to apply to not only cargo hold structures but ballast tanks, hatch covers, etc, the working group considered that the effect of ESP could typically influence the frequency of side shell structure failure of cargo holds. Then, considering ESP as a risk control option against side shell structure failure, it was assumed that the effect of ESP would be reflected in the risk reduction rate in terms of number of casualties.

According to the historical casualty data, most of serious casualties in "Accident group -1 & -2" of "Scenario -1: Flooding to cargo hold due to structural failure" was resulted from failure of side shell structure. In order to see whether the reinforcement of ESP has brought any significant change on the maritime casualty records, effect of ESP is summarized in Table 3.1, which is divided into 2 groups:

- ✓ 1st group is of data from 1978 to 1993; and
- ✓ 2nd group is of data from 1994 to 2000.

As shown in number of casualties in "Accident groups -1 and -2" of "Scenario-1-1"in Table 3.1, total casualty rate of all the bulk carrier groups after 1994 is 0.00127 (number of casualties /ship year), while that before 1993 is 0.00191 (number of casualties /ship year). An estimate of the risk reduction rate by ESP r_{ESP} was calculated using these two figures as follows.

$$r_{ESP} = \frac{0.00191 - 0.00127}{0.00191} \approx 0.34$$

Risk reduction rate derived by the above formula restrictedly represents casualties related to hold flooding due to structural failure such as side shell failure. Hence, overall risk reduction rate r_{ESP}^{all} as the effect of ESP to all casualties involving water ingress is calculated as follows.

$$r_{ESP}^{all} = r_{ESP} \times \frac{152}{237} = 0.34 \times \frac{152}{237} \approx 0.22$$

With regard to the effects of ESP by size in Table 3.1, it is confirmed that ESP is remarkably effective RCO particularly to large size bulk carrier groups such as *Cape-size* bulk carrier and *Panamax* bulk carrier.

Furthermore, it is quite interesting to know that ESP has brought about a considerable result during a short period after 1993, in comparison with life cycle of ships. Probably, one of the reasons might belong to the nature of ESP, which could work on persistently on ships notwithstanding new or existing.

In addition, the effect of ESP could be recognized visually in PLL in Figure 3.1 and F-N curves in Figure 3.2.

Table 3.1 Rough estimation of the effect of ESP

Year	No. of casualties in Accident group-1 & -2 of Scenario-1)				
	Cape-size	Panamax	Handy-size	Small-handy	Sum
1978	0	0	1	1	2
1979	1	1	0	2	4
1980	0	1	6	3	10
1981	0	0	1	3	4
1982	0	1	1	3	5
1983	0	0	1	1	2
1984	1	0	6	2	9
1985	0	0	4	3	7
1986	0	1	0	1	2
1987	1	1	5	2	9
1988	0	1	2	1	4
1989	2	1	8	2	13
1990	5	3	5	2	15
1991	7	5	4	1	17
1992	1	1	0	0	2
1993	2	1	3	2	8
Sub total	**20**	**17**	**47**	**29**	**113**
Assumed fleet profile 1978-1993	**4,527**	**9,302**	**30,749**	**14,558**	**59,136**
Casualty rate (per ship-year)	**4.42E-03**	**1.83E-03**	**1.53E-03**	**1.99E-03**	**1.91E-03**
1994	3	0	4	1	8
1995	0	0	2	0	2
1996	1	1	1	3	6
1997	0	0	2	1	3
1998	0	1	4	2	7
1999	0	1	6	1	8
2000	1	1	2	1	5
Sub total	**5**	**4**	**21**	**9**	**39**
Assumed fleet profile 1994-2000	**3,373**	**5,835**	**16,620**	**4,919**	**30,747**
Casualty rate (per ship-year)	**1.48E-03**	**6.86E-04**	**1.26E-03**	**1.83E-03**	**1.27E-03**
Effect of ESP (reduction rate)	**67%**	**63%**	**18%**	**8%**	**34%**
No. of casualties related hold flooding due to hull structural failure (Accident Group-1 & -2)					152
No. of all casualties related water ingress (Scenario-1)					237
Percentage of ESP related					**64%**
Equivalent effect of ESP in all serious casualties related water ingress					**22%**

* ESP came into effect by IACS/UR: 1993/7/1
** Assumed fleet in 2000 is an equivalent considering the period of casualty data statistics

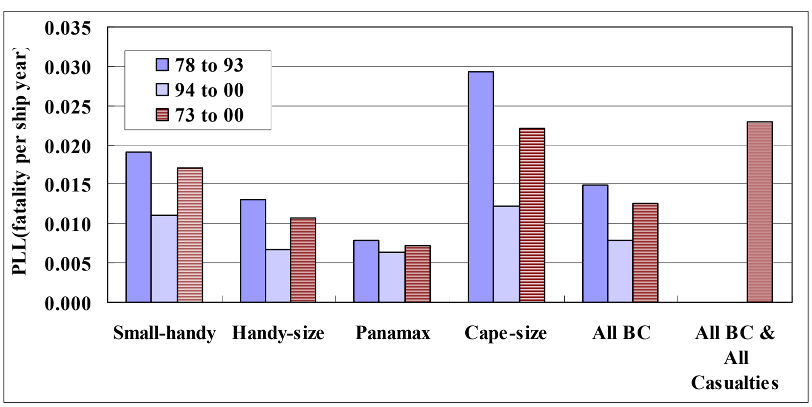


Figure 3.1 Effect of ESP in PLL of Bulk Carrier

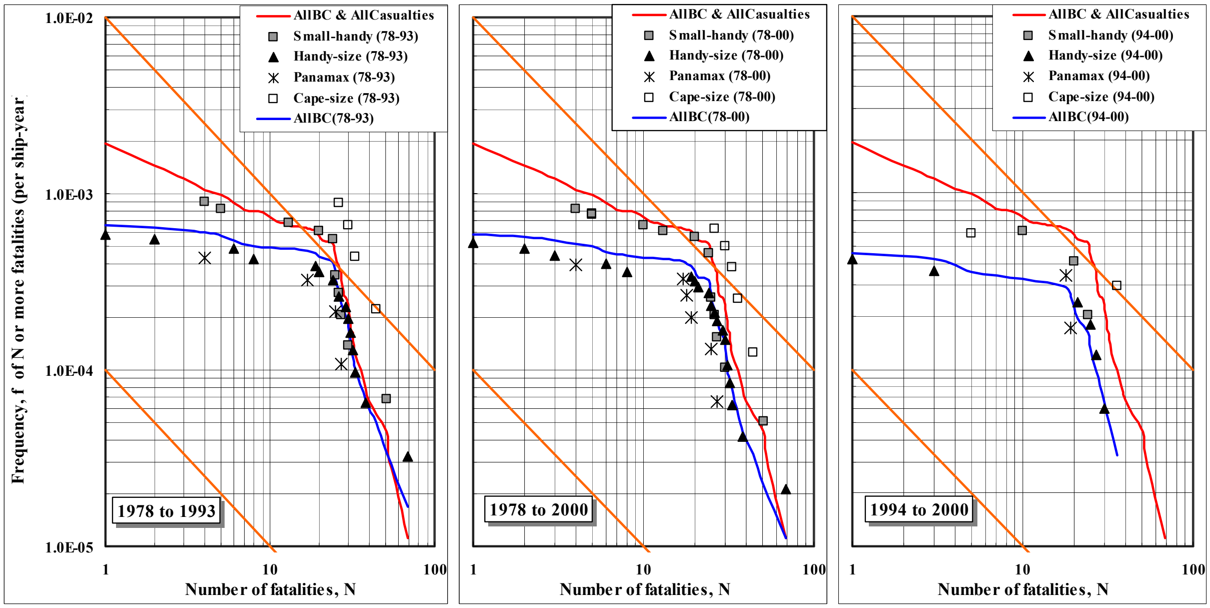


Figure 3.2 Effect of ESP in F-N Curves of Bulk Carrier

3.3 Estimation of Effects of SOLAS Chapter XII and UR S21

Because of shortage of time after the enforcements of SOLAS Chapter XII and UR S21, it is considered that enough time has not passed to reflect the effects of SOLAS Chapter XII and UR S21 in statistical casualty data. Therefore, in order to estimate the effects of SOLAS Chapter XII and UR S21, the working group, using the historical casualty data, simulated imaginary situations in future, when the effects of SOLAS Chapter XII and UR S21 might be reasonably appeared after certain years from now.

3.3.1 Methodology of Risk Reduction Simulation

Outline of simulation is summarized in Table 3.2.

Table 3.2 Outline of risk reduction simulation due to SOLAS Chapter XII and UR S21

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

Abbreviations:

New: New buildings
Ex. : Existing ships

Y: Probably effective
P: Sometimes effective
N: Not effective

*: In case of light cargo, evaluated as "P"

3.3.2 Result of Simulation

Being premised on these methodology, assumptions, conditions, etc, the imaginary F-N curves and PLL, in which the effect of SOLAS Chapter XII (including UR S21) are incorporated together with the effect of ESP as indicated in the previous section, are developed as shown in Figure 3.3 and Figure 3.4 respectively.

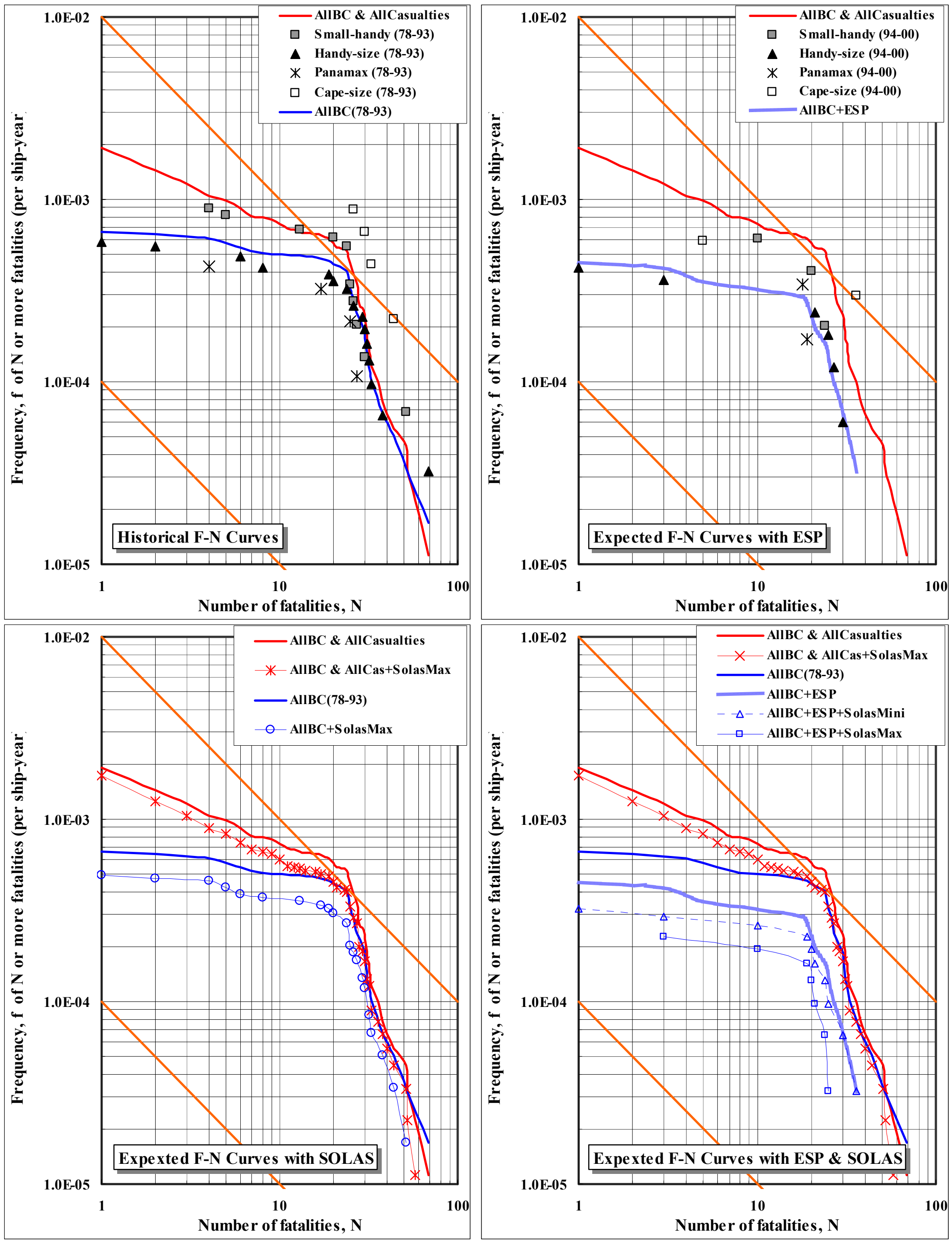


Figure 3.3 Effect of SOLAS XII (including UR S21) in F-N curve of bulk carrier

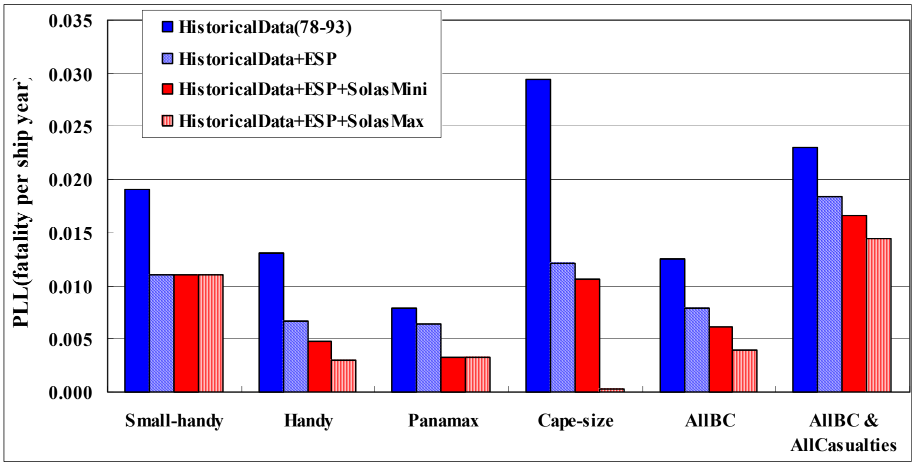


Figure 3.4 Effect of SOLAS XII.(including UR S21) in PLL of bulk carrier

3.4 Assessment of Current Base Risk

In order to assess the current base risk of bulk carriers, together with the evaluation of effect of recently introduced RCOs such as ESP and SOLAS Chapter XII/(including UR S21), F-N curves and PLL of bulk carriers are compared with those of other type of ships, such as tankers, passengers and general cargoes, as described in Figure 3.5 and Figure 3.6 respectively.

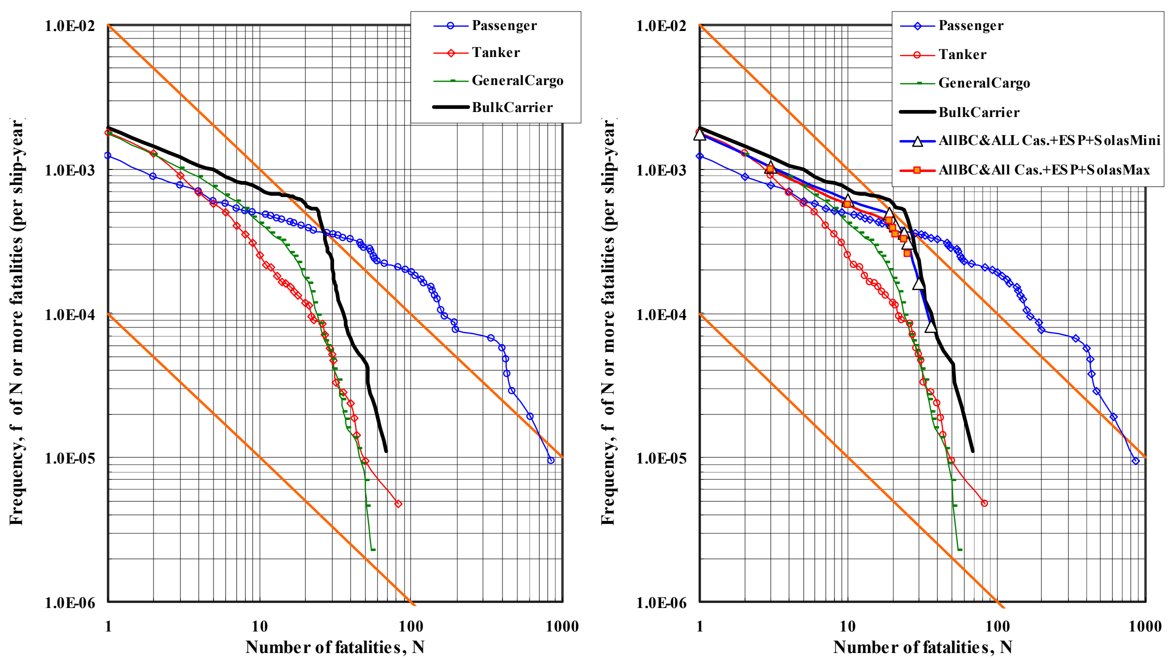


Figure 3.5 Comparison of F-N curve of bulk carrier with other type of ships

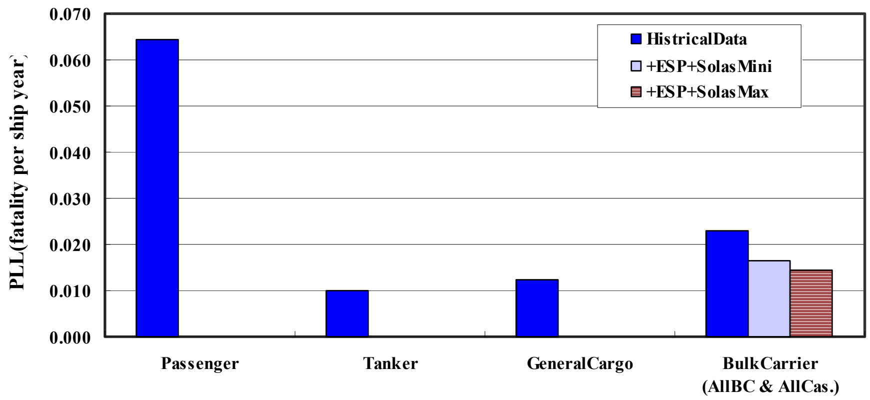


Figure 3.6 Comparison of PLL of bulk carrier with other type of ships

4 Conclusion of Risk analysis

The conclusion of "Step 2: risk analysis" is summarized in the following paragraphs. The accident scenario identifications used here are as follows:

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

1) It is considered that the relatively high-risk accident scenario of bulk carrier is "Scenario-1: Progressive flooding after initial failures/flooding". Therefore, the working group decided to focus on this scenario in the continuing steps of the investigation:

.1 76% of total loss cases in Table 2.1 are found to relate to "Scenario-1-1";

.2 81% of total loss cases in "Scenario-1-1" are due to "Accident group 1: Flooding into cargo holds due to structural failure (with consecutive flooding)" (see Table 2.1);

.3 70% of fatalities in Table 2.3 are found to relate to "Scenario-1-1"; and

.4 88% of fatalities in "Scenario-1-1" are due to "Accident group 1: Flooding into cargo holds due to structural failure (with consecutive flooding)" (see Table 2.3).

2) As for the location of structural failure, the following findings were achieved.

.1 As for fatal cases, 47% of fatalities in "Scenario-1-1" are unspecified with flooded cargo holds. However, even excluding the fatalities due to unknown hold flooding, 25% of fatalities in "Scenario-1-1" are identified to relate with flooding of No.1 cargo hold (see Table 2.4).

.2 According to the assumption in Table 2.3, 47% of fatalities in "Scenario-1-1" are considered to relate with flooding of No.1 cargo hold.

.3 According to the historical casualty data, most of the serious casualties involving hold flooding due to hull structural failure ("Accident group-1 & -2" in "Scenario-1-1") was caused by side shell failure as initial event.

3) Within the database used in the investigation, the annual frequency of total loss and the PLL indexes of

Cape-size and *Small-handy* bulk carrier groups indicate relatively high figures. However, these figures are dominated by the accidents before the enforcement of ESP, and, these figures are significantly improved in the historical data after 1994, particularly in the total loss rate of *Cape-size* bulk carrier group (see Figure 3.1 and 3.2).

As for the considerable result, brought about by ESP during a short period after 1993, in comparison with life cycle of ships, it could be considered that one of the reasons might belong to the nature of ESP, which could work on persistently on ships notwithstanding new or existing.

4) According to the simulation of the effects of SOLAS Chapter XII and UR S21, notwithstanding from optimistic views or pessimistic, certain amount of risk reduction might be expected in future. However, taking the following situations into consideration, any proposal of more cost effective RCOs will be expected in order to further improve the overall risk level of bulk carriers:

- ✓ PLL index of *Small-handy* bulk carrier group, in comparison with the others, indicate relatively high figure. In addition, considering the circumstances, where this group corresponds to bulk carrier of less than 150 m in length, which is exempted from application of SOLAS Chapter XII, and is still indicating relatively high annual frequency of total loss, proper care must be taken on *Small-handy* bulk carrier group;
- ✓ It will take considerable years until the risk level of bulk carrier would be substantially reduced by the effect of SOLAS Chapter XII;
- ✓ Although the effect of SOLAS Chapter XII shows certain amount of potential risk reduction, at the same time, the uncertainty of this simulation will have to be properly examined in due course; and
- ✓ Therefore, when these current situations are taken into consideration, further investigation would be needed to confirm whether expected risk levels of bulk carrier could sufficiently be at the same as the current risk levels of other type of ships such as tanker, general cargo, etc (see Figure 3.5 and Figure 3.6).

5) Judging from the results of historical data analysis, the soundness (including both mechanical and human factor) of securing device of hatch covers, as the first barrier against hold flooding, seems to be closely related to fatal casualty rather than strength itself of hatch cover panels.

6) Considering the fact in the historical data that cargo shift at sea may lead to fatal result, in particular for smaller size bulk carriers, it seems necessary to further investigate the risks of "cargo shift at sea".

In order to consider RCOs in the following steps, a risk picture model with regard to major casualty scenarios was developed as shown in Figure 4.1.

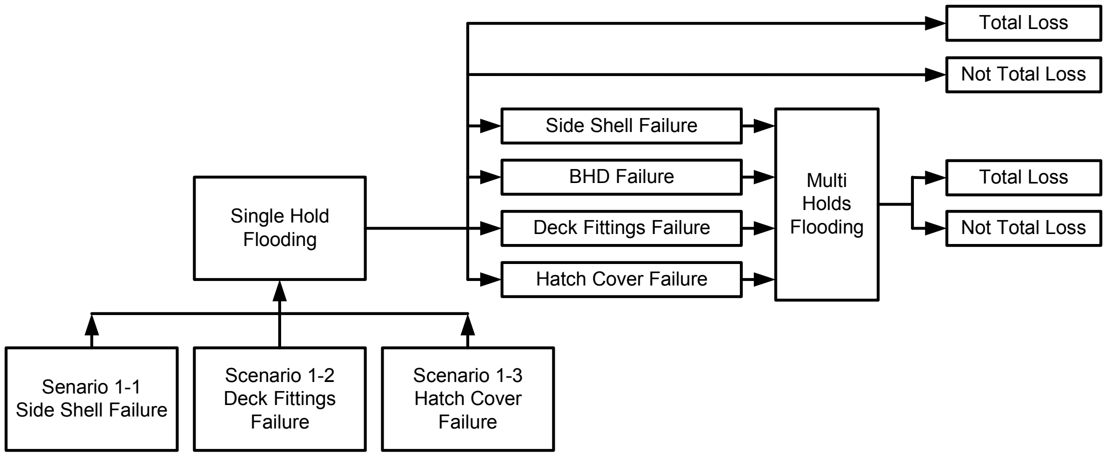


Figure 4.1 Model of serious casualty involving hold flooding

Appendix 1 Identified serious casualties, including total loss, from the LMIS casualty database in the period from 1978 to 2000

Historical Data was corrected from LMIS casualty database, etc. They are summarized in Annex 3 of MSC 75/5/X submitted by Japan. They consist of following seven tables. As an example, a part of Table B1 of the Appendix B of Annex 3 is attached hereunder

Table B1 Identified or presumed cases involving cargo hold flooding due to structural failure excluding stranding, collision, etc
Table B2 Identified cases involving other compartment flooding due to structural failure excluding stranding, collision, etc
Table B3 Serious casualty due to structural failure without water ingress
Table B4 Identified cases involving water ingress due to hatch cover failure or miscellaneous closing device failure
Table B5 Identified cases involving total loss or serious casualty due to cargo shift
Table B6 Exceptional cases such casualty during as out of voyage, e.g. valve/piping failure, accident whilst loading/discharging/ballasting, etc.
Table 7 Total loss casualty due to water ingress caused by collision, contact, etc

*** Note:**

1) *Description in* ***italic character*** *in* **Note** *is referred from the data source other than the LMIS casualty database.*
2) *Cell and line surrounded by* ***bold frame*** *shows the difference from MSC74/INF.10 and indicates that those cells or lines, or description in them are either, modified, added, inserted or moved from another table, at this investigation.*

Table B1 Identified or presumed cases involving cargo hold flooding due to structural failure excluding stranding, collision, etc.

(Ref. ID with asterisk like 148* indicates the case where involvement of cargo hold flooding is presumed with expert judgment)

Name	DWT	Date of event	Note	Total loss indicator	Number of fatalities	Age of ship at casualty	Number of cargo holds	Ref. ID
# Small-handy								
Evelpidis Era	10451 (GT)	19780116	No.3 hold flooded & sank Rock salt loaded	1	0	16	?	149
Arendal Bay	11848	19991227	No.2 hold flooded Unknown cargo loaded	0	0	25	?	150
Anderson	12051	19930917	Foundered (detail unknown) Iron loaded	1	24	18	3	148*
Luchana	14524	19860115	Unknown hold flooded Broke in two & sank Iron ore loaded	1	4	22	5	147
William Shakespeare	15328	19960628	No.4 hold flooded & foundered Steel loaded	1	0	18	?	146
Asia Eeho	15993	19830122	No.1 hold flooded Unknown voyage	0	0	16	4	145
Char Ye	16211	19840810	Nos.4 & 5 holds flooded & foundered Unknown cargo loaded	1	0	8	5	144
World Fuji	16511	19801227	No.3 hold flooded Subsequently broken up Coal loaded	1	0	16	4	143
Apiliotis	16600	19820607	No.5 hold flooded Unknown cargo loaded	0	0	19	5	142
Sincerity	16626	19900309	No.4 hold flooded Unknown voyage	0	0	14	4	141