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Classification of Capsizing and Sinking Factors☆

Yuichiro YANAGI[a*], Harukuni TAGUCHI[b]

[a*] Fluids Engineering and Ship Performance Evaluation Dept., National Maritime Research Institute, Japan, yanagi@nmri.go.jp, Corresponding Author

[b] Fluids Engineering and Ship Performance Evaluation Dept., National Maritime Research Institute, Japan

Abstract

Systematical classification of accident factors is very important to take appropriate countermeasures to reduce accidents. The aim of this study is to classify capsizing and sinking factors so as to propose a checklist which could be used to analyze future accidents. The scope is investigation reports of capsizing and sinking accidents published by Japan Transport Safety Board between 2008 and March 2017. The investigation reports were surveyed in order to extract all factors involved in the accidents. Then the factors were categorized into eight classified factors according to their characteristics and a checklist for analyzing capsizing and sinking accidents was proposed. The checklist was applied to capsizing and sinking accidents surveyed in this study and it was revealed that refraining from "navigation in bad weather" is the most effective countermeasure for capsizing and sinking. It was also revealed that "flooding," whose involvement was the highest for both capsizing and sinking, is the factor which needs countermeasures the most during navigation. It is concluded that accident analyses could be facilitated by applying the proposed checklist to future accidents.

Keywords: Accident, Analysis, Factor, Classification, Capsizing, Sinking

1. Introduction

In Japan, organizations such as Japan Transport Safety Board (JTSB) and Japan Marine Accident Tribunal survey marine accidents. The results of the surveys are published through investigation reports or written adjudications. Therefore, details of each accident could be known. On the other hand, one of the standard ways to manage risks (International Electrotechnical Commission, 2009) is to analyze a sufficient number of accidents systematically and to classify factors according to those characteristics. However, examples (Amagai et al., 1989) of systematic classification of capsizing and sinking factors are few. In this paper, investigation reports of JTSB were surveyed in order to extract and classify capsizing and sinking factors. Then, the capsizing and sinking accidents were analyzed to clarify the classified factors which need countermeasures to reduce accidents.

2. Survey Method

JTSB was set up in 2008 and it published 432 capsizing investigation reports and 82 sinking investigation reports as of March, 2017. The breakdown of the capsizing and sinking accidents are shown in Table 1 and Table 2 respectively. The highlighted situations are the scope of this study. All the reports were surveyed to extract the factors related to each accident and they were categorized into eight classified factors according to their characteristics as reported in section 3. Then the capsizing and sinking factors were analyzed for each ship type. In this paper, ships were categorized into twelve types following the categorization of JTSB: passenger ship, cargo ship, tanker, fishing vessel, recreational fishing vessel, angler tender boat, tugboat/push boat, work vessel, barge/lighter, public-service ship, pleasure boat and others.

Table 1: Breakdown of the 432 capsizing accidents

situation	number of accidents
unclear or capsizing during mooring with no people aboard	58
capsizing resulting from collision, contact or grounding	4
broaching	3
reduction of intact stability when riding a wave crest amidships	1
capsizing in waves	256
capsizing in calm water	108
capsizing related to both waves and external force other than wind or wave	2
total	432

Table 2: Breakdown of the 82 capsizing accidents

situation	number of accidents
unclear or sinking during mooring with no people aboard	18
sinking resulting from collision, contact, grounding or fire	7
sinking in waves	24
sinking in calm water	33
total	82

3. Classification of Capsizing and Sinking Factors

Since there were sinking accidents which occurred after capsizing, capsizing and sinking causes were thought to be composed of similar factors. Therefore, capsizing and sinking factors are classified together. As the result of the survey of the investigation reports, 34 factors were extracted. “Wave impact” is not included among the 34 factors since accident in waves and accident in calm water are analyzed separately to distinguish the involvement of “wave impact.” Among the 34 factors, accidents whose factor was “unclear (57 capsizing and 5 sinking)” or “capsizing or sinking during mooring with no people aboard (1 capsizing and 13 sinking)” are excluded from this study because the true factors could not be clarified. In addition, capsizing or sinking resulting from “collision (one capsizing and one sinking),” “contact (two capsizing and four sinking),” “grounding (one capsizing and one sinking)” or “fire (one sinking)” is also excluded from this study. Capsizing accidents related to “broaching (three accidents)” and “reduction of intact stability when riding a wave crest amidships (one accident)” were also found among the surveyed accidents. Since these minor factors only occur when certain conditions are satisfied and the number of accidents was small, they are excluded from this study. Therefore, the remaining 26 factors are classified and explained in the following sections.

3.1. Navigation in Bad Weather

Since the possibility of capsizing or sinking is likely to be higher in bad weather, it is organized as one classified factor. Institutions such as Japan Meteorological Agency issue advisories and warnings when precautions are needed. In this study, it is considered a bad weather when an advisory/warning was issued, when a typhoon was approaching or when it was specified that it was bad weather in the report.

3.2. Navigation in Danger Zone

Where situations shown below occur, the possibility of capsizing or sinking becomes higher. Therefore, navigating in such places are categorized as "navigation in danger zone."

- breaking waves at shore
- plunging waves
- wave shoaling
- reflected waves
- waves affected by estuary flows
- misconception of navigation position

Misconception of navigational position occurred when the captain thought he was navigating above its own past track on a GPS plotter. Since the plotter was zoomed out, the ship position was actually deviating from the past track and it navigated in shallow water area and had capsized. Therefore, misconception of navigational position is categorized as "navigation in danger zone."

In short, shallow water areas and estuaries are danger zones.

3.3. External Force Other than Wind or Wave

"External force other than wind or wave" is organized as one classified factor since the external force could lead to capsizing or seawater ingress. Examples of external force are towline tension, pushing force from push boats, tension from fishing net, anchor rope tension, discharge from an outlet of an embankment, etc.

3.4. Incapability of Maneuvering

When the following situations occur, appropriate maneuvering cannot be done and turning the bow against the wave direction or escaping from danger zones becomes difficult.

- entanglement of ropes and propeller
- breakdown of steering gear
- stuck anchor
- engine stall
- out of fuel
- stuck fishing gear
- entanglement of fishing net and net hauler
- entanglement of fishing gear and propeller
- improper anchorage
- insufficient watch

In short, a situation where actions against dangerous waves are difficult is classified as "incapability of maneuvering."

3.5. Inappropriate Maneuvering

Inappropriate maneuvering such as hard turns could heel ships. Therefore, it is organized as one classified factor.

3.6. Embarkation/Movement of People and Cargo

The following situations occur owing to "embarkation/movement of people and cargo." Therefore, it is organized as one classified factor.

- movement of people and cargo
- excessive heel/trim
- loss of stability
- decrease of freeboard
- overweight

Although excessive trim was not found in the reports, it occurs from "embarkation/movement of people and cargo" and could become a capsizing or sinking factor. Therefore, excessive trim is added in this classified factor.

3.7. Flooding

In this paper, seawater ingress on weather deck is included in "flooding." When "flooding" occurs, the stability of a ship decreases and the ship could heel owing to the shift of the water. Therefore, "flooding" is organized as one classified factor.

3.8. Excessive Heel Owing to Wind Pressure

When "excessive heel owing to wind pressure" occurs, the heel facilitates seawater to transcend the freeboard or prompts capsizing. Therefore, it is organized as one

classified factor.

4. Capsizing and Sinking Analysis Checklist

As a result of the classification of factors in chapter 3, the capsizing and sinking accidents surveyed in this study occur roughly owing to the eight classified factors. Among the eight classified factors, “incapability of maneuvering” and “inappropriate maneuvering” do not occur simultaneously. Therefore, capsizing and sinking occur as a result of the combinations of the seven classified factors shown in Table 3. Writing down the order that the event occurred in the event column and the details of the involvement in the specific factor column leads to the clarification of the event sequence of capsizing/sinking and easier grasp of the capsizing/sinking situation.

Table 3: Capsizing and sinking analysis checklist

factor	involvement	event	specific factor
navigation in bad weather	☐		
navigation in danger zone	☐		
external force other than wind or wave	☐		
incapability of maneuvering or inappropriate maneuvering	☐		
embarkation/movement of people and cargo	☐		
flooding	☐		
excessive heel owing to wind pressure	☐		

5. Capsizing Accident Analyses Using the Checklist

In this chapter, capsizing accidents are analyzed using the checklist and the results are discussed.

The ship type and size of the capsized ships are shown in Table 4. Lengths are shown for ships whose gross tonnages were unclear. About 80 percent of the capsized ships were small ships whose gross tonnages were less than 5 tonnages or whose lengths were less than 5 meters.

Table 4: Ship type and size of the capsized ships

gross tonnage or length / ship type	less than 5GT	5 to 10GT	10 to 15GT	15 to 20GT	20 to 100GT	100 to 200GT	less than 5m	5 to 10m	10 to 15m	15 to 30m	unclear	total	composition ratio (%)
passenger ship	5											5	1.2
fishing vessel	150	26	9	13	1	3	1					203	47.0
recreational fishing vessel		2	1									3	0.7
angler tender boat	4											4	0.9
tugboat/push boat	1			8								9	2.1
work vessel	13	1	2	2	1		1					20	4.6
barge/lighter								1	1	1		3	0.7
public-service ship	1											1	0.2
pleasure boat	127						43	6			4	180	41.7
others	2			1				1				4	0.9
total	303	29	12	24	2	3	45	8	1	1	4	432	100
composition ratio (%)	70.1	6.7	2.8	5.6	0.5	0.7	10.4	1.9	0.2	0.2	0.9	100	

In this study, capsizing in waves and capsizing in calm water which have a sufficient number of accidents for analysis are analyzed. Capsizing in waves has been analyzed by the authors in a former research (Yanagi and Taguchi, 2017). In this study, the method of the former research was applied to analyze capsizing in calm water.

5.1. Analyses of Capsizing in Waves

In this section, 256 capsizing accidents in waves were analyzed using the checklist in Table 3.

The relationship of the capsizing factors in waves is shown in Figure 1. Direct factors are factors which could directly lead to capsizing. Indirect factors are factors which enhances the effect of direct factors. “Wave impact” is a direct factor since it directly heels ships. “Flooding” is a direct factor since the movement of flooded water heels ships. Similarly, “inappropriate maneuvering,” “excessive heel owing to wind pressure” and “embarkation/movement of people and cargo” are direct factors. On the other hand, “navigation in bad weather” enhances the effect of “wave impact” and it could lead to “flooding.” “Navigation in bad weather”

also enhances the effect of "excessive heel owing to wind pressure" and it could lead to "embarkation/movement of people and cargo" when there is heavy snow. "Navigation in danger zone" enhances the effect of "wave impact" and "incapability of maneuvering" inhibits ships from reducing the effect of "wave impact."

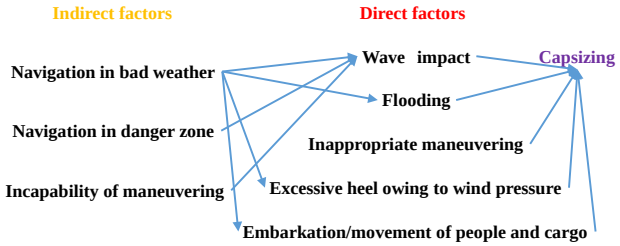

Figure 1: Relations of capsizing factors in waves

Capsizing factors for each ship type among the 256 accidents are shown in Table 5. "Incapability of maneuvering" and "inappropriate maneuvering" are separated in this table. The numbers in the round parentheses show the number of ships for the first row and the ratio that the factor was involved in the accidents of each ship type for other rows. Since there were accidents resulting from the combination of factors, the total number of factors are the same or larger than the number of ships.

As shown in the rightmost column, "flooding" was involved in more than half of the capsizing accidents. "Navigation in bad weather" and "navigation in danger zone" were involved in more than a third of the accidents.

Table 5: Breakdown of capsizing factors in waves

ship type / capsizing factor	passenger ship (2)	fishing vessel (104)	recreational fishing vessel (1)	angler tender boat (4)	tugboat and push boat (4)	work vessel (5)	public-service ship (1)	pleasure boat (132)	others (3)	total (256)
navigation in bad weather		42 (40%)	1 (100%)	3 (75%)	3 (75%)	3 (60%)		36 (27%)	2 (67%)	90 (35%)
navigation in danger zone	1 (50%)	41 (39%)		3 (75%)	1 (25%)	3 (60%)	1 (100%)	37 (28%)	1 (33%)	88 (34%)
incapability of maneuvering	1 (50%)	34 (33%)	1 (100%)			2 (40%)		27 (20%)	1 (33%)	66 (26%)
inappropriate maneuvering		3 (3%)			2 (50%)			3 (2%)		8 (3%)
embarkation/movement of people and cargo		20 (19%)			2 (50%)			16 (12%)		38 (15%)
flooding		55 (53%)		3 (75%)	4 (100%)	3 (60%)		74 (56%)	1 (33%)	140 (55%)
excessive heel owing to wind pressure		10 (10%)			1 (25%)			7 (5%)		18 (7%)
total factors	2	205	2	9	13	11	1	200	5	448
number of involved factors per ship	1.0	2.0	2.0	2.3	3.3	2.2	1.0	1.5	1.7	1.8

5.1.1. Discussion on Capsizing of Fishing Vessels and Pleasure Boats

As shown in Table 5, more than 90% of the capsized ships in waves are either fishing vessels or pleasure boats and there were not enough accidents for other ship types for discussion. Therefore, capsizing of fishing vessels and pleasure boats are discussed.

"Flooding" (53%), "navigation in bad weather" (40%), "navigation in danger zone" (39%) and "incapability of maneuvering" (33%) were highly involved in capsizing of fishing vessels.

The involvement of "navigation in bad weather" seems to be high in capsizing of fishing vessels because the fishing season drives fishermen to depart even when they knew about the bad weather. In addition, fish catching requires much cooperation with colleagues and even if a captain is reluctant to depart, it might need to do so if consorts decide to depart.

The involvement of "navigation in danger zone" also seems to be high in capsizing of fishing vessel because small fishing vessels tend to operate in shallow water area.

The involvement of "incapability of maneuvering" seems to be high in capsizing of fishing vessel because the use of fishing gear could lead to the situations of

"incapability of maneuvering" shown in section 3.4. In addition, concentration on fish catching seems to lead to insufficient watch and contribute to the high ratio of "incapability of maneuvering."

Regarding capsizing factors of pleasure boats, "flooding" is overwhelmingly high (56%). Then "navigation in danger zone" (28%) and "navigation in bad weather" (27%) follow.

5.1.2. Factors Involved in Capsizing in Waves

The number of factors involved in capsizing in waves and the corresponding number of capsized ships are shown in Table 6. There were twenty accidents that capsized purely by "wave impact." The capsizing patterns are shown in the following sub-subsections.

Table 6: Factors involved in capsizing in waves

number of factors	0	1	2	3	4	5	6	total
number of ships	20	85	97	48	5	1	0	256

Number of factors "0" indicates capsizing purely by "wave impact."

5.1.2.1. Capsizing with One Factor in Waves

Breakdown of capsizing with one factor in waves is shown in Table 7. Numbers in the round parentheses indicate the ratio of the factor involved in capsizing with one factor in waves. The ratios of "flooding" and "navigation in danger zone" are high and their influences on capsizing of ships seem to be higher than other factors.

Table 7: Capsizing with one factor in waves

factor	number of ships
flooding	34 (40%)
navigation in danger zone	27 (32%)
incapability of maneuvering	8 (9%)
embarkation/movement of people and cargo	8 (9%)
navigation in bad weather	6 (7%)
inappropriate maneuvering	1 (1%)
excessive heel owing to wind pressure	1 (1%)
total	85

5.1.2.2. Capsizing with Two Factors in Waves

Capsizing patterns and the corresponding number of ships for capsizing with two factors in waves are shown in Table 8. For instance, pattern No. 1 whose event 1 is "navigation in bad weather" and event 2 is "flooding" indicates a pattern when a ship departed in bad weather, wave ingress occurred on weather deck and had capsized.

Table 8: Capsizing with two factors in waves

No.	event 1	event 2	number of ships
1	navigation in bad weather	flooding	20 (21%)
2	navigation in bad weather	navigation in danger zone	16 (16%)
3	incapability of maneuvering	flooding	15 (15%)
4	navigation in danger zone	flooding	10 (10%)
5	navigation in bad weather	incapability of maneuvering	6 (6%)
6	embarkation/movement of people and cargo	flooding	6 (6%)
7	navigation in bad weather	excessive heel owing to wind pressure	4 (4%)
8	incapability of maneuvering	navigation in danger zone	4 (4%)
9	flooding	embarkation/movement of people and cargo	3 (3%)
10	incapability of maneuvering	embarkation/movement of people and cargo	2 (2%)
11	flooding	incapability of maneuvering	2 (2%)
12	navigation in bad weather	inappropriate maneuvering	1 (1%)
13	navigation in danger zone	incapability of maneuvering	1 (1%)
14	inappropriate maneuvering	navigation in danger zone	1 (1%)
15	embarkation/movement of people and cargo	inappropriate maneuvering	1 (1%)
16	incapability of maneuvering	excessive heel owing to wind pressure	1 (1%)
17	excessive heel owing to wind pressure	embarkation/movement of people and cargo	1 (1%)
total			97

In 5.1.2.1., it was revealed that "flooding" and "navigation in danger zone" have strong influences on capsizing when combined with "wave impact." In Table 8, the four most frequent patterns included at least either of them. This is reasonable since adding a factor to the factors that solely have strong influences increases the danger of capsizing. And "navigation in bad weather" was involved in about half of the capsizing as event 1.

5.1.2.3. Capsizing with Three Factors in Waves

Capsizing patterns and the corresponding number of ships for capsizing with three factors in waves are shown in Table 9. All patterns except No. 11 involved either or both "flooding" and "navigation in danger zone."

"Navigation in bad weather" appeared in more than 60% of the patterns as event 1.

5.1.3. Discussion on Capsizing in Waves

Sub-subsection 5.1.2.1 revealed that "flooding" and "navigation in danger zone" have stronger influences on capsizing of ships compared with other factors. Capsizing with two or more factors in waves occurs after the external force resulting from the combined factors exceeds the righting moment. Therefore, reducing the number of involved factors leads to the

prevention of capsizing. After the occurrence of events leading to capsizing, preventing the latter part of events becomes complicated since it has to be done simultaneously with mitigating the former part of events. Hence preventing event 1 is most effective. "Navigation in bad weather" which was involved in more than a third of the accidents occurred mainly as event 1 in capsizing with two or more factors in waves. Therefore, refraining from "navigation in bad weather" is extremely important in order to prevent capsizing.

Table 9: Capsizing with three factors in waves

No.	event 1	event 2	event 3	number of ships
1	navigation in bad weather	navigation in danger zone	flooding	9 (19%)
2	navigation in bad weather	navigation in danger zone	incapability of maneuvering	4 (8%)
3	navigation in bad weather	flooding	incapability of maneuvering	4 (8%)
4	navigation in bad weather	flooding	excessive heel owing to wind pressure	3 (6%)
5	navigation in bad weather	excessive heel owing to wind pressure	flooding	3 (6%)
6	navigation in danger zone	incapability of maneuvering	flooding	3 (6%)
7	incapability of maneuvering	navigation in danger zone	flooding	3 (6%)
8	navigation in bad weather	incapability of maneuvering	navigation in danger zone	2 (4%)
9	navigation in bad weather	incapability of maneuvering	flooding	2 (4%)
10	navigation in danger zone	flooding	incapability of maneuvering	2 (4%)
11	navigation in bad weather	incapability of maneuvering	embarkation/movement of people and cargo	1 (2%)
12	navigation in bad weather	embarkation/movement of people and cargo	flooding	1 (2%)
13	embarkation/movement of people and cargo	navigation in bad weather	flooding	1 (2%)
14	navigation in bad weather	flooding	embarkation/movement of people and cargo	1 (2%)
15	navigation in danger zone	flooding	inappropriate maneuvering	1 (2%)
16	navigation in danger zone	embarkation/movement of people and cargo	flooding	1 (2%)
17	incapability of maneuvering	flooding	embarkation/movement of people and cargo	1 (2%)
18	embarkation/movement of people and cargo	flooding	incapability of maneuvering	1 (2%)
19	embarkation/movement of people and cargo	flooding	inappropriate maneuvering	1 (2%)
20	embarkation/movement of people and cargo	incapability of maneuvering	flooding	1 (2%)
21	incapability of maneuvering	excessive heel owing to wind pressure	flooding	1 (2%)
22	excessive heel owing to wind pressure	flooding	incapability of maneuvering	1 (2%)
23	embarkation/movement of people and cargo	flooding	excessive heel owing to wind pressure	1 (2%)
total				48

In addition, as to fishing vessels, involvement of "incapability of maneuvering" is high owing to fish catching and countermeasures against "incapability of maneuvering" is important for fishing vessels.

5.2. Analyses of Capsizing in Calm Water

In this section, 108 capsizing accidents in calm water are analyzed using the checklist in Table 3 and the results are discussed. "Navigation in danger zone" and "incapability of maneuvering" were not involved in this group of accidents because these are related to "wave impact."

The relationship of capsizing factors in calm water is shown in Figure 2. The relationship is basically the same with capsizing factors in waves. The difference is that "external force other than wind or wave" appears as direct factor since it could heel ships.

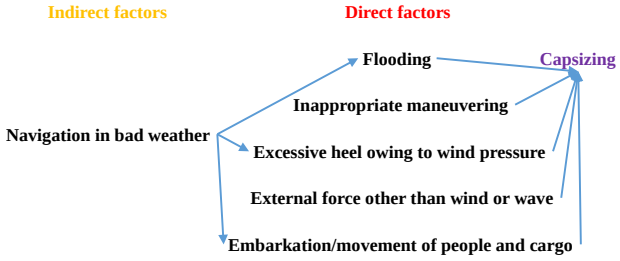

Figure 2: Relations of capsizing factors in calm water

Capsizing factors for each ship type for the 108 accidents are shown in Table 10. As indicated in the rightmost column, "flooding" was involved in about half of the accidents. "Flooding" in calm water results from corrosion of hull bottom, seawater ingress from propeller inspection windows, holes in seawater engine cooling systems, river current, boat plug, whirlpools, maintenance hole, etc. "Embarkation/movement of people and cargo" was involved in more than 40% of the accidents and this ratio is much higher than capsizing in waves. "External force other than wind or wave"

appeared in more than a third of the accidents.

Table 10: Breakdown of capsizing in calm water

capsizing factor \ ship type	passenger ship (1)	fishing vessel (53)	recreational fishing vessel (1)	tugboat and push boat (4)	work vessel (12)	barge and lighter (1)	pleasure boat (35)	others (1)	total (108)
navigation in bad weather		1 (2%)					6 (17%)	1 (100%)	8 (7%)
external force other than wind or wave	1 (100%)	21 (40%)		4 (100%)	11 (92%)	1 (100%)	3 (9%)		41 (38%)
inappropriate maneuvering							4 (11%)		4 (4%)
embarkation/movement of people and cargo		29 (55%)					17 (49%)		46 (43%)
flooding		31 (58%)	1 (100%)		6 (50%)		15 (43%)		53 (49%)
excessive heel owing to wind pressure		2 (4%)					7 (20%)	1 (100%)	10 (9%)
total factors	1	84	1	4	17	1	52	2	162
number of involved factors per ship	1.0	1.6	1.0	1.0	1.4	1.0	1.5	2.0	1.5

5.2.1. Factors involved in Capsizing in Calm Water

The number of factors involved in capsizing in calm water and the corresponding number of capsized ships are shown in Table 11. Each capsizing pattern is shown in the following sub-subsections.

Table 11: Factors involved in capsizing in calm water

number of factors	1	2	3	4	5	6	total
number of ships	58	46	4	0	0	0	108

5.2.1.1. Capsizing with One Factor in Calm Water

Breakdown of capsizing with one factor in calm water is shown in Table 12. As shown in this table, “external force other than wind or wave,” “embarkation/movement of people and cargo” and “flooding” seem to have strong influences on capsizing in calm water.

Table 12: Capsizing with one factor in calm water

factor	number of ships
external force other than wind or wave	25 (43%)
embarkation/movement of people and cargo	18 (31%)
flooding	13 (22%)
inappropriate maneuvering	1 (2%)
excessive heel owing to wind pressure	1 (2%)
navigation in bad weather	0
total	58

5.2.1.2. Capsizing with Two Factors in Calm Water

Capsizing patterns and the corresponding number of ships for capsizing with two factors in calm water are shown in Table 13. The two most frequent patterns are combinations of “external force other than wind or wave,” “embarkation/movement of people and cargo” and “flooding” whose ratios were high in Table 12. The third most frequent pattern was “excessive heel owing to wind pressure” during “navigation in bad weather.” Since the ratio of “excessive heel owing to wind pressure” was low in Table 12, wind pressure may not be a menace during normal weather, but becomes one for small ships in bad weather.

Table 13: Capsizing with two factors in calm water

No.	event 1	event 2	number of ships
1	embarkation/movement of people and cargo	flooding	19 (41%)
2	external force other than wind or wave	flooding	11 (24%)
3	navigation in bad weather	excessive heel owing to wind pressure	7 (15%)
4	inappropriate maneuvering	flooding	3 (7%)
5	flooding	embarkation/movement of people and cargo	3 (7%)
6	external force other than wind or wave	embarkation/movement of people and cargo	2 (4%)
7	excessive heel owing to wind pressure	flooding	1 (2%)
total			46

5.2.2. Discussion on Capsizing in Calm Water

From Table 10, it was revealed that “flooding,” “embarkation/movement of people and cargo” and “external force other than wind or wave” need countermeasures for capsizing in calm water. From sub-subsection 5.2.1.2., it was revealed that the danger of “excessive heel owing to wind pressure” surges when combined with advisories or warnings on strong wind.

6. Sinking Accident Analyses Using the Checklist

In this chapter, sinking accidents are analyzed using the checklist and the results are discussed.

The ship type and size of the sunk ships are shown in Table 14.

In this study, sinking in waves and sinking in calm water are analyzed. Sinking in waves has been analyzed by the authors in a former research (Yanagi and Taguchi, 2017). In this study, the former research was applied to analyze sinking in calm water.

Table 14: Ship type and size of the sunk ships

gross tonnage or length / ship type	less than 5GT	5 to 10GT	10 to 15GT	15 to 20GT	20 to 100GT	100 to 200GT	200 to 500GT	500 to 1600GT	1600 to 3000GT	less than 5m	5 to 100m	total	composition ratio (%)
passenger ship				1								1	1.2
cargo ship				1	1			1	1			4	4.9
tanker							2					2	2.4
fishing vessel	7	3	2			2	2					16	19.5
recreational fishing vessel	2		1									3	3.7
tugboat/push boat	1		1	11	2	1						16	19.5
work vessel	2	1	2	3								8	9.8
barge/lighter						1					3	4	4.9
public-service ship			2									2	2.4
pleasure boat	19	1	1	1						3		25	30.5
others	1											1	1.2
total	32	5	9	17	3	4	4	1	1	3	3	82	100
composition ratio (%)	39.0	6.1	11.0	20.7	3.7	4.9	4.9	1.2	1.2	3.7	3.7	100	

6.1. Analyses of Sinking in Waves

In this section, 24 sinking accidents in waves were analyzed using the checklist in Table 3.

The relationship of sinking factors in waves is shown in Figure 3. For a ship to sink, it practically needs to lose buoyancy. The only factor which could lose buoyancy is "flooding." Therefore, "flooding" is the only direct factor and the other factors are indirect factors.

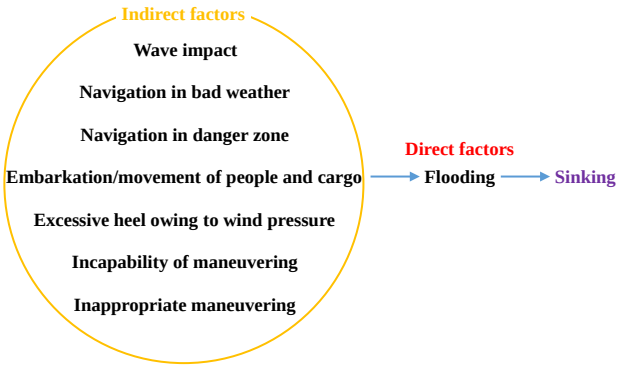

Figure 3: Relations of sinking factors in waves

Sinking factors for each ship type for the 24 accidents are shown in Table 15. "Inappropriate maneuvering" was not involved in sinking in waves analyzed in this paper.

The involvement of "navigation in bad weather" and "incapability of maneuvering" were high in addition to "flooding."

6.2. Analyses of Sinking in Calm Water

In this section, 33 sinking accidents in calm water were analyzed using the checklist in Table 3.

The relationship of sinking factors in calm water is shown in Figure 4. The relationship is basically the same with sinking factors in waves.

Sinking factors for each ship type for the 33 accidents are shown in Table 16. "Navigation in bad weather," "inappropriate maneuvering" and "excessive heel owing to wind pressure" were not involved in sinking in calm water analyzed in this paper.

7. Factors Which Need Countermeasures the Most

As for capsizing in waves, "navigation in bad weather" was involved in 35% of the accidents and it was the first event for most of the accidents. Although the ratio of "navigation in bad weather" was not high in capsizing in calm water, it was a menace to ships when combined with "excessive heel owing to wind pressure." As for sinking in waves, "navigation in bad weather" was involved in 42% of the accidents. Therefore, refraining from "navigation in bad weather" seems to be the most

effective countermeasure to prevent capsizing and sinking.

Table 15: Breakdown of sinking factors in waves

sinking factor \ ship type	cargo ship (2)	tanker (1)	fishing vessel (4)	recreational fishing vessel (1)	tugboat and push boat (6)	work vessel (1)	barge and lighter (2)	pleasure boat (7)	total (24)
navigation in bad weather	2 (100%)	1 (100%)	2 (50%)		4 (67%)	1 (100%)			10 (42%)
navigation in danger zone			1 (25%)			1 (100%)		1 (14%)	3 (13%)
incapability of maneuvering	1 (50%)	1 (100%)	2 (50%)		2 (33%)			4 (57%)	10 (42%)
embarkation/movement of people and cargo	1 (50%)		1 (25%)				1 (50%)		3 (13%)
flooding	2 (100%)	1 (100%)	4 (100%)	1 (100%)	6 (100%)	1 (100%)	2 (100%)	7 (100%)	24 (100%)
excessive heel owing to wind pressure		1 (100%)		1 (100%)	1 (17%)			1 (14%)	4 (17%)
total factors	6	4	10	2	13	3	3	13	54
number of involved factors per ship	3.0	4.0	2.5	2.0	2.2	3.0	1.5	1.9	2.3

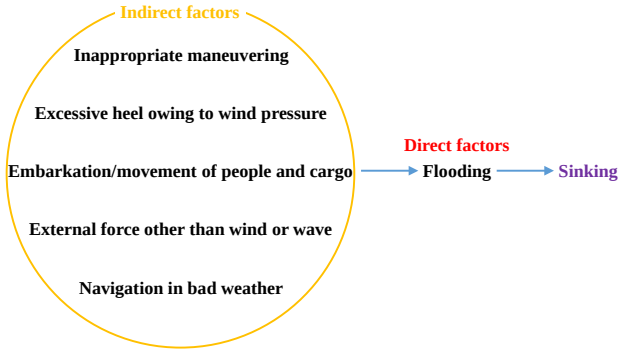

Figure 4: Relations of sinking factors in calm water

To prevent and mitigate "navigation in bad weather," havens between departure place and destination should be decided in case the weather deteriorates. Then, weather information should be acquired to decide the departure. After the decision of departure, continual acquisition of weather information and watch of sudden change of weather are necessary. This would help a quick escape to a haven.

The involvement of "flooding" was the highest in both capsizing and sinking accidents. Hence countermeasures against "flooding" are also necessary during navigation.

Table 16: Breakdown of sinking factors in calm water

sinking factor \ ship type	cargo ship (2)	tanker (1)	fishing vessel (7)	recreational fishing vessel (1)	tugboat and push boat (4)	work vessel (2)	barge and lighter (2)	public-service ship (1)	pleasure boat (12)	others (1)	total (33)
external force other than wind or wave					2 (50%)	1 (50%)					3 (9%)
embarkation/movement of people and cargo	1 (50%)	1 (100%)				1 (50%)			1(8%)		4 (12%)
flooding	2 (100%)	1 (100%)	7 (100%)	1 (100%)	4 (100%)	2 (100%)	2 (100%)	1 (100%)	12 (100%)	1 (100%)	33 (100%)
total factors	3	2	7	1	6	4	2	1	13	1	40
number of involved factors per ship	1.5	2.0	1.0	1.0	1.5	2.0	1.0	1.0	1.1	1.0	1.2

8. Conclusions

A checklist for analyzing capsizing and sinking accidents was made based on the survey of investigation reports published by JTSB and the classification of the accident factors extracted from the reports. By applying the checklist to the capsizing and sinking accidents surveyed in this paper, it was revealed that refraining from "navigation in bad weather" is the most effective countermeasure for capsizing and sinking. "Flooding," whose involvement was the highest in both capsizing and sinking, is the factor which needs countermeasures the most during navigation.

By applying the checklist to future accidents, accident analyses could be facilitated.

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