MA2021-2

MARINE ACCIDENT
INVESTIGATION REPORT

February 18, 2021

Japan Transport Safety Board

The objective of the investigation conducted by the Japan Transport Safety Board in accordance with the Act for Establishment of the Japan Transport Safety Board is to determine the causes of an accident and damage incidental to such an accident, thereby preventing future accidents and reducing damage. It is not the purpose of the investigation to apportion blame or liability.

TAKEDA Nobuo
Chairperson
Japan Transport Safety Board

Note:

This report is a translation of the Japanese original investigation report. The text in Japanese shall prevail in the interpretation of the report.

MARINE ACCIDENT INVESTIGATION REPORT

Vessel type and name:	Cargo vessel JIA DE
IMO number:	8989848
Gross tonnage:	1,925 tons

Accident/Incident type:	Foundering
Date and time:	Around 21:39, October 12, 2019 (local time, UTC+9 hours)
Location:	Higashi-Ogi Island offing to the south-east, Kawasaki City, Kanagawa Prefecture Around 137° true bearing, 1 nautical mile from the lighthouse on the Kawasaki Higashi-Ogi Island breakwater (approximately 35°28.9'N, 139°47.8'E)

January 20, 2021

Adopted by the Japan Transport Safety Board

Chairperson	TAKEDA Nobuo
Member	SATO Yuji
Member	TAMUARA Kenkichi
Member	KAKISHIMA Yoshiko
Member	OKAMOTO Makiko

SYNOPSIS

<Summary of the accident>

When the Cargo vessel JIA DE, manned with a master and eleven crewmembers, left a wharf of Keihin Port, and was anchoring at K1 anchorage point of Keihin Port on the way to proceed to Song Dang Port, the Socialist Republic of Vietnam, then the vessel received winds and waves that had increased due to the typhoon No.19 (Asian name "Hagibis", hereafter referred to as "the typhoon") approaching and heeled to the starboard side, and subsequently rolled over and was flooded due to taking on sea water into the interior of the cargo holds, and thereby foundered around the anchorage at around 21:39 on October 12, 2019.

The master and three crewmembers were rescued, but eight crewmembers died.

<Probable causes>

It is considered probable that the accident occurred because the Cargo vessel JIA DE foundered due to the fact that sea water which was being retained due to wave uprush on the upper deck (hereafter referred to as "the Retained Water") began flooding due to taking on sea water in the interior of the cargo holds, and then her steering was uncontrollable and she was receiving winds and wave uprush from the port fore side to port side, and furthermore her hull greatly heeled to the starboard side and she continued to be flooded due to taking on sea water in the interior of the cargo holds, and she subsequently rolled over due to her stability having been decreasing and flooding due to taking on sea water into the interior of the cargo holds progressed, with the result being that she foundered. This situation began while JIA DE was anchoring in the nighttime under conditions of rolling and pitching due to receiving winds and waves that had increased due to the typhoon approaching the area of K1 anchorage point of Keihin Port.

It is considered probable that the Retained Water on the deck began flooding due to taking on sea water in the interior of the cargo holds because the lids for opening parts of the ventilation cylinders of the cargo holds were in an open condition, and the water receiver railings at the connection parts between the panels of the hatch covers of the cargo holds had a number of broken holes and some parts of the panels were deformed, and thereby the hatch covers were not securely weather-tight. In addition, it is considered probable that wave uprush on the deck further increased because her dry draft had been decreasing due to ingress water into the interior of the cargo holds and the Retained Water.

It is considered probable that JIA DE was in a state in which her steering was uncontrollable because ingress water that infiltrated into the marine diesel oil (MDO) tank interior through air vents on the upper deck was supplied to the diesel generator engines with MDO through the fuel oil (FO) supply line of the diesel generator engines, and then the diesel generator engines experienced combustion failure or misfiring, and subsequently stopped, and thereby the blackout occurred.

It is considered probable that after the steering of JIA DE was uncontrollable and she was receiving further increased winds and wave uprush from the port fore side to port side, she heeled to the starboard side due to receiving winds and waves and came to roll on that angle, and then heeling to the starboard side gradually increased due to receiving strong wind and heavy waves due to the typhoon. It is considered probable that after she attained the angle of stability in maximum condition, and subsequently the lateral heeling angle increased due to continuous waves, because this thereby led to the lateral heeling angle attaining the angle of loss of residual stability and she rolled over to the starboard side.

<Safety Recommendation>

It is considered probable that the accident occurred because the cargo vessel JIA DE foundered due to the fact that sea water which was being retained due to wave uprush on the upper deck (hereafter referred to as “the Retained Water”) began flooding due to taking on sea water in the interior of the cargo holds, and then her steering was uncontrollable and she was receiving winds and wave uprush from the port fore side to port side, and furthermore her hull greatly heeled to the starboard side and she continued to be flooded due to taking on sea water in the interior of the cargo holds, and she subsequently rolled over due to her stability having been decreasing and flooding due to taking on sea water into the interior of the cargo holds progressed, with the result being that she foundered. This situation began while JIA DE was anchoring in the nighttime under conditions of rolling and pitching due to receiving winds and waves that had increased due to the typhoon No.19 (Asian name “Hagibis”) approaching the area of K1 anchorage point of Keihin Port.

It is considered probable that the Retained Water on the deck of JIA DE began flooding due to taking on sea water in the interior of the cargo holds because the lids for opening parts of the ventilation cylinders of the cargo holds were in an open condition, and the water receiver railings at the connection parts between the panels of the hatch covers of the cargo holds had a number of broken holes and some part of the panels of the hatch covers were deformed, and thereby the hatch covers were not securely weather-tight. In addition, it is considered probable that wave uprush on the deck further increased because her dry draft had been decreasing due to ingress water into the interior of the cargo holds and the Retained Water.

It is considered probable that JIA DE was in a state in which her steering was uncontrollable because ingress water that infiltrated into the marine diesel oil (MDO) tank interior through the air vents on the upper deck was supplied to the diesel generator engines with MDO through the fuel oil supply line of the diesel generator engines supply line, and then the diesel generator engines experienced combustion failure or misfiring, and subsequently stopped, and thereby the blackout occurred.

In view of the results of this accident investigation, the Japan Transport Safety Board recommends that the Panama Maritime Authority, the Republic of Panama (hereafter referred to as “Panama”) as the flag state of JIA DE should take the following measures to prevent similar accidents and to reduce damage.

The Panama Maritime Authority, Panama should instruct the Owners and the Management Companies (hereafter referred to as “the Companies”) of Panama flag vessels to engage in the following practices due to securing safety for crewmembers and vessels in stormy weather and rough seas.

(1) The Companies should instruct masters and crewmembers to reliably carry out closing of opening parts on exposed decks such as lids of opening parts of ventilation cylinders of cargo holds, etc. in case that stormy weather and rough seas are expected.

(2) The Companies should instruct masters and crewmembers to secure significant dry draft in any sea condition, and therefore should crewmembers to carry out adjustment of the ship’s condition.

(3) The Companies should instruct masters and crewmembers to carry out the drain discharging operation in which each drain valve of fuel oil tanks is operated not only

periodically as routine work, but also on a timely basis in a condition of rolling and pitching in stormy weather and rough seas so as not to supply fuel oil with infiltrated water into the fuel oil supply lines of generator engines, etc. in case that air vent pipes of fuel oil tanks were not equipped automatic opening and closing-type air vent head, etc. to automatically prevent the infiltration of water.

(4) The Companies should instruct masters and crewmembers to conduct refresher training for crewmembers concerning survival techniques at sea for getting ready for abandon ship, such as taking out belongings, escape behavior from the interior of the vessel, putting on a life jacket and immersion suit, dressing warmly, etc.

(5) The Companies should implement maintenance necessary including the water receiver railings of the hatch cover to secure weather-tightness of the hatch cover of the cargo holds themselves with regard to the vessels managed and owned by the Companies.

Table of contents

1 PROCESS AND PROGRESS OF THE INVESTIGATION

1.1 Summary of the Accident

When the Cargo vessel JIA DE, manned with a master and eleven crewmembers, left a wharf of Keihin Port, and was anchoring at K1 anchorage point of Keihin Port on the way to proceed to Song Dang Port, the Socialist Republic of Vietnam, then the vessel received winds and waves that had increased due to typhoon No.19 approaching and heeled to the starboard side, and subsequently rolled over and was flooded due to taking on sea water into the interior of the cargo holds, and thereby foundered around the anchorage at around 21:39 on October 12, 2019.

The master and three crewmembers were rescued, but eight crewmembers died.

1.2 Outline of the Accident Investigation

1.2.1 Setup of the Investigation

The Japan Transport Safety Board appointed an investigator-in-charge and one other marine accident investigator to investigate this accident on October 13, 2019, and later appointed two marine accident investigators in addition.

1.2.2 Collection of Evidence

October 13 and 14, 2019, and February 20, 28 and 29, 2020: On-site investigation and interviews

October 16 to 19, 21 and 22: Interviews and collection of questionnaires

October 24 to 26, 28 to November 3, 8 and 10 to 12, 21, December 6 and 13, 2019, and January 10, 2020: Collection of questionnaires

November 13 and 14, and July 8, 2020: Interviews

1.2.3 Tests and Research by Other Institutes

With respect to the accident, the JTSB entrusted to the National Maritime Research Institute (NMRI) the investigations into the stability and the circumstances of foundering of the JIA DE.

1.2.4 Comments from Parties Relevant to the Cause

The procedure of comments on the draft report which were invited from the parties relevant to the cause of the accident, was implemented.

1.2.5 Comments from Flag State

Comments on the draft report were invited from the flag state and the substantially interested state of the JIA DE.

2 FACTUAL INFORMATION

2.1 Events Leading to the Accident

2.1.1 The Navigational Track of the JIA DE According to the Automatic Identification System

According to the "Records of the Automatic Identification System (AIS)*1 data (hereinafter referred to as "the AIS record") of the JIA DE (hereinafter referred to as "the Vessel") received by a private data company in Japan", the Vessel's navigation track from 13:59:47 to 21:35:49 on October 12, 2019 was as shown in Table 1 below.

It should be noted that no AIS record from the Vessel was received after 21:35:49 on October 12.

Table 1 AIS Record of the Vessel (Excerpt)

Date *Recording period*	Time (hr:min:sec)	Ship's Position*		Course Over The Ground※ (°)	Heading* (°)	Speed Over The Ground (knots (kn))
		Latitude (N) (°-′-″)	Longitude (E) (°-′-″)			
October 12 Since using two anchors mooring *Approximately Hourly*	13:59:47	35-28-44.0	139-47-36.0	13.6	Un-available	0.4
	14:59:44	35-28-46.0	139-47-37.0	225.1		0.2
	15:59:47	35-28-48.5	139-47-38.0	189.8		0.4
	16:59:39	35-28-49.2	139-47-38.0	120.2		0.5
	18:02:40	35-28-50.0	139-47-38.0	120.2		0.6
Since Stand -by *Approximately every 10 min.*	18:50:37	35-28-49.6	139-47-38.0	287.5		0.1
	19:02:39	35-28-50.0	139-47-38.7	354.8		0.5
	19:11:38	35-28-49.7	139-47-38.2	225.6		0.4
	19:20:40	35-28-49.9	139-47-38.5	210.7		0.3
	19:32:37	35-28-50.3	139-47-38.9	133.5		0.4
	19:41:40	35-28-50.2	139-47-38.0	68.5		0.2
	19:50:38	35-28-50.5	139-47-38.7	87.3		0.3
	20:02:41	35-28-50.8	139-47-38.5	235.0		1.0
	20:11:41	35-28-51.5	139-47-39.4	349.4		0.6
	20:20:38	35-28-52.1	139-47-40.1	21.9		1.0
	20:32:41	35-28-52.7	139-47-41.3	209.7		0.8
	20:41:39	35-28-53.2	139-47-43.0	337.3		0.5
Timely	20:47:33	35-28-53.5	139-47-43.0	89.0		2.0
	21:07:20	35-28-54.9	139-47-46.4	301.6		2.4
	21:10:18	35-28-55.3	139-47-48.2	157.5		1.4
	21:14:24	35-28-55.5	139-47-48.1	107.7		3.6
	21:23:52	35-28-56.5	139-47-48.8	243.9		0.7
	21:26:49	35-28-56.3	139-47-49.8	110.6		1.4

*1 AIS (Automatic Identification System) is a device that can automatically transmit and receive information such as vessel identification codes, ship types, names, positions, and courses, and exchange information with other vessels or land-based navigation aids.

	21:29:51	35-28-55.7	139-47-50.8	304.1		0.9
	21:32:50	35-28-56.2	139-47-50.4	109.8		1.5
	21:35:49	35-28-56.6	139-47-49.8	120.0		2.5
	～	No AIS record from the Vessel				

* The vessel position indicates the position of the GPS antenna installed above the navigation bridge. The antenna of the Vessel was set on the deck above the navigation bridge; the location of the antenna was 61 m from the fore side, 18 m from the stern side, 6 m from the port side and 7 m from the starboard side, and then the courses over the ground and headings are indicated in true bearings (hereinafter the same).

2.1.2 Voice Record Data by VHF Radiotelephone

According to the VHF wireless telephone communication history (hereinafter referred to as "VHF" except in Chapter 6) provided by the Tokyo Wan Vessel Traffic Service Center (hereinafter referred to as "Tokyo MARTIS"), the voice communication records between Tokyo MARTIS and the Vessel were seven times from 21:07 and 21:23 on October 12, 2019 were as shown in Table 2.

Because VHF channel 16 is the common channel for calling and responding and the other channels are for individual radio communication, vessels that are sailing or anchoring are obliged to listen to information on channel 16.

Table 2 VHF Communication History

Time	Speaker	Receiver	CH	Content
20:00-20:09 1st time	Communication between the Vessel and Tokyo MARTIS		16 14	Summary The Vessel informed Tokyo MARTIS that a vessel which was at her port side was dredging and closing to her.
20:10-20:11 2nd time	Ditto		16	Summary Tokyo MARTIS confirmed the position of the Vessel.
20:16-20:18 3rd time	Ditto		16 66	Summary The Vessel informed Tokyo MARTIS that the dredging vessel which had been at her port side was dragging and closing to her, but then the dredging vessel was leaving her to the stern side, and thereby was clear and kept a safe distance between the Vessel and the dredging vessel. Tokyo MARTIS confirmed that the Vessel continued to be at her anchorage point.
20:23-20:23 4th time 21:05-21:06 5th time	Ditto			No communication between the Vessel and Tokyo MARTIS.
21:07-21:08	Tokyo MARTIS	The Vessel	16	JIA DE, JIA DE, 3EMK4 (her call sign), THIS IS TOKYO MARTIS. THIS IS TOKYO MARTIS.

6th time	The Vessel	Tokyo MARTIS		TOKYO MARTIS, JIA DE, OVER.
	Tokyo MARTIS	The Vessel		CHANGE TO 6, 9, 69, OVER.
	The Vessel	Tokyo MARTIS	69	TOKYO MARTIS, TOKYO MARTIS, MOTOR VESSEL JIA DE CALLING. HOW DO YOU READ ME? OVER.
	Tokyo MARTIS	The Vessel		JIA DE, THIS IS TOKYO MARTIS. [WARNING.] ACCORDING TO OUR RADAR, YOU SEEM TO BE DRAGGING ANCHOR. [QUESTION.] ARE YOU DRAGGING ANCHOR NOW? OVER.
	The Vessel	Tokyo MARTIS		I’M ALL TIME USE ENGINE. I’M ALL TIME USE ENGINE. OVER.
	Tokyo MARTIS	The Vessel		QUESTION. CAN YOU MANEUVERING? OVER.
	The Vessel	Tokyo MARTIS		MANEUVERING. BUT I’M DROPPING ANCHOR. I’M DROPPING ANCHOR. OVER.
	Tokyo MARTIS	The Vessel		I COPY. AND MANEUVERING I COPY. KEEP WATCH CH 16 AND KEEP SHARP LOOKOUT. BACK TO CH16. OUT.
	The Vessel	Tokyo MARTIS		CH16. OUT.
21:23-21:24 7th time	Tokyo MARTIS	The Vessel	16	MOTOR VESSEL JIA DE, JIA DE, CALL SIGN 3EMK4, THIS IS TOKYO MARTIS.
	The Vessel	Tokyo MARTIS		TOKYO MARTIS, JIA DE, OVER.
	Tokyo MARTIS	The Vessel		GO UP TO CH 66 DOUBLE 6.
	The Vessel	Tokyo MARTIS	66	JIA DE CALLING.
	Tokyo MARTIS	The Vessel		THIS IS TOKYO MARTIS. [WARNING.] ACCORDING TO OUR RADAR, YOU SEEM TO BE DRAGGING ANCHOR. [QUESTION.] ARE YOU DRAGGING NOW? OVER.
	The Vessel	Tokyo MARTIS		NO, DROP ANCHOR, 9 SHACKLE, 9 SHACKLE. SO – (Unclear) – NOW – (Unclear) -. I CHECKED NORMAL CONDITION. THANK YOU ADVICE.
	Tokyo MARTIS	The Vessel		DROP ANCHOR. BUT USING ENGINE. IS THAT CORRECT? OVER.
	The Vessel	Tokyo MARTIS		USE ENGINE ALL TIME ALREADY USING.
	Tokyo MARTIS	The Vessel		OK. BACK TO CH 16. OUT.

	The Vessel	Tokyo MARTIS		16. OUT.

2.1.3 Events Leading to the Accident According to the Information of Crewmembers and Others

According to the statements and the replies to the questionnaires of Master of the Vessel (hereinafter referred to as "Master"), Chief Engineer, Navigation Officer (hereinafter referred to as "N. Officer A"), Oiler (hereinafter referred to as "Oiler A"), the person in charge of the Vessel agent (hereinafter referred to as "the Agent"), and the reply of MARTIS, the events leading to the accident were as follows:

(1) Development of Events from the Vessel's Arriving at the Port to her Foundering

On October 9, 2019, the Vessel manned with Master and eleven crewmembers (two with nationality of the Republic of the Union of Myanmar, two with nationality of the Socialist Republic of Vietnam and seven with nationality of the People's Republic of China) arrived at No.2 public wharf (hereinafter referred to as "the Wharf") of Kawasaki Dai 1 District of Keihin Port at around 06:30, and then loaded steel scrap of approximately 3,045 tons[*2], and subsequently was scheduled to navigate to Song Dang Port, the Socialist Republic of Vietnam. However, typhoon No.19 (Asian name "Hagibis") was approaching the Kanto Region, Japan, therefore the Vessel rescheduled to anchor in Tokyo Wan temporarily and received direction from the harbour master concerning anchoring at K1 anchorage point of Keihin Port (hereinafter referred to as "K1 anchorage").

The Vessel left the Wharf at around 22:00 on October 10, and then anchored with the starboard anchor and extended seven shackles (the length of one shackle was 27.5 meters) of anchor chains at K1 anchorage at around 23:45.

The Vessel conducted bunkering and received Marine Diesel Oil (MDO) of approximately 9.303 t and Heavy Fuel Oil (HFO) of approximately 10.500 t at K1 anchorage from around 07:30 to around 09:58 on October 11.

At around 12:00 on October 12, Master gave some notifications to nine crewmembers during lunch in the dining room, concerning attention for the approaching typhoon and the Vessel's actions after that time, and subsequently conveyed similar notifications to two duty crewmembers: one crewmember in the navigation bridge, and another crewmember in the engine room.

At around 14:00, the Vessel dropped the port anchor and extended five shackles and half anchor chains with an angle of 50° between the starboard anchor chains and the port anchor by Master's order, and subsequently the Vessel was in a condition of using two anchors.

At around 19:00, Master ordered the stand-by station for the purpose of preparing for winds and waves increased due to the typhoon approaching. N. Officer A, another N. Officer (hereinafter referred to as "N. Officer B"), Boatswain, Able Seaman and Ordinary Seaman were assigned in the navigation bridge, and Chief Engineer, Engineer and the other Oiler (hereinafter referred to as "Oiler B") were assigned in the engine room. Subsequently Master had the engine department conduct preparations of the main engine running and commanded maneuvering of the Vessel himself in the navigation bridge.

Master was maneuvering the Vessel to direct the heading of the Vessel against winds and

[*2] Steel scrap of 3045.000 MT (metric tons) was calculated by "bulk specific gravity" as 1.000, where "bulk specific gravity" means the ratio of the weight in air of a given volume of permeable material to the weight in air of an equal volume of distilled water.

waves from the south-east using the steering and the main engine and was stabilizing her attitude. At this time, the Vessel had been rolling approximately 5° by the indication on the clinometers, and subsequently pitting movement was added due to maneuvering her against winds and waves.

At around 20:00, winds and waves had increased and become stronger, and thereby the Vessel heeled by more than 10°. At this time, when Master was checking the Vessel's position and was keeping watch around her with ECDIS (Electronic Chart Display and Information System) and the radars, he was aware that the other vessel which had been at her port side was dredging and was approaching the Vessel, and then called the call name of the dredging vessel by VHF and conducted maneuvering of the Vessel using the steering and the main engine to avoid collision with the dredging vessel. Master directed N. Officer B to report to Tokyo MARTIS (1st Communication by VHF) that a vessel was dredging near the Vessel.

Master recognized that the dredging vessel was moving to the stern side of the Vessel. At around 20:16, the Vessel received a contact from Tokyo MARTIS (3rd Communication) and reported that the dredging vessel had left the Vessel's position and kept clear around her.

At around 21:07 (6th Communication) and around 21:23 (7th Communication), the Vessel received inquiries regarding whether the Vessel was dredging or not, and subsequently Master had N. Officer B send the reply that the Vessel was anchoring and was using the main engine, and was stabilizing her attitude well. After this time, No. 2 diesel generator engine, which was in running condition, stopped suddenly and electric power was lost in the Vessel (hereinafter referred to as "the blackout"), and thereby the Vessel fell into an uncontrollable steering state due to the electric power supply to the steering gear being cut off.

As the Vessel was able to run the main engine, Master tried to maneuver the Vessel to stabilize her attitude only by using the main engine. Chief Engineer and Engineer then started No.1 generator, which was in stand-by condition, in manual operation, and then turned on the air circuit breaker of No.1 generator on the main switch board and supplied electric power within one or two minutes after the blackout.

Chief Engineer and Engineer checked the fuel oil supply line (hereinafter referred to as "the FO line") of No.2 diesel generator engine, and then they discovered that some ingress water had infiltrated in the FO line, and subsequently conducted work to discharge ingress water from the FO line and put the No.2 generator into a condition of being available for running.

Subsequently, No.1 diesel generator engine stopped immediately, and then No.2 generator was started by Chief Engineer and Engineer, and electric power was recovered in the Vessel.

Master thought of emergency steering operation and left the Vessel maneuvering to N. Officer B, and subsequently moved with Able Seaman from the navigation bridge to the steering gear room, and conducted preparations for emergency steering operations.

No.2 generator stopped twice after it was restarted, and each time the crewmembers of the engine department discharged ingress water from the FO line, and restarted No.2 generator again and again. As a result, at around 21:32, electric power was supplied continuously in the Vessel and was recovered.

Master and Able Seaman confirmed that electric power was recovered, and then returned to the navigation bridge, and subsequently Master conducted Vessel maneuvering while she received winds and waves from the direction between the fore side and port fore side.

Even though the cargo hold hatch covers on the upper deck of the Vessel had been covered over by tarpaulin sheets (a kind of composite waterproof sheet manufactured by fiber fabric and synthetic resin) secured with ropes, etc., the sheets had already turned up from the edges of the sheets due to receiving wind and waves, and subsequently detached due to the action of waves and winds in order of No.1 cargo hold and No.2 cargo hold, and thereby the hatch covers were exposed to winds and waves directly.

At around 21:34, the Vessel heeled to the starboard side by approximately 5°on the indication of the clinometer, and subsequently was gradually increasing to heel to the starboard side by approximately 30°. At that time, Master felt this was a situation with the danger of capsizing, and then directed N. Officer B to give notice of the abandon ship station and to whistle the general emergency signal (this signal is used on board vessels in times of emergency).

Master picked up three life jackets which had been stored in the navigation bridge interior, and then handed a life jacket to each of N. Officer A, Able Seaman and Chief Cook, who was just coming to the navigation bridge, and subsequently went to his room, which was one level down, and put important documents such as certificates, passports, etc. into a bag and grabbed it, and then moved to the master station (a meeting place for the abandon ship station).

Master, N. Officer B, Chief Engineer, Boatswain, Oiler A, Oiler B and another Oiler (hereafter referred to as “Oiler C”) gathered at the master station of the port side on the boat deck, and subsequently the Vessel heeled further to the starboard side by approximately 45˚.

Master thought there was no time to launch the life raft into the sea, and then directed the crewmembers who were at the master station to jump into the sea directly, and subsequently he saw that the crewmembers jumped into the sea off the Vessel’s port side in order of Oiler B and Oiler C, Master and Oiler A, and Chief Engineer, but did not know of other crewmembers’ behavior.

N. Officer A put on a life jacket and still remained at the port wing of the navigation bridge. While he saw the Vessel heeling further to the starboard side, he felt something in the cargo hold was moving to the starboard side, and subsequently the Vessel rolled over rapidly to the starboard side and foundered, and at a similar time N. Officer A entered the sea.

According to the radar records of Tokyo MARTIS, at around 21:39, the shadow of the Vessel disappeared from the screen of the radar.

The date and the time of occurrence of the accident was at around 21:39 on October 12, 2019, and the location of the accident was around 137º, 1 nautical mile (M) from the lighthouse on the Kawasaki Higashi-Ogi Island breakwater.
(Refer to Figure 1 and Annex Figure 1 Schematic Diagram of the Accident Location)

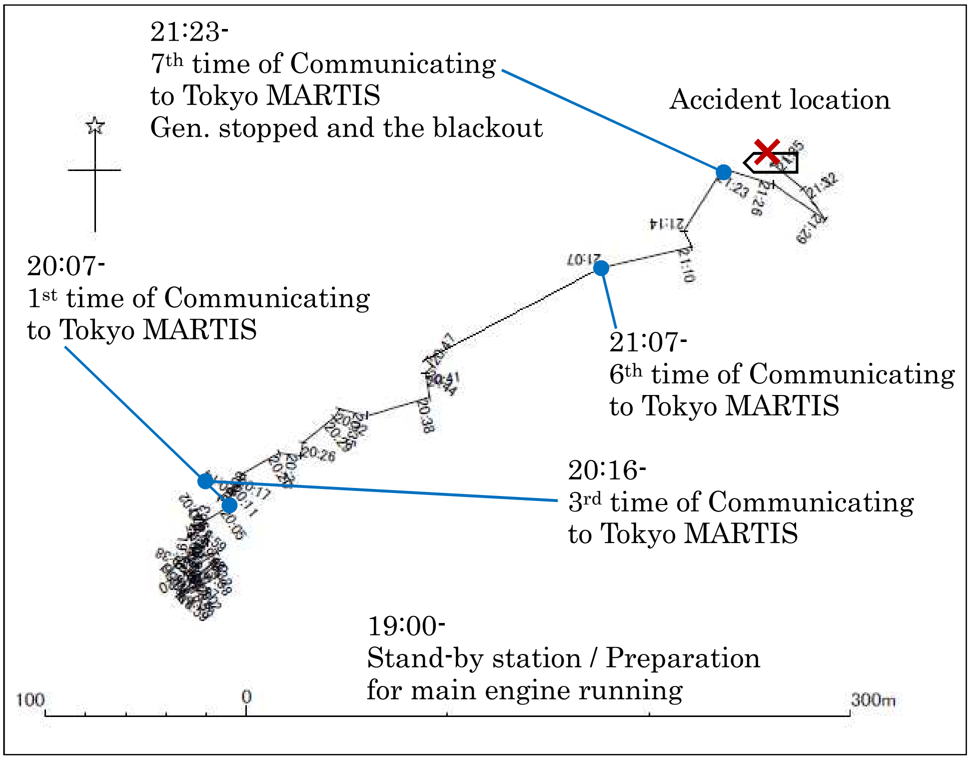

Figure 1 Situation of the Vessel (Time: JST)

(2) Development of Events from Foundering to Search and Rescue, Discovery and Recovery of the Crewmembers

According to the statement of a salvage company (hereinafter referred to as "Company A") and the information of the Japan Coast Guard (JCG) and, the search and rescue actions were as follows:

(i) At around 23:20 on October 12, JCG received an emergency report from a vessel anchoring at around the offing position of 1.3 M from Higashi-Ogi Island, Kawasaki district, Kawasaki City, Kanagawa Prefecture to Tokyo MARTIS that some persons were swimming around a vessel. JCG patrol vessels (hereinafter referred to as "the patrol vessels"), JCG patrol boats (hereinafter referred to as "the patrol boats") and aircraft belonging to JCG were deployed and investigated.

(ii) At around 00:20 on October 13, the patrol boats arrived around the location where the emergency report was made, and then perceived an oily smell and discovered the lifebuoys which had the mark of "JIA DE" written on them; however, there was no sign of the Vessel which had anchored at the anchorage point.

(iii) At around 01:30, two patrol vessels, six patrol boats, one helicopter belonging to JCG and a JCG special rescue team (hereinafter referred to as "the SRT") were investigating around the accident location. A rescue boat which was loaded on the patrol vessel (hereinafter referred to as "the loaded rescue boat") rescued Chief Engineer, and then rescued Master and Oiler A at around 01:40, who were in a drifting condition in the sea, and subsequently were able to confirm them as crewmembers of the Vessel. Furthermore, in addition, two loaded rescue boats, one patrol vessel, one survey ship belonging to JCG (hereinafter referred to as "the survey vessel") and four members of the JCG national strike team, as well as one fire boat which belongs to the Fire Department of Kawasaki City, joined in the search and rescue action, at around 02:55, and N. Officer A, who was in a drifting condition in the sea, was discovered and was rescued.

The life raft of the Vessel was discovered around the accident location but there were no persons in it.

(iv) At around 03:00, the survey vessel discovered an object like the Vessel which was under the sea at an offing position of approximately 1.4 M from Higashi-Ogi Island, and subsequently, at around 05:50, the SRT dove and searched, and thereby confirmed that the vessel found at around the accident location was the Vessel. By around 06:30, they discovered and recovered two drifting crewmembers on the sea and three crewmembers in the Vessel interior, which had already foundered.

(v) As a result of the search and rescue action on October 14, JCG discovered and recovered one crew member at Yokosuka City offing, Kanagawa Prefecture and one crewmember was discovered and recovered in the Vessel interior; however, one crewmember continued missing out of Master and eleven crewmembers.

(vi) Company A raised the foundered Vessel around the accident location by a crane vessel between February 13 and 15, 2020, and at that time, discovered one crewmember in the Vessel interior who had been missing at the time of the accident. JCG received this report from Company A and the SRT recovered the crewmember on February 14. (See Figure 2)

Raising work by crane vessel


Raising the Vessel


The Vessel mooring at a barge

Figure 2 Raising Work for the Vessel

2.2 Casualties and Injuries to Persons

According to the statements by Master and the person in charge of the Agent, and the information provided by JCG, the casualties, injuries to persons, etc. were as follows:

N. Officer B, Engineer, Boatswain, Able Seaman, Oiler B, Oiler C and Chief Cook, and Ordinary Seaman who was discovered when the Vessel was recovered, underwent judicial autopsies, and as a result, eight crewmembers were diagnosed as having drowned.

Chief Engineer and N. Officer A were hospitalized due to the possibility of having water in their respiratory organs, and subsequently were in hospitals in Yokohama City, Kanagawa Prefecture (Chief Engineer for two days, and N. Officer A for four days).

2.3 Damage to Vessel

According to information provided by JCG, the Vessel foundered and was in sea water with a depth of approximately 28 meters around the accident location, her heading to the south-west, her port side upward and grounded in a condition of heeling to her starboard side.

2.4 Crew Information

(1) Gender, Age, and Certificate of Competence

(i) Master: Male, 54 years old, national of the Republic of the Union of Myanmar (hereinafter referred to as "Myanmar")

Endorsement attesting to recognition of certificate under STCW*[3] regulation I/10: Management Level (Navigation), issued by the Republic of Panama (hereinafter referred to as "Panama")

Date of Issue: July 14, 2019

(Valid date: December 22, 2021)

Master had a license as a master for gross tonnage less than 3,000 tons that was issued by Myanmar.

(ii) Chief Engineer: Male, 33 years old, national of the Socialist Republic of Vietnam (hereinafter referred to as "Vietnam")

Endorsement attesting to recognition of certificate under STCW regulation I/10: Management Level (Marine Engineering), issued by Panama

Date of Issue: September 15, 2019

(Valid date: December 15, 2019)

Chief Engineer had a license as a chief engineer for engine output less than 3,000 kW that was issued by Vietnam.

(iii) N. Officer A: Male, 47 years old, national of the People's Republic of China (hereinafter referred to as "China")

Endorsement attesting to recognition of certificate under STCW regulation I/10: Operational Level (Navigation), issued by Panama

Date of Issue: September 22, 2019

(Valid date: December 22, 2019)

N. Officer A had an Operational Level (Navigation) license that was issued by China.

(iv) Oiler A: Male, 27 years old, national of Myanmar

Endorsement attesting to recognition of certificate under STCW regulation I/10: Support, issued by Panama

Date of Issue: September 13, 2019

(Valid date: August 18, 2024)

Oiler A had an oiler certificate that was issued by Myanmar.

(v) Other crewmembers

According to the statements by Master and Chief Engineer and N. Officer A, Ordinary Seaman had an Operational Level (Navigation) license issued by Vietnam, and the other crewmembers also had licenses or certificates issued by their respective native countries.

(2) Sea-going Experience, etc.

According to the statements by Master, Chief Engineer, N. Officer A and Oiler A, their experience was as follows:

(i) Master

Master had belonged to the navy as a navigation officer from 1985, and then qualified for a license as a navigation officer for merchant vessels in the seafarer training center of the

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*3 "STCW (Convention)" refers to the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers of 1978.

Department of Marine Administration, and subsequently embarked as a navigation officer of merchant vessels from 2009. He embarked in the Vessel and had been assigned as a master from June, 2019.

He was in good health at the time of the accident.

(ii) Chief Engineer

Chief Engineer qualified for a license as a marine engineer in a marine school in Vietnam and had embarked in merchant vessels, and subsequently, after studying the subject of ship management in a marine school, he qualified for a license as a chief engineer in 2017, and then embarked in the Vessel from September, 2019.

He was in good health at the time of the accident.

(iii) N. Officer A

N. Officer A qualified for a license as a navigation officer in a nautical school in China and had experience on board general cargo vessels of a similar type to the Vessel, and subsequently embarked in the Vessel from May, 2019.

He was in good health at the time of the accident.

(iv) Oiler A

Oiler A qualified for a certificate as an oiler in the seafarer training center of the Department of Marine Administration, and subsequently embarked in the Vessel from August, 2019.

He was in good health at the time of the accident.

(v) The other crewmembers

The other crewmembers were in good health at the time of the accident.

2.5 Vessel Information

2.5.1 Particulars of Vessel

IMO number:	8989848
Port of registry:	Panama City (Panama)
Owner:	Jia de Marine Shipping Co., Limited (Hong Kong, Special Administrative Region of China) (hereinafter referred to as "Company B")
Management company:	Realshipping Int'l Marine Co., Limited (Hong Kong, Special Administrative Region of China) (hereinafter referred to as "Company C")
Gross tonnage:	1,925 tons
L×B×D:	82.65 m × 13.00 m × 6.60 m
Load line: [*4]	Summer LL (load line): 1,112 mm downward from the upper edge of the deck line
Hull material:	Steel
Engine:	Diesel engine × 1

[*4] "Load line" refers to a marking of the minimum "freeboard" (height from the waterline to the top surface of the upper deck) when a vessel is fully loaded that is regulated and calculated based on the International Convention on Load Lines of 1966 (LL Convention). It is the threshold at which sufficient freeboard can be maintained for safe navigation with sufficient reserve buoyancy while a vessel is under way. There are various load lines, including the winter load line and the summer fresh water load line. In the sea area in which the Vessel was operating, the summer load line was applied throughout the year.

Output:	750 kW
Propulsion:	4 blades - Fixed pitch propeller × 1
Built Year:	2002

(See Photo 1)

Photo 1 The Vessel (before the accident)

2.5.2 Load Conditions, etc.

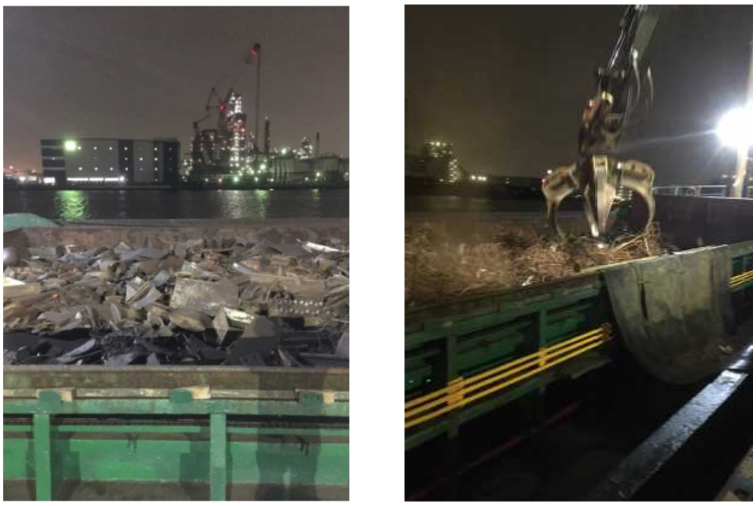
According to the statements by Master and Chief Engineer, the replies to the questionnaires by the Agent and the Cargo loading company, the loading business record which was delivered by the Cargo loading surveyor and the international LL certificate, the cargo loading condition of the Vessel at the time of departing from the Wharf of Keihin Port, and on the day of the accident, fuel oil storage, the draft, etc. at K1 anchorage were as in Table 3 and Photo 2.

According to the Bunker delivery receipt, the specification of MDO specified that water content was 0.05 percent.

Table 3 Storage of Cargo, Fuel Oil, etc. and Condition of Draft, etc.

Loading Objects	Weight (tons)
Steel scrap (No.1 cargo hold)	1,348.880
Steel scrap (No.2 cargo hold)	1,696.120
MDO	Approximately 17.903
HFO	Approximately 61.852
Lubricating oil	Approximately 2.58
Fresh water	Approximately 67.0

At K1 Anchorage after Bunkering	
Draft (Fore/Aft)	Approximately 5.30 m / Approximately 5.80 m Mean approximately 5.55 m Dry draft (hull mid.) approximately 1.050 m
Heel	None
* Summer LL was 5.488 m	



*　The cargo of steel scrap was loaded with heavy equipment, and subsequently the surfaces of steel scrap were pushed down and made level.

Photo 2　Loading of Steel Scrap in the Cargo Holds in Keihin Port

2.5.3 Hull Structure and Ship Operation Equipment

According to the on-site investigation, the statements by Master, Chief Engineer, Oiler A, the person in charge of the Agent and the parson in charge of Company A, and the General Arrangement Plan and the schematic diagram of the cargo holds, it was as follows:

(1)　Hull Structure and Equipment

The Vessel, which was engaged in international navigation, was a double-decker-type bulk carrier with a docking bridge.　The Vessel had a No. 1 cargo hold and No. 2 cargo hold arranged from the fore, her forecastle in the bow and her bridge above the deck structure on the sterncastle deck.

The Vessel, on the day of the accident, did not have any problem in her hull except the hatch covers of the cargo holds.　The Vessel had GMDSS[*5] equipment installed, but distress signals were not received by JCG, etc.　Moreover, there were no information that the equipment such as EPIRB[*6] was not discovered after the accident.

(See Figure 3, Annex Figure 2　General arrangement)

[*5]　"GMDSS (Global Maritime Distress and Safety System)" refers to a radio communication system based on global system regarding to distress and safety at sea, all the passenger vessels and cargo vessels above 300 tons involved in international voyage have to install GMDSS equipment due to securing distress signal and radio communication stably in emergency situation, and furthermore, GMDSS transmit maritime safety information as navigation warning, weather warning, etc.

[*6]　"EPIRB (Emergency position-indicating radio beacon station)" refers to a radio transmitter, a type of buoy, that transmits distress signal to satellites.　When a vessel is foundering, the water pressure sensor of the radio transmitter begins to operate and the transmitter comes to the surface automatically, and subsequently a distress signal is transmitted by automatic operation.

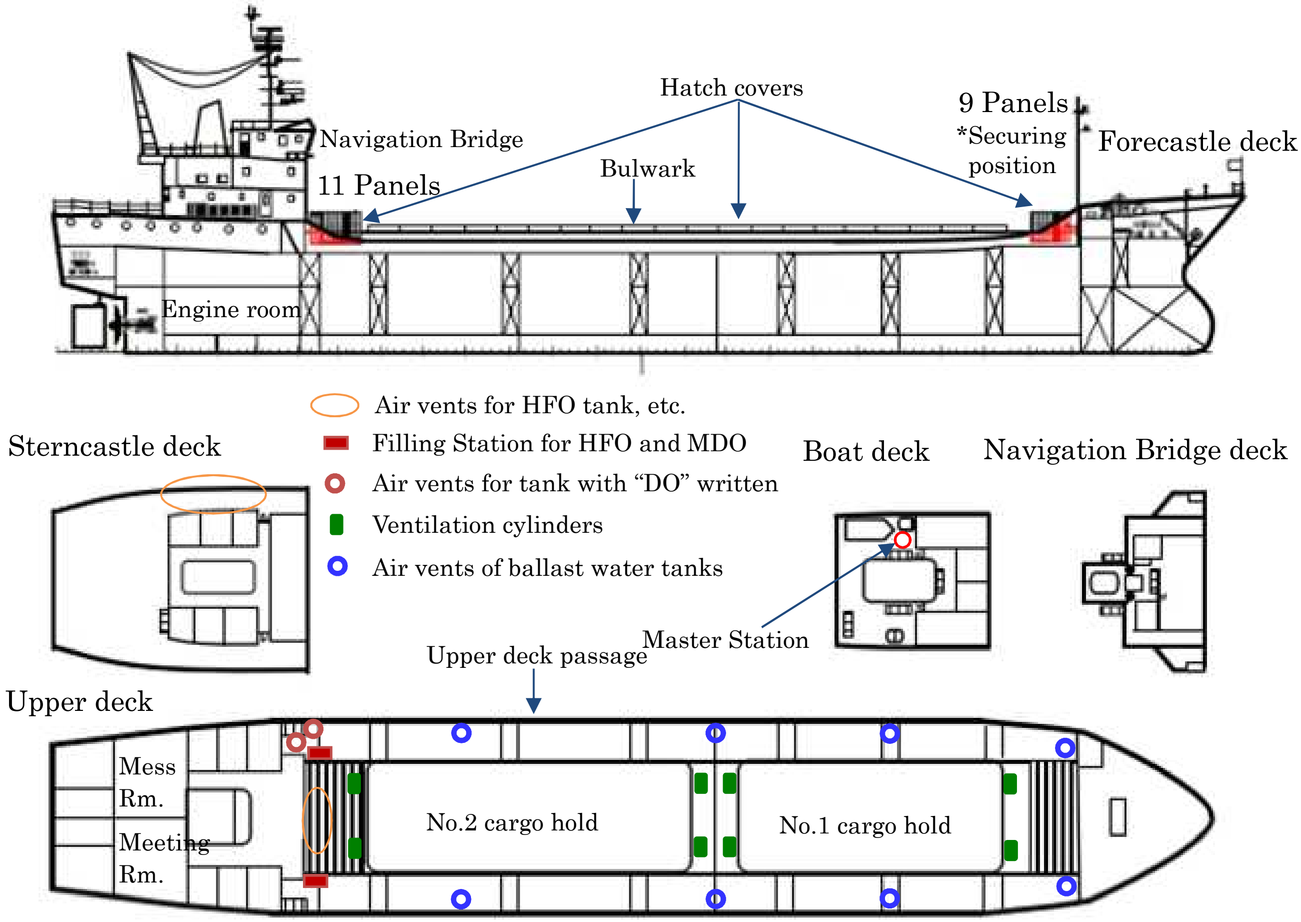


Figure 3 General Arrangement Plan (Abstract)

(2) Main Engine, Generator, Main Switch Board and Other Machinery

The main engine was installed at the middle position on the aft side on the bottom deck, and the two generators were set on both sides of the main engine. The main switch board was also set on the port stern side on the second deck.

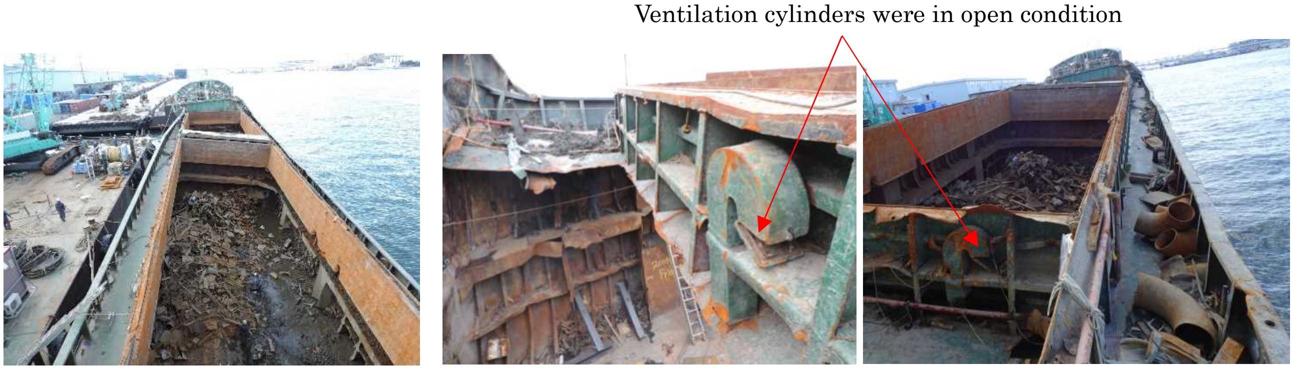
There was no malfunction or failure with the main engine, the two generators, the main switch board and the other machinery when leaving the Wharf of Keihin Port.

(3) Cargo Holds and Hatch Covers

The Vessel had two cargo holds; the capacity of No.1 cargo hold and No.2 cargo hold were 2,000 m^3 and 2,286 m^3, respectively. Two ventilation cylinders were arranged on both sides at the fore and stern of each cargo hold, respectively, and there were eight ventilation cylinders in total on board the Vessel.

When the Vessel was recovered, some lids of the opening parts of the ventilation cylinders were not tightened by the stopper devices, the stopper devices and the butterfly nuts were loosened fully on the screws, and thereby the four opening parts were in an open condition at least. The cross-sectional shape of the opening parts of the ventilation cylinders was a square where the length on one side was 200 mm.

(See Figure 4)



Cargo holds and port passage viewed from Nav. bridge

Ventilation cylinder of No.1 cargo hold fore port side

Ventilation cylinder of No.2 cargo hold stern starboard side and starboard passage

Figure 4　Cargo Holds and Ventilation Cylinders

Single pull-type hatch covers were installed, and consisted of nine panels in No.1 cargo hold and eleven panels in No.2 cargo hold, respectively, and the size of a hatch cover panel (hereinafter referred to as "the Panel") was manufactured with a length (fore-stern) of approximately 2.1 meters, width (port-starboard) of approximately 8.65 meters and thickness of 0.3 to 0.4 meters.

Long-quadrilateral rubber packing with a width of approximately 150 mm was attached around the undersurface of the Panels. When closing the hatch covers, the rubber packing touched the hatch coaming and was furtherer adhered due to pressing downward by clamps (metal tightening objects) which were set in the hatch coaming, and thus the hatch cover construction continued to secure weather-tightness (no ingress water in any oceanographic condition).

The condition of the hatch covers was warped and was deformed with respect to approximately one-fourth of all of the Panels, and when the hatch covers were closed, there was some clearance of approximately 5 mm partially between the Panels and the hatch coaming. Moreover, it was confirmed that the rubber packings were not set on the Panel's undersurface when the Vessel was recovered from the foundering location; however, it was impossible to clarify the condition of the rubber packing when the Vessel was sailing.

The Panels had a clearance of approximately 5 mm at each connection part between the Panels, and water receiver railings (hereinafter referred to as "the Receivers") were attached in the port and starboard directions on the undersurface of each connection part. The Receivers received ingress water between the Panels and prevented the infiltration of water into the interior of the cargo holds; however, there were broken holes in part of the Receivers due to their being in rusty condition.

(See Figure 5)

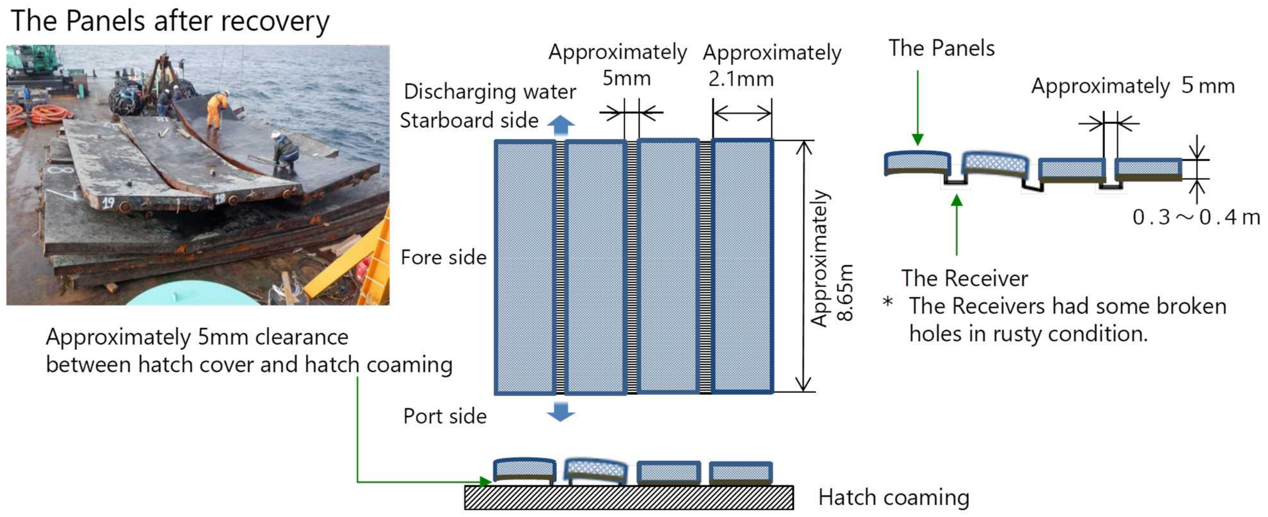


Figure 5 Construction and Condition of the Panels

The hatch covers of the cargo holds were covered with tarpaulin sheets secured by means of ropes, steel battens as one of the materials and wooden wedges while closing the hatch covers as waterproofing measures to secure weather-tightness.

The Vessel had been using these tarpaulin sheets since before Master embarked in the Vessel from June 2019. When departing from Keihin Port on October 10, the hatch covers were also covered with these sheets. In the on-site investigation after the accident, there was some wreckage of the torn sheets, the torn tightening ropes and the wedges in both passages on the upper deck.

(4) The Fuel Oil (FO) Line and the FO Tanks

A schematic diagram of the FO supply line is shown in Figure 6-1.

MDO was stored in the MDO tank, with the height of MDO tank being from the bottom deck to the second deck, and was supplied through a duplex strainer to the generators and the main engine, which was in stand-by condition while entering and leaving port, etc.

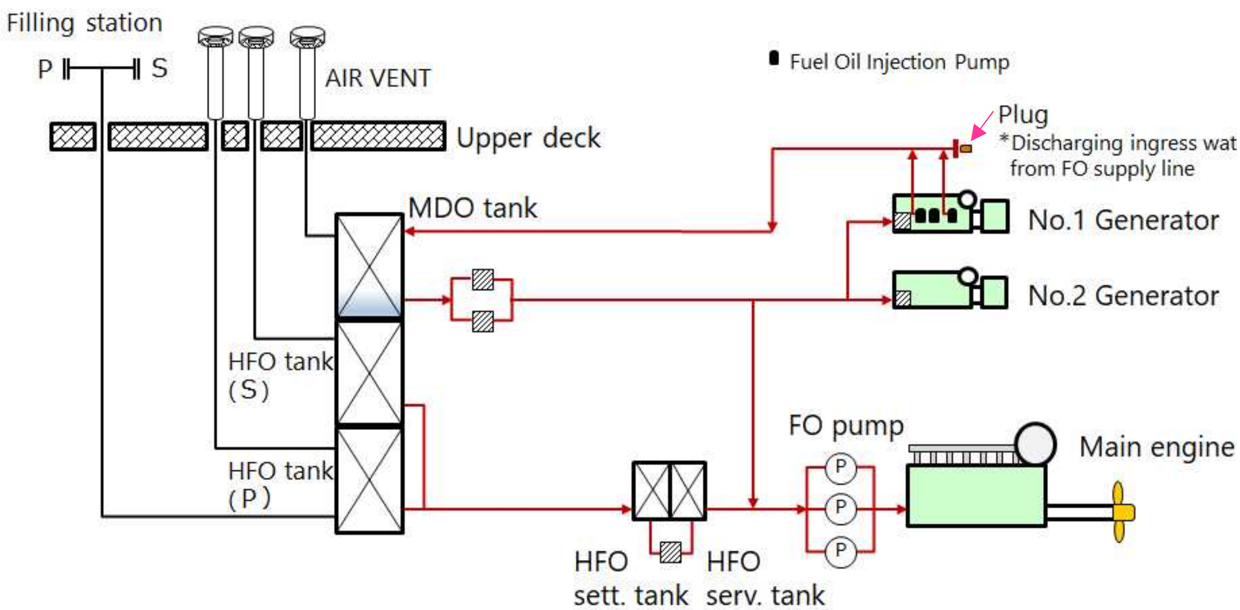


Figure 6-1 Schematic Diagram of the FO Supply Line

The air vents of the MDO tanks and HFO tanks were arranged around both sides on the sterncastle deck, in front of the deck house and the port side on the upper deck, and still more respective air vents were located above each tank. An air vent had a top cover on the top of the air vent, and could be opened or closed by moving the top cover vertically and fixing the top cover at each position with three stopper bolts. However, the air vents did not have construction and devices against up-rushing waves so as to automatically prevent the ingress of water into the air vent pipes. There were two air vents with "DO" written on the coamings, which seemed to be for the MDO tanks, and were at the port stern part on the upper deck, and their heights were approximately 0.7m. (See Figure 6-2)

Moreover, the other FO tanks were arranged in the double bottom tanks under the engine room; however, the kind and condition of FO which was stored in the tanks were unknown, and the tanks were not used on the day of the accident.

Arranged position, port-stern part on upper deck


Construction of air vents for similar air vents


① Deck house side of port-stern part


② Bulwark side of port-stern part

❖ The air vents of fuel oil tanks with "DO" written on the coamings were covered at the top of the covers by plastic bags, etc. to prevent oil pollution and were secured when the Vessel was recovered.

Figure 6-2 Air Vent Pipes for MDO Tank, etc.

(5) Ballast Water Tanks

Ballast water tanks were arranged in order of No. 1, No.2, No. 3 and No. 4 from the fore part and were divided on both sides, for a total eight tanks in the bottom part of the Vessel, and were connected to an air vent pipe on the upper deck from each tank. In the on-site investigation, some wreckage of torn pieces of tarpaulin sheets was found in the clearance between the air vent pipes and the top covers. This was evidence that the tarpaulin sheets were drawn with ingress water into the ballast tanks when the accident occurred. (See Figure 7)

Air vent pipe of the port side passage on Upper deck — Construction of top cover of air vent pipe — Wreckage of torn piece of tarpaulin sheet drawn into air vent pipe

Figure 7 Condition of Air Vent Pipe of Ballast Water Tank

2.5.4 Regulation of Weather-tightness of Cargo Holds and Hatch Covers

Regulation 16 of Chapter II of Annex I of the LL Convention stipulate as follows:

Regulation 16: Hatchways closed by Weathertight Covers of Steel or other Equivalent Materials

(1) All hatchways (omission) shall be fitted with hatch covers of steel or other equivalent material. (Omission) such covers shall be weathertight and fitted with gaskets and clamping devices. (Omission) The arrangements shall ensure that the tightness can be maintained in any sea conditions, and for this purpose tests for tightness shall be required at the initial survey, and may be required at renewal and annual surveys or at more frequent intervals.

(2) to (7) Omitted

2.6 Weather and Sea Conditions

2.6.1 Weather Warnings

According to the Japan Meteorological Agency (JMA), local weather warnings for Yokohama City and Kawasaki City were issued as shown in Table 4.

Table 4 Weather Warning Issuance

Date and Time		Weather Warning	Remarks
October 11	10:33	High wave warning	* The warning was lifted at 03:37 on October 13.
October 12	06:23	Storm warning	
	15:30	Emergency heavy rain warning	* The warning was lifted at 11:58 on October 13.

2.6.2 Meteorological Observations

(1) According to JMA's weather record, the records on October 12 of meteorological observations issued by Yokohama Local Meteorological Observatory, which is located in the west-south-west direction approximately 14 km from the accident location, and Haneda Observatory station, Tokyo Meteorological Observation Station, which is in the west-north-west direction approximately 8 km from the accident location, were as shown in Table 5 and

Table 6.

Table 5 Record of Meteorological Observations issued by Yokohama Local Meteorological Observatory

Time	Weather	Wind Direction	Wind Speed m/s	Atmospheric Pressure hPa	Precipitation Mm	Air Temp. ℃	Visibility km
20:00	Rain	SE	16.8	969.9	0.5	23.7	2.00
21:00	Rain	South	20.2	968.3	0.5	23.5	2.52
22:00	Rain	SW	9.6	978.7	0.5	23.7	4.36

Table 6 Record of Meteorological Observations issued by Haneda Observatory station

Time	Wind Direction	Wind Speed (AVE.) m/s	Wind Speed (MAX.) m/s	Precipitation mm	Air Temp. ℃	Remarks
05:50	NE	-	15.4	-	-	Wind speed (MAX.) exceeded 15 m/s.
15:20	ESE	16.3	-	-	-	Wind speed (AVE.) exceeded 15 m/s.
18:00	ESE	14.6	18.5	1.0	24.3	
18:30	SE	18.0	24.2	1.5	24.3	
19:00	SE	15.8	22.1	1.0	24.3	
19:30	SE	14.9	23.8	0.0	24.0	
20:00	SE	18.0	24.7	0.5	23.8	
20:30	SSE	23.1	32.9	1.5	23.5	
21:00	SSW	32.3	42.7	0.5	23.3	
21:30	SSW	28.9	39.6	1.0	23.8	
22:00	SW	15.9	23.7	1.5	23.4	

(2) Current and Sea Water Temperature

According to the information provided by JCG, at around the time of the accident on October 12 in Yokohama Shinko Port, Yokohama City was at the end of ebb tide, and the current height was 184 cm at 21:00, 153 cm at 21:30 and 155 cm at 22:00.

According to information provided by JCG, at around 22:00, the sea water temperature at Urayasu City offing, Chiba Prefecture closed to the accident location was 24.2 ℃.

2.6.3 Waves

The waves condition which JMA estimated with the Waves Model in shallow sea water[*7] (hereafter referred to as "the Waves Condition") in Tokyo Wan between 18:00 and 22:00 on October 12 was as shown as Table 7 and Figure 8. The area of wave height from 4.0 to 5.0 m had extended throughout Tokyo Wan from 21:00 to 22:00, and it was a period in which the factor of blowing up from west to east was increasing.

[*7] "The Waves Model in shallow sea water" refers to calculating waves only in shallow sea water such as a bay, etc. with a high resolution, e.g., a horizontal resolution of 2 km, and the result of the calculation is an estimation value.

Table 7 Condition of Waves and Winds in Tokyo Wan between 18:00 and 22:00

Time	Wave Height (m)	Frequency (sec)	Wave Direction (°)	Wind Speed (m/s) From West to East	Wind Speed (m/s) From South to North
18:00	5.2032	7.1245	104.1	-13.56	9.92
19:00	3.7393	6.7464	121.0	-19.60	16.50
20:00	4.0420	6.7119	155.7	-15.07	24.51
21:00	4.2060	7.0981	190.3	6.62	26.91
22:00	4.6685	7.2101	212.7	23.41	20.62

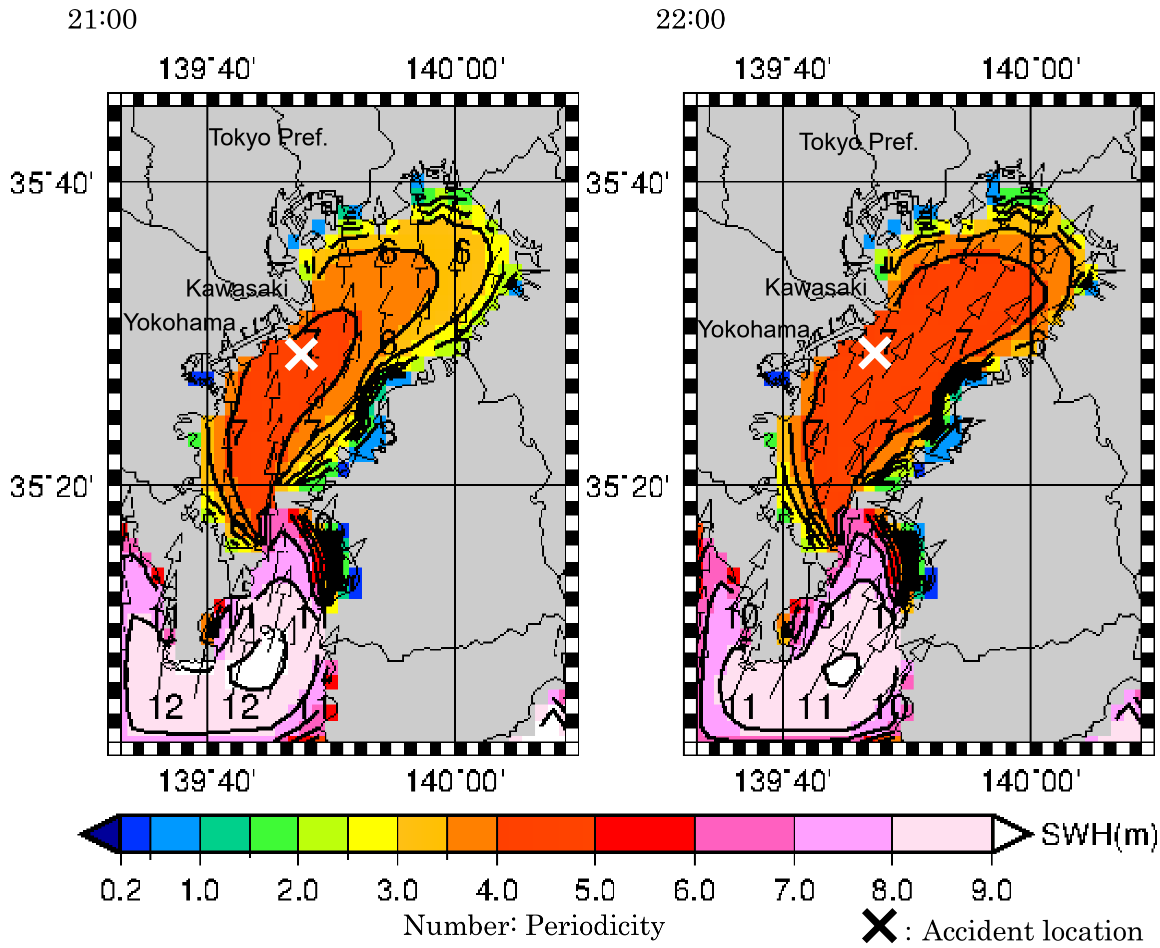


Figure 8 Condition of Waves in Tokyo Wan

2.6.4 Observations by Crewmembers

According to the statements by Master, at around the time of the accident on October 12, the weather condition was rain, the wind direction was from the south, the wind force was 6 to 7, the visibility was poor, and the wave height was from 3.0 to 4.5 m.

Master had already obtained information on the typhoon and weather by facsimile, NAVTEX receiver and Internet information via mobile phone, and received the weather figures for five days from the Agent during mooring at Keihin Port.

2.6.5 Information on the Typhoon

According to JMA, the route, the force and other circumstances of the typhoon were as follows:

(1) Circumstances of the Typhoon

The typhoon formed near Minamitori Island (Marcus Island), Ogasawara Village, Tokyo

Metropolitan Area on October 6, and then at around 19:00 on October 12, made landfall on the Izu Peninsula while remaining large and strong in scale and force. It subsequently proceeded the north-north-east and passed through the Kanto Region with a central barometric pressure of 955 hPa, maximum wind speed of 40 m/s at the center of typhoon and a speed of approximately 35 km/h, and finally become an extratropical cyclone off the east coast of Japan. (See Figure 9)

09:00 on October 12, 2019　　　　21:00 on October 12, 2019

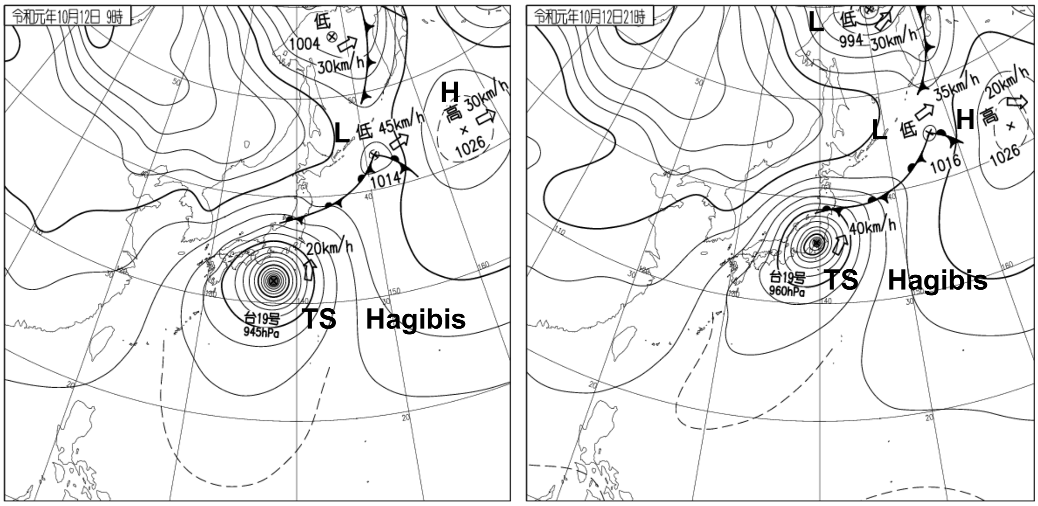


Figure 9　Surface Weather Chart at 09:00 and 21:00 on October 12, 2019

(2) Route of the Typhoon

The typhoon route, which was issued on the JMA website, was as shown in Figure 10. Keihin Port, in which the Vessel was anchoring, was in the right-side half-circle (the dangerous semicircle) of the typhoon's advancing axis.

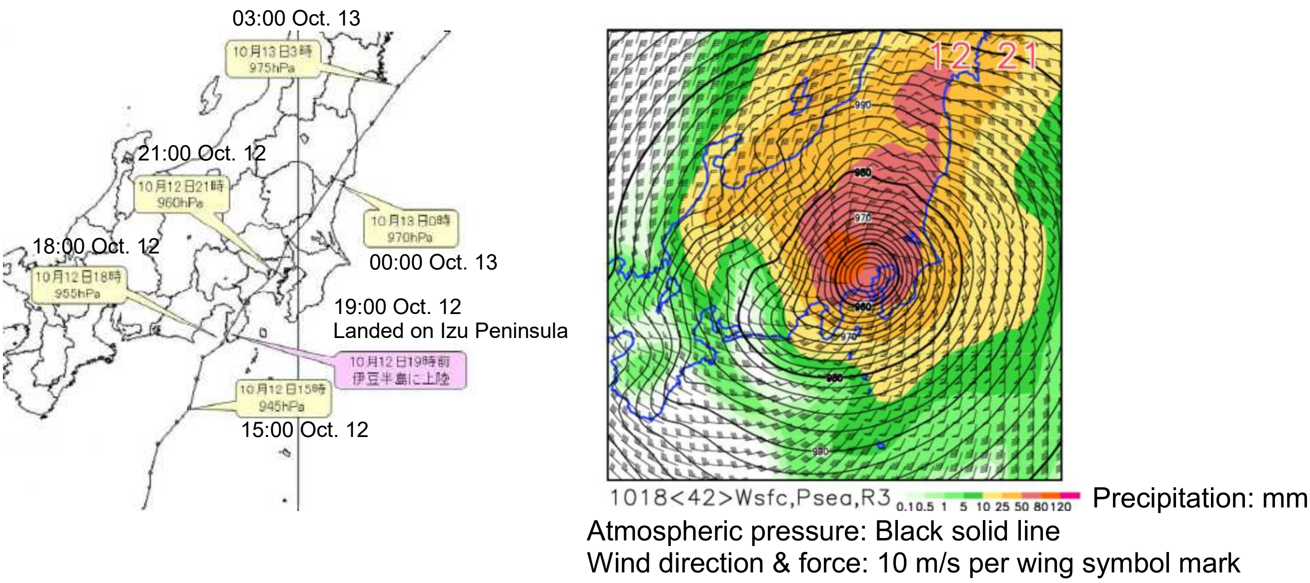


Figure 10　Route and Wind Rose of the Typhoon

2.7 Information of Ship Operation Management, etc.

2.7.1 Business Contents of Company C

According to the statements by Master, Chief Engineer and N. Officer A and the replies to the questionnaire by the Agent, Company C chartered the Vessel owned by Company B, conducted ship operation and management business, and then provided the Vessel for sailing in occasional sea-going service among Japan (Port of Kawasaki, Kagoshima, Niigata, Shimizu, etc.), the Republic of Korea (hereinafter referred to as "Korea") (Busan Port, etc.), China (Qingdao Port, etc.), Vietnam (Song Dang Port, etc.), etc., transferring steel, mixed scrap of various metals, etc.

Master usually received directions and schedules for calling at ports for cargo loading from the Qingdao branch office of Company C. He was informed of her schedule of calling at Keihin Port in October 2019 when the Vessel called at the Port of Zhenhai District, Changwon City, Korea in September.

The crewmembers' assignment in the Vessel was managed by Company C. Company C hired Chinese crewmembers directly, and the Seafarers Recruitment and Placement Service in Myanmar and Vietnam, which had made a contract with Company C, dispatched crewmembers to the Vessel from these countries.

2.7.2 Safety Management System

According to the statement by Master and the Safety Management Manual (hereinafter referred to as "SMM"), Company C had installed a Safety Management System (hereinafter referred to as "SMS"), and then formulated directions and procedure documents, etc. and implemented them with regard to ship management and ship operation.

Related articles to shipboard operations, maintenance of hull and equipment and crewmember's training which were provided for the SMS are excerpted and shown as follows:

(1) Ship Operation in Emergency Situations

7 Ship Operations

1. Development of Plans for Shipboard Operations

Shipboard Operations are divided into 2 parts of Critical and Special Operations so that the pivotal operation concerning with safety and pollution prevention are become the focus of attention when we establish our plans for shipboard operations.

The Company has established the document of <Procedure of developing Plans for Shipboard Operation> exactly identifying Critical Shipboard Operation and Special Shipboard Operation, which is guide for establishment plan and procedure for ship's operations.

Critical Shipboard Operation

Critical Shipboard Operation are those where an error may immediately cause an accident or a situation which could threaten people, the environment or the ship;

Master of the Vessel had kept in mind the need to conduct the following things as measures for stormy weather concerning a typhoon, etc. according to the SMS.

(i) Confirmation and tests in advance for steering gear, navigation equipment, GMDSS, main engine, auxiliary machinery and generators, and confirmation of all of piping lines and tanks. Preparation for the main engine and trying the engine in advance.

(ii) Confirmation of closing of all weather-tight doors, securing anchors, condition of hatch closing. Using two anchors if it is necessary in anchoring condition.

(iii) Securing fixed positions for all movable deck machines.

(iv) Confirmation and preparation for emergency facilities in emergency stations and life jackets for all crewmembers.

(2) Maintenance for Hull and Facilities Including Cargo Holds

10 Maintenance of Ship & Equipment

1. Maintenance, Repair And Survey

The company has established document of <Ship & Equipment Maintenance Procedure> to ensure ship can be maintained, repaired and surveyed safely and duly to meet ship's seaworthiness in conformity with the provisions of the relevant rules and regulations of the classification, administration of flag state and port state.

Technical department is in charge of management and monitoring for ship's maintenance and repairing. All technical superintender must be familiar with not only relevant rules and regulations of the classification, administration of flag state and port state control but also ship and equipment condition. According to <Ship and Equipment Maintenance Procedure>, the superintender should be requested to provide adequate technical support and technical feedback for ship's maintenance work. The master is liability to lead crew to strictly perform the regulation of <Ship and Equipment Maintenance Procedure>.

The technical department should establish an annual plan for ship maintenance and organize performance after approved by the General Manager according to the rules or regulations of relevant international convention, flag & port state and the classification, as well as ship condition and survey status. Company has established document of <Ship's Repairing and Accepting Procedure>.

The Company has established <Ship's Precautionary Inspection, Maintenance Period and Distribution> according to requirement of ship's equipment manual and condition. Ensuring ship's maintenance to be carried out as planed, annual maintenance plan should be drawn up by ship and perform after approved by company as per requirement of <Ship and Equipment Maintenance Procedure>. The superintendent should timely inspect its fulfillment.

Master of the Vessel appointed N. Officer B as the responsible person for the maintenance of the cargo holds and cargo loading equipment according to the SMS, and gave orders and had the crewmembers conduct works as follows:

(i) Inspection before and after loading cargo and unloading cargo

(ii) Maintenance for the cargo holds at intervals of every month, three months, six months and yearly

Crewmembers had conducted maintenance works for the cargo holds including the hatch covers, e.g., daily work on hull maintenance such as chipping, cleaning and painting for the hatch coming, etc. N. Officer B conducted periodic inspections monthly regarding the condition of the cargo holds, the hatch covers, the attached rubber packing, etc.

(3) Training for Crewmembers

6 Resources and Personal

3. Conversance of Responsibility

As per the requirement of STCW78/95, the company has to ensure all crew employed to be familiar with their own responsibilities as well as ship's arrangement, equipment, operation procedure and particulars;

5. Training

The company has established <Training Procedure for Personnel Ashore and on board>, which is continuously indicated necessary requirement of SMS and ensure the training shall *be provided to all personnel ashore and on board.*

Master of the Vessel instructed the crewmembers to perform the training for emergency stations periodically through the opportunity of drills, etc. and to acquire knowledge of how to put on life jackets and immersion suits*8 in the abandon ship station, survival techniques at sea, handling of emergency fire pumps and fire hoses, etc. Moreover, he had some crewmembers who could understand the training contents in English explain the contents to other crewmembers in their native languages.

2.7.3 Port State Control (PSC)

According to the statement by Master and the Web site of Tokyo MOU which possesses the database of PSC inspection, the Vessel had records indicating that she had often undergone PSC in calling at ports and detention was directed four times in the past two years. PSC officers had pointed out the following directions from the under-mentioned items from (1) to (4), which were extracted only concerning emergency facilities and devices, hull construction, emergency training for crewmembers, and moreover the Vessel was taken an inspection for the cargo holds and received the under-mentioned comments in the calling port on August, 2019.

(1) January 2018 (at Nakhodka Port, Russian Federation)
- (i) Fire-protection self-closing doors and Fire protection bulkhead
- (ii) Related articles of ISM Code

(2) March 2018 (at Ulsan Port, Korea)
- (i) Emergency fire pump and Fire main piping diagram
- (ii) Self-closing device of fire doors
- (iii) Fire-fighting devices

(3) April 2019 (at Niigata Port, Japan)
- (i) Fire detector
- (ii) Fire-fighting drill
- (iii) Emergency fire pump

(4) June 2019 (at Weihai Port, China)
- (i) Hull construction
- (ii) Lighting system
- (iii) Alarm device of Ingress water
- (iv) Related articles of ISM Code

When the Vessel called at Qingdao Port, China on August 2019, she took a PSC inspection and underwent an inspection for the cargo holds, and thereby usage of the tarpaulin sheets was recognized as a temporary measure for maintaining weather-tightness of the hatch covers.

2.7.4 Docking and Ship Inspection

According to the statement of Master, the Vessel was dry-docked in a shipyard of Qingdao Port in August 2019 and underwent a ship's inspection and maintenance was conducted concerning her hull, the steering units, the main engine, etc. The persons in charge of SMS in Company C visited the Vessel to supervise the above-mentioned works for repairs and the ship's

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*8 "Immersion suits" refers to a type of water proof and protection against cold suit that protect the wearer from hypothermia in winter or at cold water when vessel being into emergency situation as foundering, capsizing, etc.

inspection. However, Company C had not informed Master the contents of the works in advance concerning the ship's inspection, and moreover did not conduct repairment of the deformed Panels and the holey Receivers of the cargo holds.

2.8 Information on Ship Maneuvering before the Accident

According to the statement by Master and the AIS record, even though Master maneuvered the Vessel to direct the heading against winds and waves using the steering and the main engine before the accident, and then it was difficult to stabilize the attitude of the Vessel due to the blackout and uncontrollable steering while receiving winds from between the south-south-west and south-west. Moreover, she was swept away to the east-south-east direction, and subsequently, immediately before the accident occurred, she was swinging and was swept away to the north-west, and thereby she came to be in the direction between the south-west and west and was receiving winds and waves to her port side.

After the accident, Master thought that even though he had had some experience concerning conducting maneuvering of a Vessel in stormy weather, he felt that maximum instantaneous wind exceeded approximately 50 m/s and thought that the typhoon at that time was much more stronger winds and heavier waves.

(See Table 8)

Table 8 Comparison between Heading of the Vessel and Wind Direction

Time	Heading of the Vessel	Wind Direction (Haneda Observatory Station)
18:00	SE	SE
18:30	SE	SE
19:00	SE	SE
19:30	South – SW	SE
20:00	SE – South – SW	SSE
20:30	SE – South – SW	SSW
21:00	SW	SSW
21:30	SW	SW
Around 21:39, the time of the accident	SW – West	SSW – SW

2.9 Information on Ship Mobility and the Retained Sea Water on Deck

According to the statements by Master, Chief Engineer, N. Officer A and Oiler A, the Vessel was as follows:

(1) At around 18:00, the Vessel was rolling by approximately 5° due to receiving waves of a wave height from 1.0 to 1.5 m. Although wave uprush was coming from her fore side to the upper deck, the circumstance of discharging sea water was significant through the discharging holes of the bulwarks.

(2) At around 19:00, winds and waves were stronger than the condition under item (1) and the wave height was from 2.0 to 3.0 m. Therefore, the Vessel was rolling by approximately 5° with the addition of pitching movement. Sea water which was coming from the fore side to the upper deck was being retained between one-fourth and fully in both passages around No.2 cargo hold (hereinafter referred to as "the Retained Water"). At that time, the circumstance

of discharging sea water became such that sea water was not continuing to significantly discharge through the discharging holes.

(3) At around 20:00, winds and waves were stronger than the condition under item (2) and the wave height was from 3.0 to 4.0 m. Therefore, the Vessel was rolling heavily by 10° to 20°.

The wave uprush was greater, and was coming not only from her fore side, but also from both sides, and remained as the Retained Water on the upper deck. Furthermore, the top of the hatch covers of both cargo holds were washed up and were covered with spraying sea water of a height from 0.2 to 0.5 m. Circumstances like this continued until the time the accident occurred.

(4) At around 21:23, the Vessel was swept away to the east-south-east due to uncontrollable steering due to the blackout, and then was in a situation in which she was difficult to maneuver as regards directing her heading against winds and waves. Subsequently, she was in a condition of receiving strong winds which were changing wind direction due to blowback wind after passing of the typhoon, and thereby was receiving heavy waves from the port fore side to port side and on the upper deck. At around 21:34, the Vessel heeled to the starboard side by approximately 5° and increased heeling by approximately 20° due to rolling. Subsequently, heeling increased more and more in that condition and did not stabilize, and furthermore she was heeling to the starboard side by approximately 30°.

(See Figure 11)

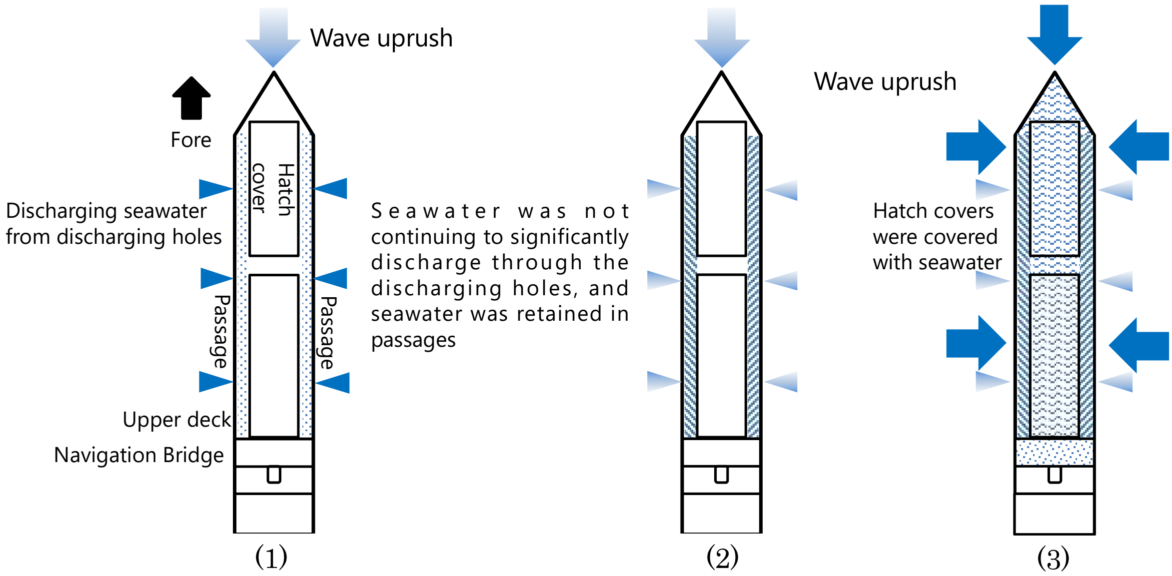


Figure 11 Wave Uprush and the Retained Water on Upper Deck

2.10 Information on Ingress Water into the FO Line

According to the statements by Chief Engineer and Oiler A, the situation was as follows:

(1) Drain Discharging Operation of Fuel Oil Tanks

The crewmembers of the engine department conducted a drain discharging operation which involved operating each drain valve of the fuel oil tanks, and confirmed whether there was some ingress water or not by discharging a little fuel oil from the bottom of the FO tanks (hereinafter referred to as "the Discharging Operation"). The Discharging Operation was conducted twice in a watch as one of the routine tasks in engine room watch-keeping when a duty crewmember entered the engine room and when two hours had elapsed during the watch.

Oiler A conducted the Discharging Operation in order of the HFO settling tank, HFO service tank and MDO tank at around 12:00 and around 14:00 in the engine room watch-keeping on October 12, and at that time he confirmed there was no ingress water in the HFO and MDO, and then at around 16:00, he saw that Oiler C, who was the next duty watch crewmember, conducted the Discharging Operation for the MDO tank.

(2) Discharging Ingress Water from the FO Line and FO Tanks

When the generator engine stopped suddenly at the first time before the accident occurred, Chief Engineer and Engineer thought there were some problems in the FO line of the generator engines. They loosened and removed the plug from the FO outlet common line of the FO injection pumps and confirmed that some water had infiltrated into the FO line, even though FO was supplied.

Chief engineer discharged ingress water and FO which contained water from the plug hole, with approximately two buckets per the recovery operation of the generator engine, and furthermore other ingress water, etc. was discharged from FO strainers and the Discharging Operation of the MDO tank by Engineer and Oiler C.

Every time the generator engine stopped, ingress water in the FO line was discharged. After the generator engines had been started three times, the generators were able to be in running condition and supplied electric power continuously. The amount of ingress water, etc. discharged from the FO strainers and MDO tank was unknown.

(3) Confirmation of Condition of FO Tanks in Engine Room Watch-keeping

According to the STCW Convention, Section A-VIII/2, Part 4-2 "Principles to be observed in keeping an Engineering Watch", the observation for the condition of FO tanks is as follows:

"*Taking over the watch*"

58.4 *the condition and level of fuel in the reserve tanks, settling tank, day tank and other fuel storage facilities*;

2.11 Investigation and Research Work

JTSB entrusted the analysis investigation (hereafter referred to as "the Analysis") with regard to the purpose of researching the stability and the circumstances of foundering in the accident involving the Vessel to the National Maritime Research Institute.

The Analysis supposed that at the time of the accident, the Vessel had the Retained Water due to receiving wave uprush, and then was flooded due to taking on sea water into the interior of the cargo holds, and subsequently received stronger winds and heavier waves, with the result that she heeled to the starboard side and rolled over, and thereby foundered. Moreover the Analysis considered and calculated stability, lateral heeling moment and heeling angle due to winds based on the weather, sea condition, control of her hull's attitude, etc.

The contents and the results of the Analysis were as follows:
(Refer to Annex "Analysis and Investigation Report on the Foundering of Cargo Vessel A") (hereafter referred to as "the Annex report of the Analysis")

2.11.1 Summary of the Investigation

(1) Estimation of Stability Performance of the Vessel at the Time of the Accident

Because information relating to the stability of the Vessel could not be acquired, her stability performance was estimated by utilizing the data documents relating to the stability of an analogous cargo vessel, in case of there being the Retained Water in the passages on the upper deck and of being flooded due to taking on sea water into the interior of the cargo holds at the time of the accident.

(2) Consideration of Progress of the Vessel's Hull Heeling until her Foundering Occurred

Based on the results of item (1), the Analysis estimated the stability performance, and concluded that the Vessel was heeling to the starboard side due to receiving winds from the port fore side, and then began to roll due to receiving waves in the condition of heeling to the starboard side due to winds, and heeling to the starboard side furthermore increased. In addition, the condition of the situation of ingress water in the cargo holds and lateral heeling were verified.

2.11.2 Estimation of the Vessel's Stability

(1) Estimation of the Height of the Center of Gravity

In case of estimating the Vessel's stability, the height of the center of gravity (KG)*9 of the Vessel was determined from the data documents relating to the stability of an analogous cargo vessel, and by extending the estimation range of the Analysis, the light loading condition KG (hereinafter referred to as "KG_L") was determined by setting the values at 4.49 m and 4.82 m.

(2) Estimation of Stability on the Day of the Accident

The weight of loaded cargo and the weight of stored ballast water on board the Vessel at K1 anchorage on the day of the accident was as shown in Table 9. The stability of the Vessel's displacement on the day of the accident was as shown in Table 10, and the initial condition of stability and stability curve*10 in the above-mentioned vessel condition was as shown in the Figure in Table 10.

Moreover, on the day of the accident, there was some remaining water in all 6 of the ballast tanks, so the Analysis was conducted with the change of the height of the center of gravity with a lateral heeling in consideration of free water movement.

Table 9 Loading Weight On Board and Weight On Board of Ballast Water on the Day of the Accident

Load	Weight (t)	Specific gravity
Steel scrap (Cargo Hold No. 1)	1,348.9	1.000 (Bulk specific gravity)
Shredded scrap (Cargo Hold No. 2)	1,696.1	
Marine Diesel Oil	17.9	0.880
Heavy Fuel Oil	61.9	0.980
Lubricating Oil	2.6	0.860
Fresh Water	67.0	1.000
Ballast water	24.8	1.025
Constant	100.0	
Total	3319.2	–

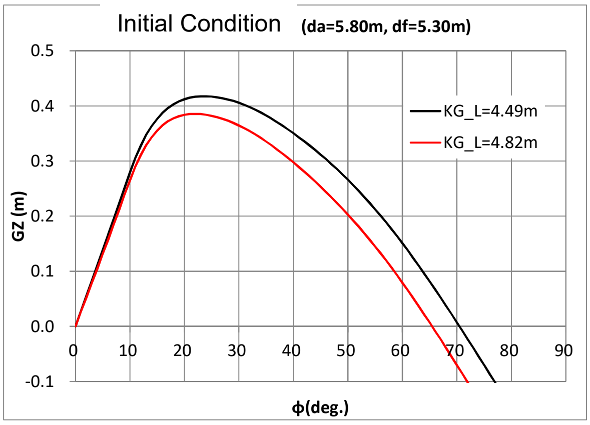
Ballast W. tank		Weight (tons)
Ballast W. Tank No. 1	P	0.0
	S	1.6
Ballast W. Tank No. 2	P	10.7
	S	0.0
Ballast W. Tank No. 3	P	3.0
	S	9.2
Ballast W. Tank No. 4	P	0.1
	S	0.2
Total		24.8

*9 "Height of the center of gravity (KG)" refers to the height from the top surface of the bottom plating to the center of gravity of the hull.

*10 "Stability curve" refers to a graph representation of the righting arm (a value obtained by dividing the couple that attempts to return a heel to its original position by displacement) against the hull's heel angle.

Table 10 Hull Condition and Curve of Stability on the Day of the Accident (Initial Condition)

KG_C m	4.49	4.82
Fore draft m	5.30	
Stern draft m	5.80	
Average draft m	5.55	
Displacement t	4424.8	
Height of center of gravity m	3.877	3.960
Metacentric height[*11] (GoM) m	GM1 1.44	GM2 1.35
Heel angle (°)	0	



2.11.3 Estimation of Circumstances Leading Up to Foundering

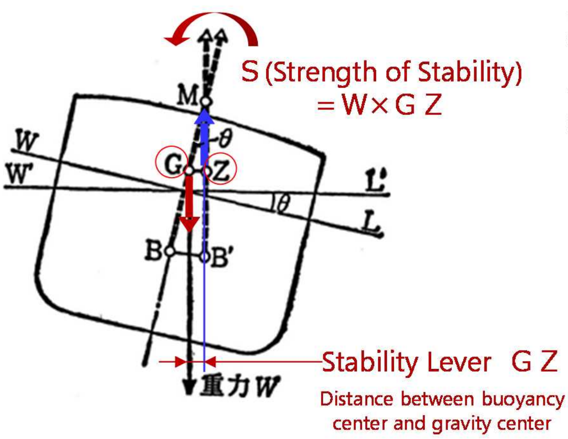
In the context of leading up to the foundering of the Vessel with the Retained Water due to receiving wave uprush to the upper deck and being flooded due to taking on sea water into the interior of the cargo holds, Analysis was conducted to calculate the residual stability in case of lateral heeling moment occurring due to receiving winds and waves.

Moreover, the volume of the Retained Water was calculated by estimating the capacity of both passages on the upper deck utilizing the general arrangement in consideration of stern trim. In the Analysis, the influence of ingress water occurring in the cargo holds adopted a value in consideration of the influence of free water movement in the cargo holds even though the Vessel had loaded steel scrap in the cargo holds.

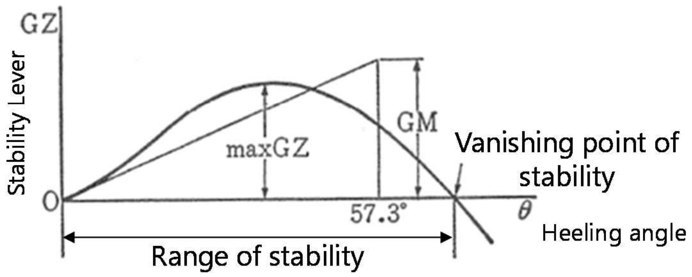
(1) Influence of the Retained Water

The results of analysis for the curve of stability, etc. in case of there being the Retained Water on the upper deck are as shown in Figure 12. The results show that as the height of the weight center is raised, the metacentric height and the stability become lower. However, it

[*11] "Metacentric height" refers to the distance (GM) between the hull center of gravity G and the metacenter M, which is the intersection point of the line of action of the buoyant force that passes through the center of buoyancy when the vessel is heeling and the hull center line. In the Analysis, it refers to metacentric height (GoM) that takes free water movement into account.

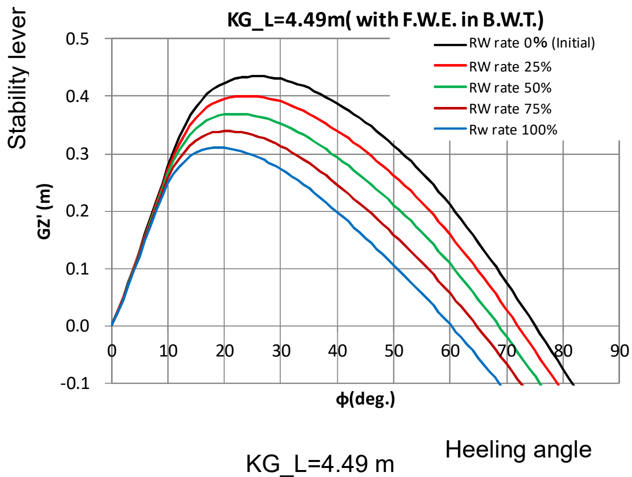


G: Gravity center B: Buoyancy center θ: Inclination angle (rad.)
W: Weight (Weight of vessel = Displacement (tons))
M: Metacenter (Cross point of action line in condition of upright posture and inclination posture) GZ: Righting lever (m))
S: Couple of Force which was generated by gravity at vessel's inclination and buoyancy (t-m) S = W*GZ S value is large = Stability is increasing

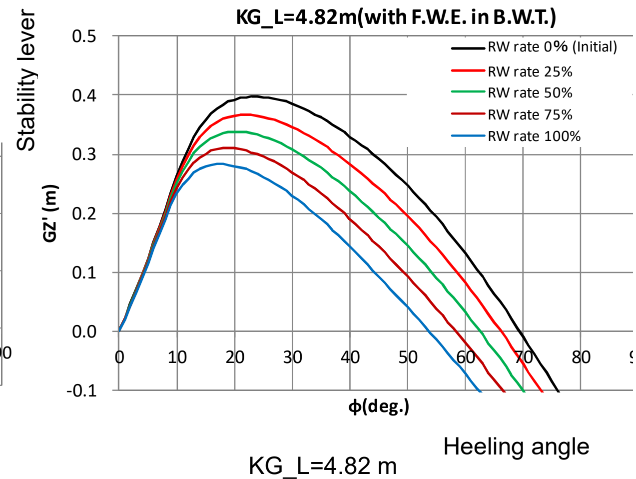


GZ is a function of vessel inclination angle, and the GZ-θ curve is called the Stability Curve, which is shown in its condition of changes, and is used for evaluation of vessel stability. GZ gradually increases as inclination is increases, after approaching the maximum value, GZ decreases and will be "zero, 0"

References "Navigation and Ship Building version 2.0, published by KAIBUN-DO, NOHARA Takeo, SHOJI Kuniaki" could not be said that the influence of the Retained Water becomes high, even though the metacentric height in the case of a Full Retained Water ratio of 100 % (Full condition) was less than approximately 7 % (GM1=1.34 m, GM2=1.25 m) of the initial condition (GM1=1.44 m, GM2=1.35 m), and thereby it is assumed to be highly probable that the Vessel had significant residual stability, even though she experienced wave uprush and the Retained Water being on the upper deck due to upcoming sea water.



KG_L=4.49 m



KG_L=4.82 m

Condition	GM1 (m)	GM2 (m)	da (m)	df (m)	dm (m)	τ (m) Trim	Retained Water ratios
Initial condition	1.44	1.35	5.80	5.30	5.55	0.50	0 %
Condition 1	1.42	1.33	5.88	5.34	5.61	0.54	25 %
Condition 2	1.39	1.31	5.91	5.41	5.66	0.50	50 %
Condition 3	1.37	1.28	5.95	5.49	5.72	0.45	75 %
Condition 4	1.34	1.25	5.98	5.57	5.78	0.41	100 %

Figure 12 Curve of Stability (Influence of the Retained Water)

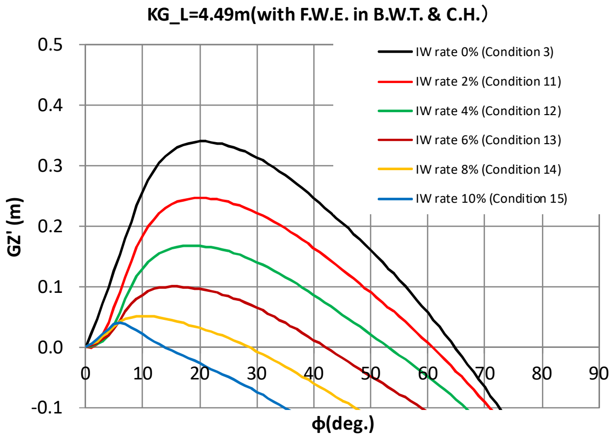
(2) Influence of Ingress Water into Cargo Holds

At the time of the accident, the Vessel was also assumed to be flooded due to taking on sea water into the cargo holds in addition to the Retained Water, and the stability curves, etc., which were analyzed in case of there being an ingress water ratios in the cargo holds (IW ratio) from 2 % (weight of ingress water 40.8 t) to 8 % (weight of ingress water 203.8 t) against the capacity of the cargo holds are then as shown in Figure 13. Moreover, the Retained Water, in consideration of discharging water outboard from the heel side in rolling condition as well as her hull's heeling, was adopted as a Retained Water ratio (RW ratio) of 75 % in the Analysis.

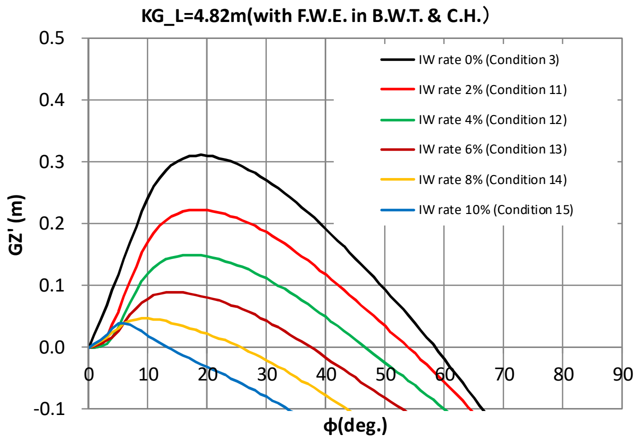
In case of flooding due to taking on sea water into the cargo holds, the peak of stability (Stability lever "GZ") was reducing markedly. For example, in the case of KG_L=4.82 m, GZ was zero at an heeling angle of approximately 14° , whereby the Vessel lost her stability and was in a condition to readily roll over.

In case of estimation of flooding due to taking on sea water into the interior of the cargo holds, the metacentric height was reduced significantly due to the large influence of free water movement in comparison with the case of no ingress water in the cargo holds. For example, in the case of Condition 11 (KG_L=4.49 m, IW ratio 2 %), the metacentric height (GM1) was

0.07 m, and the value was 5 % of the metacentric height in Condition 3 in which there was no ingress water in the cargo holds.



KG_L 4.49 m



KG_L 4.82 m

Condition	W (t)	GM1 (m)	GM2 (m)	da (m)	df (m)	dm (m)	τ (m)	RW ratios + IW ratios
Condition 3	4582.1	1.37	1.28	5.95	5.49	5.72	0.45	75 % + 0 %
Condition 11	4669.5	0.07	0.00	6.01	5.62	5.82	0.39	75 % + 2 %
Condition 12	4756.8	0.16	0.10	6.06	5.76	5.91	0.30	75 % + 4 %
Condition 13	4844.2	0.24	0.20	6.11	5.91	6.01	0.20	75 % + 6 %
Condition 14	4831.5	0.33	0.30	6.16	6.05	6.11	0.10	75 % + 8 %
Condition 15	5018.9	0.40	0.39	6.20	6.20	6.20	0.01	75 % + 10 %

Figure 13 Curve of Stability and Hull Condition (Influence of Ingress Water in Cargo Holds)

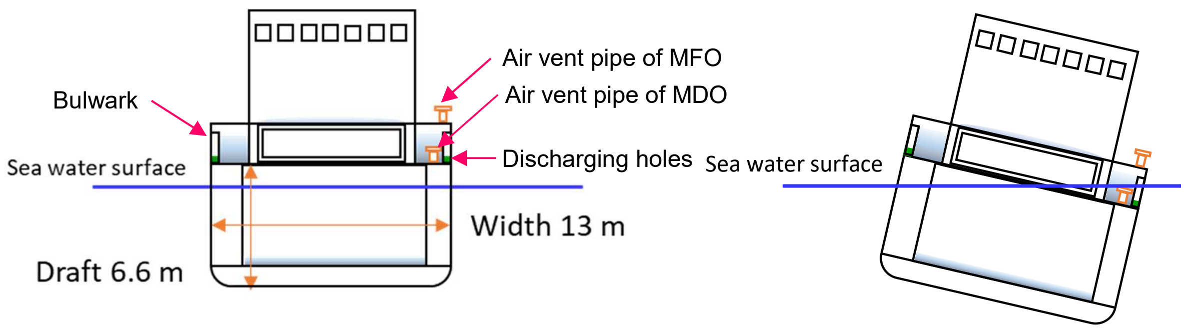
(3) Condition of Hull's Heel Angle and Air Vent Pipes of the FO, etc.

When heeling of the Vessel's hull occurred in the case of ship conditions as shown in the Table below in Figure 12, the submerged angles of the discharging holes, the top of the bulwark, the upper deck and the sterncastle deck on which the air vent pipes of MDO and HFO were located are shown in Table 11 and the Figure below.

The submerged angles were decreased according to ingress water in the cargo holds increasing, in the case of IW ratio 8 %, the submerged angle of the discharging holes was at 5.1° , the submerged angle of the top of bulwark was at 12.6° and the submerged angle of the sterncastle deck was at 26.6° , and thereby these angles reduced approximately 3° in comparison with the condition of no ingress water in the cargo holds (Condition 3).

Table 11 Submerged Angles of Each Position (Degree) (Abstract)

Condition (Mean draft)	Bulwark		Port of Stern castle Deck
	Discharging Holes	Top	
Condition 3 (5.72 m) Retained water ratio 75 %	7.8°	15.5°	29.6°
Condition 11 (5.82 m) RW ratio 75%+ IW ratio 2%	7.0°	14.7°	28.8°
Condition 14 (6.05 m) RW ratio 75%+ IW ratio 8%	5.1°	12.6°	26.6°



Heel angle EVEN　　　　　　　　Heel angle13°

(4) Lateral Heeling Moment Angle and Heeling Angle Due to Winds

The Vessel movement noted in item 2.9 was generated due to receiving the influence of winds and waves that increased due to the typhoon approaching, and in this viewpoint, in the case of her hull's condition with a Retained Water ratio of 75 % as shown in the Table below of Figure 13, subsequently the Analysis analyzed the lateral heeling moment angle and heeling angle due to winds acting on the hull with changing wind force, wind direction and the heading of the Vessel as in Table 12.

Lateral heeling moment K_A due to winds was estimated by the FUJIWARA formula*12 based on her hull shape above the load line in past study and research, and the heeling angle ϕ_{wind} was acquired from the estimated lateral heeling moment due to winds, displacement W and metacentric height GM. Moreover, the relative ship speed was similar to the wind speed because the ship speed was zero.

Table 12 Analysis Conditions (Vessel's Condition, Wind Direction, Wind Speed and Heading of the Vessel)

- Vessel's condition　Retained Water ratio: 75 %,
  Displacement, GM1, GM2 and draft as in the Table below in Figure 12
- Wind direction, wind speed and heading of the Vessel

Wind speed (m/s)	Wind direction (˚)	Heading of the Vessel (˚)	Ship speed (kn)	Relative speed (m/s)	Relative wind direction (˚)
30.0	202.5 SSW	225.0 SW	0	30.0	22.5
35.0				35.0	
40.0				40.0	
30.0		270.0 West		30.0	67.5
35.0				35.0	
40.0				40.0	

(i) Lateral heeling moment K_A due to winds

The results of estimation of the lateral heeling moment K_A due to winds is as shown in Table 13 in the case of Conditions 11, 12 and 14.

C_K is the heeling moment coefficient due to winds and was estimated based on the FUJIWARA formula, and D_W in the Table is the heeling couple of the force lever ($D_w=K_A/W$)

*12 FUJIWARA Toshifumi, UENO Michio, IKEDA Yoshiho, "A New Estimation Method of Wind Forces and Moments Acting on Ships on the Basis of Physical Component Models", Journal of Marine Science and Technology, Vol.2, pp.243-255, October 2005 calculated using the heeling lever.

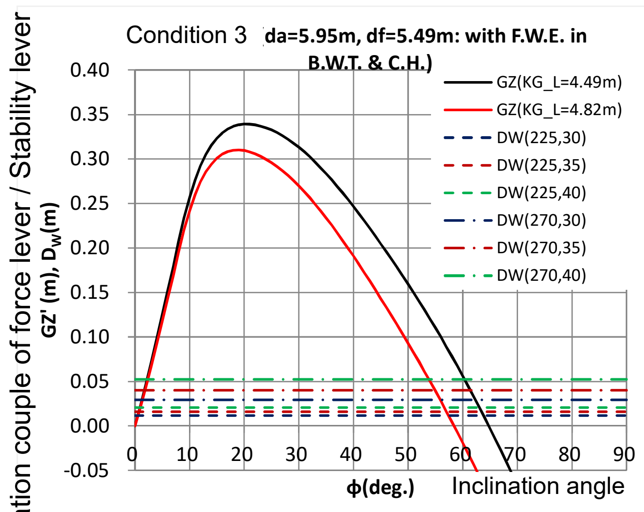
The stability and the heeling couple of the force lever of Conditions 3, 11, 12 and 14 are as shown in Figure 14, and the notation shown as "DW(225,30)" in the Figure means the heeling couple of the force lever in the case of the heading of the Vessel being 225° and wind speed being 30 m/s.

As mentioned above, the greater the ingress water in the cargo holds increased, the lower the stability GZ and the heeling couple of the force lever decreased, and thereby the more the reduction in stability is remarkable. Therefore, the residual stability, which responds to the upper part above the heeling couple of the force lever D_w line parallel to the horizontal axis of the stability curve GZ indicated by a solid line in Figure 14, was greatly reducing accompanied by increasing flooding due to taking on sea water into the cargo holds. The effective stability was almost lost in the condition of an ingress water ratio of 8 % (Condition 14), in the case of the heading of the Vessel of 270° and wind speed of 40 m/s (heeling couple of force lever: green dashed line), even if her KG_L was at 4.49 m.
(See Figure 14)

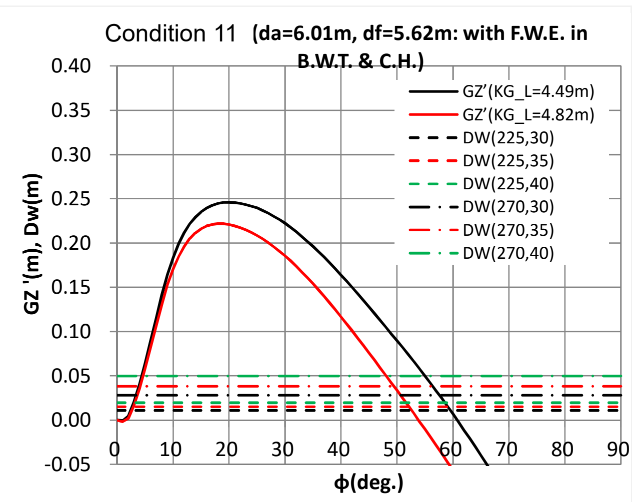
Table 13 Estimation of Heeling Angle due to Winds (Condition of Ingress Water into Cargo Holds)

Wind Force m/s	Wind Direction °	Heading of the Vessel °	Condition 11 RW ratio 75% + IW ratio 2%			Condition 12 RW ratio 75% +IW ratio 4%			Condition 14 RW ratio 75%+IW ratio 8%		
			C_K	K_A tf*m	D_w M	C_K	K_A tf*m	D_w m	C_K	K_A tf*m	D_w m
30.0	202.5 SSW	225.0 SW	0.763	51.32	0.011	0.774	49.42	0.010	0.796	45.53	0.009
35.0				69.85	0.015		67.26	0.014		61.97	0.012
40.0				91.23	0.020		87.86	0.018		80.94	0.016
30.0		270.0 West	1.946	130.98	0.028	1.987	126.94	0.027	2.072	118.55	0.024
35.0				178.27	0.038		172.78	0.036		161.37	0.033
40.0				232.85	0.050		225.68	0.047		210.76	0.043

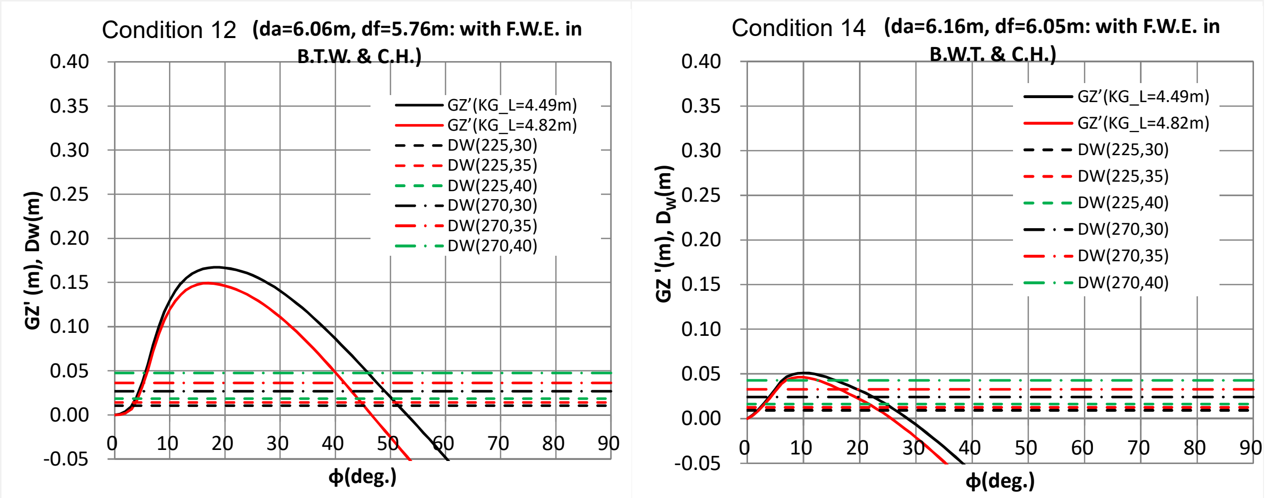
* Condition 3 (RW ratio 75% and no ingress water in cargo holds) was omitted.



Condition 3



Condition 11



Condition 12　　Condition 14

Figure 14　Stability and Heeling Couple of Force Lever due to Winds

(ii)　Heeling angle due to winds　ϕ_{wind}

The results for the estimated heeling angle due to winds in the case of Conditions 11 to 15 is shown in Table 14, and the condition of ingress water in the cargo holds and the condition of the heeling angle are shown in Figure 15. The cells shaded with gray in the table show that the heeling angle due to winds indicates a condition of exceeding the angle of the discharging holes of the bulwark being submerged into sea water.

The lateral heeling angle at which she was receiving winds from the lateral direction closely in the case of the heading of the Vessel being at 270° was 1.4 to 2.5 times that of the case of the heading being at 225.5°. And then, in the case that the lateral heeling angle was more than 5°, it was limited in the case of the heading of the Vessel being at 270° and the ingress water ratios being more than 4%.

Furthermore, if the discharging holes of the bulwark were submerged into sea water, the discharge of the Retained Water was obstructed, and thereby it is assumed probable that the capacity of ingress water came to increase more than the condition of the Analysis (ingress water ratio of 75%).

Table 14　Estimation of Heeling Angle due to Winds (RW ratio 75% and IW in Cargo Holds)

	KG_L＝4.49m						KG_L＝4.82m					
Heading of the Vessel	225.0			270.0			225.0			270.0		
Wind Force	30.0	35.0	40.0	30.0	35.0	40.0	30.0	35.0	40.0	30.0	35.0	40.0
Condition 3	0.5	0.7	0.9	1.3	1.7	2.2	0.6	0.8	1.0	1.4	1.9	2.4
Condition 11	2.4	2.7	3.0	3.4	3.9	4.4	2.6	2.9	3.2	3.6	4.1	4.6
Condition 12	3.1	3.4	3.8	4.4	5.0	5.5	3.4	3.8	4.1	4.7	5.2	5.8
Condition 13	2.4	3.1	3.7	4.6	5.3	6.1	2.8	3.5	4.1	4.9	5.6	6.4
Condition 14	1.9	2.3	2.9	3.9	4.9	6.2	2.0	2.5	3.1	4.1	5.2	6.9
Condition 15	1.4	1.9	2.3	3.2	4.1	6.0	1.5	1.9	2.4	3.2	4.2	—

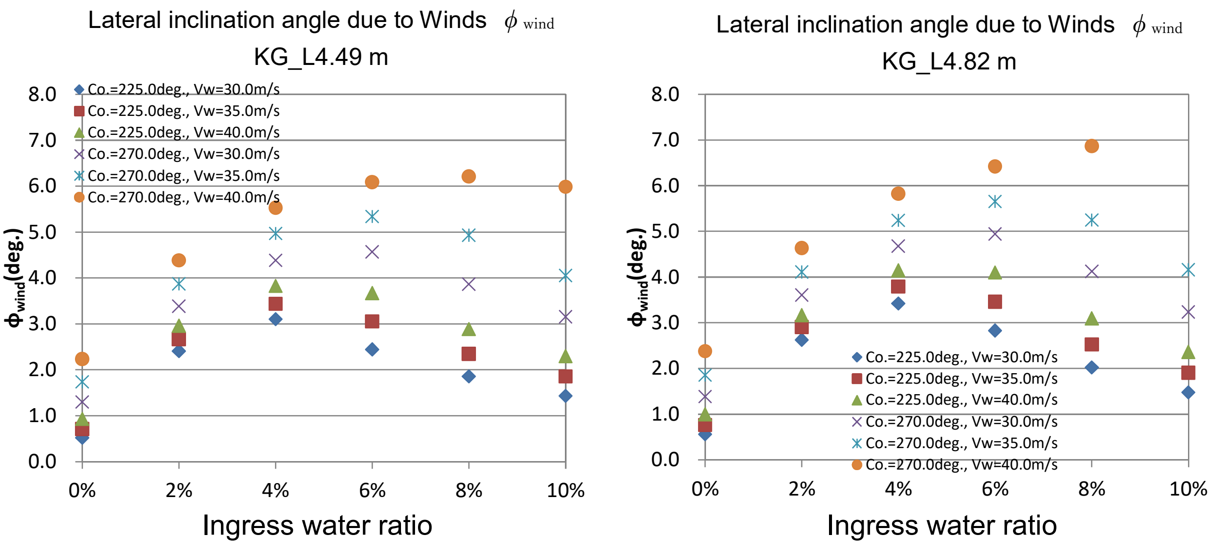


Figure 15　Condition of Ingress Water into Cargo Holds and Heeling Angle Due to Winds

2.11.4　Progress of Hull Heeling to Foundering

(1)　Estimation of the Accident Scenario

With investigation of the progress of the Vessel's heeling at the time of the accident from residual stability in consideration of the heeling couple of force due to winds, and then in view of the situation of her being greatly heeled to starboard and being rolled over, thereby the situation of the occurrence of the accident was assumed to be the following accident scenario (hereafter referred to as the "Accident Scenario").

a)　The Vessel was heeling between 10° and 20° due to receiving waves with the condition of a Retained Water ratio of 75% on average in both passages on the upper deck.

b)　At around 21:30, the Vessel had been changing her heading, and then she heeled to the starboard side by approximately 5° due to winds of an average wind speed of 30 m/s, and subsequently was in the condition of rolling between 10° and 20° .

c)　At around 21:34, the Vessel was in the condition of rolling to the weather side (port side) at the maximum heeling angle, and then began to heel to the lee side (starboard side) again.

d)　The Vessel's lateral heeling angle to the starboard side was beyond the submerged angle of the top of the bulwark, and then the Retained Water became similar water as the sea water around the Vessel (hereafter referred to as "Overboard Water"), and subsequently increased heeling more than the previous condition and attained an heeling angle of approximately 30° , such that the heeling angle became more than maximum stability.

e)　The Vessel came to be in an unstable condition*13 in that the stability curve was negative, and furthermore was in a condition of being difficult to stabilize due to the submerged bulwark dragging subject to the weight of sea water.　Therefore, lateral heeling was increasing due to the influence of receiving waves continuously, and the lateral heeling came to be approximately 45° which corresponded to the angle of loss of residual stability in consideration of the heeling couple of force lever due to winds of average wind speed,

*13　WATANABE Yoshihiro, Some Considerations on the Instability of Asymmetric Rolling at the Large Heeling of a Ship, Journal of Seibu Zosen Kai. Transactions of the West-Japan Society of Naval Architects, No.34, pp.59-71, July 1967.

and thereby the Vessel rolled over to the starboard side.

(2) Analysis Based on the Accident Scenario

The analysis based on the Accident Scenario was conducted with concrete values for the time of the accident occurrence taken into the Accident Scenario, and then the investigation was conducted taking into account the situation of the occurrence of the accident.

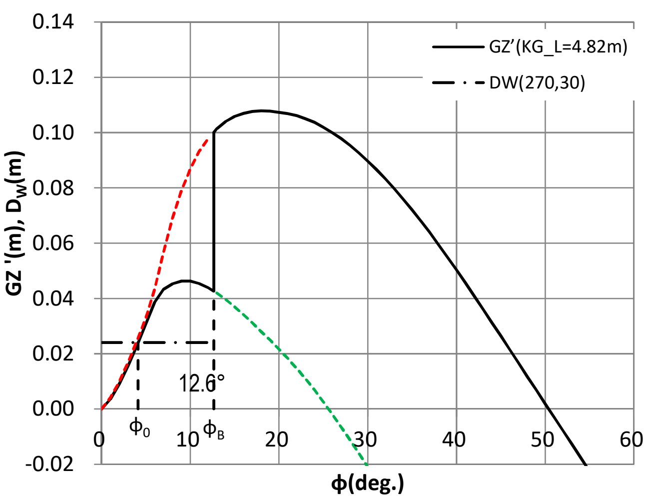
The analysis based on the Accident Scenario was taken up and conducted in the case of the center of gravity on KG_L= 4.82 m, the condition of the Retained Water ratio as 75% and the ingress water ratio in the cargo holds as 8% (hereafter referred to as "the Hull Condition"), and subsequently was as follows:

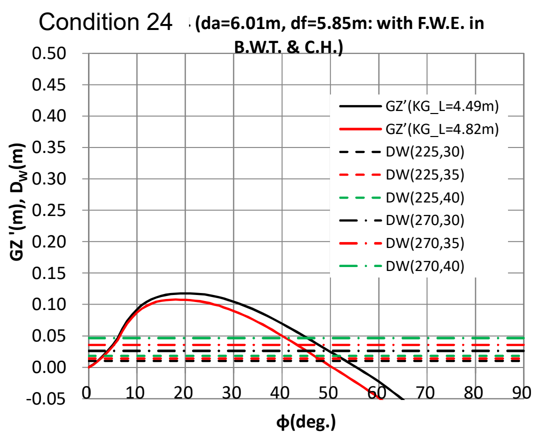
(i) Stability curve

In case that the top of the bulwark was submerged, it seemed that all of the Retained Water on the Vessel became Overboard Water, and it is assumed to be probable that the stability transited to the condition of only being ingress water into the cargo holds without the Retained Water.

Figure 16 is the stability curve of the Hull Condition, as shown in Table 11, with the submerged angle of the top of the bulwark (ϕ_B) as 12.6°. Based on the Retained Water being Overboard Water, with the lateral heeling angle as ϕ, the case of $0 \leqq \phi \leqq \phi_B$ was the stability of Condition 14 (a Retained Water ratio of 75%), and the case of $\phi_B \leqq \phi$ was the stability of "a Retained Water ratio of 0% and ingress water ratio in the cargo holds" (hereafter referred to as "Condition 24", Annex report of the Analysis).

In Figure 16, the red dotted line is the stability curve of Condition 24 in the case of $0 \leqq \phi \leqq \phi_B$, and the green dotted line is the stability curve of Condition 14 (a Retained Water ratio of 75%) in the case of $\phi_B \leqq \phi$.





Stability Curve in Condition 24
RW ratio 0% + IW ratio 8%

Figure 16 Stability Curve and Heeling Couple of Force Lever at the Accident Occurrence
Stability curve Condition 14, Condition 24: KG_L=4.82m
Heeling couple of force lever Heading: 270°, Wind force: 30 m/s; Condition 14

(ii) Heeling angle and amplitude of heeling

The estimated result of the heeling angle due to winds shown in Table 14 is the angle corresponding to ϕ_0 which coincides with the stability GZ and the heeling couple of force lever D_w shown in Figure 16. Figure 17 shows the stability GZ (the solid line) and the heeling couple of force DW(270, 30) of the heading of the Vessel at 270° and winds of wind force 30 m/s in the case of Condition 14 and KG_L=4.82 m, and therefore ϕ_0 indicates an heeling to the right side of 4.1° as shown in Table 14.

In the case of rolling due to waves in a condition of heeling to the lateral direction (steady-state heeling) of only ϕ_0 due to winds, depending on the characteristics of the stability curve, the amplitude is asymmetrical heeling, in which there is a difference between rolling to the port side and rolling to the starboard side. In this situation, the amplitude of heeling can be used to analyze the lateral heel center as ϕ_0 using the formula in the Instruction of Ship Inspection[*14].

In Figure 17, ϕ_{1p} is the maximum heeling angle of the port side, ϕ_{1s} is the maximum heeling angle of the starboard side, and ϕ_a is the amplitude of heeling due to estimated waves.

In the condition of Figure 16, the middle value 15° between 10° and 20° of heeling is taken up in accordance with the Accident Scenario b), and the analysis then conducted with the results as shown in Figure 17. The maximum heeling angle of the port side ϕ_{1p} is 11.1° and the maximum heeling angle of the starboard side ϕ_{1s} is 18.9°.

However, in case that the lateral heeling angle exceeds the submerged angle 12.6° of the top of the bulwark, the stability transits to the condition of ingress water being in the cargo holds without the Retained Water (Condition 24), and furthermore it is assumed that the heeling couple of force due to winds also transits to the couple of force of Condition 24.

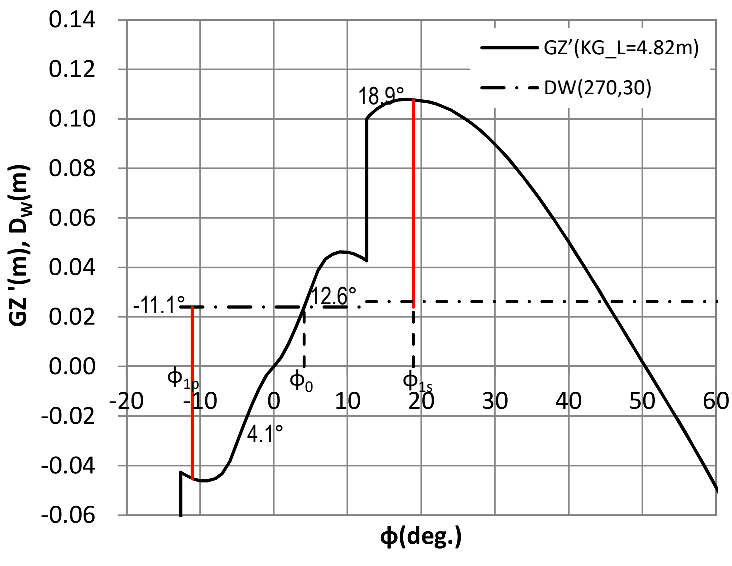


Figure 17 Calculation of Rolling in Steady-state Heeling Condition
Condition 14, Condition 24: KG_L=4.82 m
Middle of heeling ϕ_0: 4.1° , Amplitude of heeling due to waves: 15°

[*14] Supervised by Maritime Technology and Safety Bureau of Ministry of Transport, edition compiled by the society for researches and investigations of the Regulation related to the Ship Safety Law; Based on The Instruction of Ship Inspection, The Interpretation for the Regulation related to Ship Safety Law, pp.507, Seizando-shoten publishing Co., Ltd., February 2000.

(iii) Calculation of maximum lateral heeling to the starboard side

In accordance with the Accident Scenarios c) and d), in case that the Vessel was receiving gusts of wind in a condition of heeling at the maximum angle to the weather side of the waves (port side) ($\phi = \phi_{1p}$), and then heeled back to the lee side (starboard side), the maximum lateral heeling angle is ϕ_{ℓ}, and thereby, based on a concept of energy balance similar to the C coefficient standard[*15] of the Rule of Ship Stability, can be calculated using Figure 18.

D_{wg} by means of gusts of wind is defined as the heeling couple of force DW (270, 40) due to wind of a wind speed of 40 m/s in a condition of the heading of the Vessel as 270° and the lateral heeling angle is 6.9° (Table 14) in the case of gusts of wind acting quasi-statically. Furthermore, conducting the analysis utilizing the analyzed value (ϕ_{1p}= -11.1°) in item (ii) as the maximum heeling angle to the port side, the maximum heeling angle is 29.2°. Moreover, the transit of the stability curve in case of a lateral heeling angle to the starboard side exceeding the submerged angle 12.6° (ϕ_B) of the top of the bulwark is similar to that mentioned above.

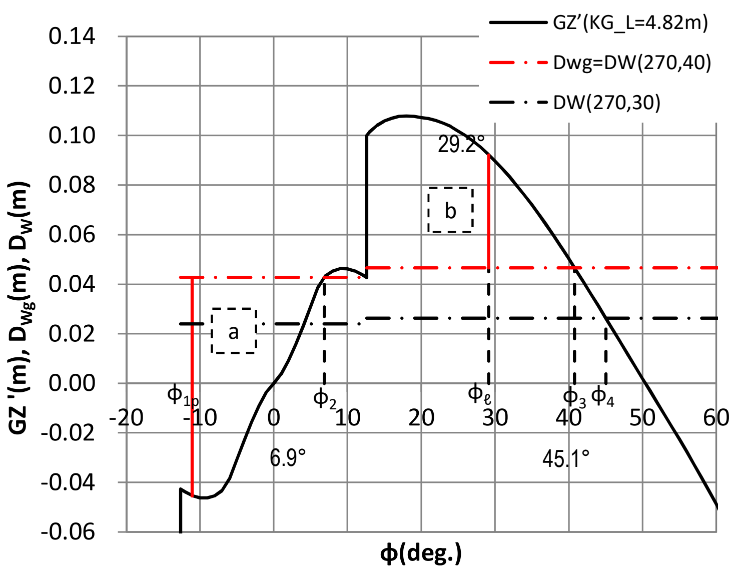


Figure 18 Calculation of Energy Balance

Condition 14, Condition 24: KG_L=4.82 m, Heading of the Vessel: 270°,

Wind speed 40 m/s, Maximum lateral heeling angle to port side ϕ_{1p}: -11.1°

(iv) Comparison of maximum lateral heeling angle to starboard side and heeling angle of maximum stability occurring

As a result of the analysis of item (iii), in the case of the Hull Condition and the heading of the as Vessel 270°, in a situation of receiving wind of an average wind speed of 30 m/s and rolling to both sides due to waves with an amplitude of 30° on both sides, the maximum heeling angle to the starboard side is thereby 29.2° in case of receiving gusts of wind with a wind speed of 40 m/s.

[*15] The C coefficient standard of the Rule of Ship Stability refers to a judgement method of stability performance, which compares inclination energy and stability in a condition of receiving winds, when a vessel receives standard steady wind, and is rolled by lateral waves and heeled to weather side the greatest extent.

On the other hand, as shown in Figure 18, the heeling angle where the maximum value of stability in this condition occurs is approximately 18°, and the heeling of the stability curve is negative at the maximum heeling angle of 29.2° to the starboard side. Therefore, with the Vessel having fallen into an unstable condition at the maximum angle to starboard in case of receiving gusts of wind, and furthermore, due to the submerged bulwark dragging subject to the weight of sea water and the Vessel in a condition of being difficult to stabilize, according to the Accident Scenario e), it is assumed that the lateral heeling angle increased due to continuing to receive the influence of waves.

As a result, the angle of loss of residual stability in the case of receiving wind of an average wind speed of 30 m/s in the condition of shown in Figure 18 corresponds to ϕ_4 and is 45.1°.

(3) Conclusions of the Analysis Based on the Accident Scenario

The results of conducting the analysis for the above-mentioned items 2.11.4(2) i) to iii) by the combination of two patterns of KG_L (4.49 m and 4.82 m), six patterns of ingress water into the cargo holds (ratios from 0 to 10 % in 2 % increments) and the heading of the Vessel at 270° are shown in Table 15 and Table 16. The maximum heeling angle to the starboard side in case of receiving gusts of wind is shown as the condition of exceeding the heeling angle of the maximum value of stability occurring by shading in the cells of each Table.

Table 15 Analysis Results of Energy Balance (KG_L=4.49 m, Heading of the Vessel 270°)

IW Rate	ϕ_0 (deg.)	ϕ_{1p} (deg.)	ϕ_2 (deg.)	ϕ_B (deg.)	ϕ_ℓ (deg.)	ϕ_{max} (deg.)	ϕ_3 (deg.)	ϕ_4 (deg.)	a (deg.)	b (deg.)	c (deg.)
0 %	1.3	-13.7	2.2	15.5	18.3	25.5	71.3	73.0	3.11	17.00	5.47
2 %	3.4	-13.4	4.4	14.7	19.0	26.0	69.6	71.6	2.27	12.26	5.41
4 %	4.4	-13.1	5.5	14.0	20.1	25.5	65.9	68.2	1.74	8.10	4.65
6 %	4.6	-12.5	6.1	13.3	22.0	23.5	58.6	61.9	1.34	4.45	3.31
8 %	3.9	-11.4	6.2	12.6	26.8	20.5	45.2	49.7	1.01	1.69	1.67
10 %	3.2	-8.2	6.0	11.9	-	11.0	27.2	33.2	0.66	0.14	0.22

Table 16 Analysis Result of Energy Balance (KG_L=4.82 m, Heading of the Vessel 270°)

IW Rate	ϕ_0 (deg.)	ϕ_{1p} (deg.)	ϕ_2 (deg.)	ϕ_B (deg.)	ϕ_ℓ (deg.)	ϕ_{max} (deg.)	ϕ_3 (deg.)	ϕ_4 (deg.)	a (deg.)	b (deg.)	c (deg.)
0 %	1.4	-13.6	2.4	15.5	18.5	23.5	65.5	67.2	2.94	13.75	4.68
2 %	3.6	-13.3	4.6	14.7	19.4	24.0	63.6	65.7	2.13	9.65	4.52
4 %	4.7	-12.9	5.8	14.0	20.7	23.5	59.7	62.3	1.64	6.21	3.79
6 %	4.9	-12.3	6.4	13.3	22.9	22.0	52.1	55.8	1.27	3.33	2.63
8 %	4.1	-11.1	6.9	12.6	29.2	18.0	40.8	45.1	0.96	1.24	1.30
10 %	3.2	-	-		-	-	-	-	-	-	-

With the results from the above-mentioned Table, the following results are obtained within the range of the Analysis.

(i) The occurrence of the maximum heeling angle to starboard in case of receiving gusts of wind in the condition of exceeding the heeling angle of the maximum value of stability is limited to the condition that the ingress water ratios in the cargo holds is more than 6 %.

(ii) Among the results, the angle of loss of residual stability corresponding to the assumed Accident Scenario shown in item (1) becoming approximately 45° occurs when the ingress water ratio in the cargo holds is 8 %.

(iii) In the condition of her heading being 270° and the ingress water ratio in the cargo holds being 10 %, the Vessel is in a condition of heeling with the maximum angle to the port side and will roll over immediately in the case of receiving gusts of wind to the port side (KG_L=4.49 m, Table 15), or to roll over without a condition of balance in the case of gusts of wind acting independently (KG_L=4.82 m, Table 16).

2.11.5 Conclusion of Circumstances Leading Up to Foundering

The results of the Analysis indicated that the circumstances leading up to the Vessel foundering were as follows.

(1) In accordance with 2.11.3 (1), at the time of the accident, sea water that washed up on the upper deck of the Vessel became the Retained Water, but even though stability was decreasing, it did not have a significant influence, and stability was then secured in the heeling angle in which the hull was rolling between approximately 10° and 20° .

(2) In accordance with 2.11.3 (2), in case of assuming flooding due to taking on sea water into the cargo holds, stability was reduced markedly, and thereby the ingress water was a more significant influence than the Retained Water.

As shown in Figure 13, in the case of there being ingress water in the amount of 8 % of the volume of the cargo holds, the Vessel had fallen into a condition of readily rolling over if the heeling angle exceeded the peak of stability, which was approximately 10° , and furthermore, stability was zero when the heeling angle was between 25.5° and 28.5° in such a case of receiving gusts of wind due to the typhoon, and thereby she was in condition of not avoiding rolling over due to the action of a slight moment.

(3) The Vessel in the case of an ingress water ratio of 75 % was in a condition in which the discharging holes were submerged at a lateral heeling of approximately 7.8° and the top of the bulwark was submerged at approximately 15.5° . The discharging of the Retained Water was thereby obstructed by the submerging of the discharging holes of the bulwark, and furthermore, the hull was in a condition of being difficult to stabilize due to the submerging of the top of the bulwark.

Moreover, the bulwark came to be further submerged with a slight heeling angle in case of there being ingress water in the cargo holds.

(4) In accordance with 2.11.3 (4) i), the lateral heeling moment increases as wind speed rises, and ingress water increases as stability reduces. In Figure 14, in the case of receiving wind with a wind speed of 30 m/s in Condition 11 and Condition 12, and even though the Vessel had still secured stability, in the case of wind of a similar wind speed in Condition 14 (a Retained Water ratio of 75 % and ingress water ratio of 8 %), the range of stability on the line of heeling couple of force DW (270, 30) was at approximately 19° in KG_L 4.49 m and was at approximately 15° in KG_L 4.82 m. She could not avoid rolling over due to the action of a slight moment when these ranges of stability were exceeded.

Then, in Condition 15 (a Retained Water ratio of 75 % and ingress water ratio of 10 %), the position of the stability curve in the case of the Vessel having a heading of 270° was under the heeling couple of force lever D_w, and stability came to be in an unstable condition, and thereby she was in a condition of capsizing at any time due to wind with a wind force of 40 m/s.

In accordance with 2.11.3 (4) ii), the heeling angle due to winds increases as the volume of ingress water into the cargo holds increases. At the time of the accident, the Vessel in Condition 11 to Condition 13 directed her heading the westward, approximately 270° , in case of assuming the wind direction being the south-south-west and receiving wind with a wind speed of approximately 30 m/s from the port side, and thereby the heeling angle heeled to starboard by 3.4° to 4.6° in KG_L 4.49 m and 3.6° to 4.9° in KG_L 4.82 m.

Moreover, when receiving strong wind exceeding a maximum instantaneous wind speed of 40 m/s, the Vessel was in a condition of the heeling angle coming to exceed 6° and this was a condition in which the discharging holes of the bulwark were submerged.

(5) In 2.11.4, the Accident Scenario was shown from the circumstances of the accident in items 2.1.3 and 2.8: at the time of the accident, it is possible to assume progress in which the Vessel was heeling to the starboard side, and then increased heeling to starboard more and more, and thereby finally rolled over.

2.12 Information on Rescue and Reducing Damage

According to the statements by Master, Chief Engineer, N. Officer A and Oiler A, and the information provided by JCG, the situation was as follows:

(1) Clothes and Life Jackets Worn by Rescued Crewmembers

(i) Master wore a short-sleeved shirt and long trousers, and was not wearing a life jacket.

(ii) Chief Engineer took off his clothes before jumping into the sea, and only wore a half-sleeved shirt, short pants and a life jacket so it would be easy to swim.

(iii) N. Officer A wore a long sleeved work shirt, long trousers and a life jacket.

(iv) Oiler A wore a long-sleeved shirt, long trousers and a life jacket.

(2) Activities while Awaiting Rescue at Sea

(i) Master had also been a diver in the Navy of Myanmar and was proficient at swimming, and moreover was very knowledgeable about survival techniques at sea.

After the accident, Master and Oiler A were drifting holding on to a life buoy with their arms, and then kept together in the sea and paid attention to saving their strength without swimming. When receiving big waves many times, they held their breath each time, and if they took sea water into their mouth, they swallowed it into their stomach without drawing sea water into their respiratory organs.

Master maintained a strong attitude that they absolutely must survive, and when Oiler A mentioned pain in his leg muscles and fatigue, Master cheered him by grabbing his body. Subsequently Master noticed the patrol boat and indicated their position by flashing his life jacket light when they were discovered and rescued by the loaded rescue boat.

(ii) Chief Engineer was drifting and awaiting rescue while occasionally swimming, and when he noticed the patrol boat, he began to swim in its direction.

(iii) N. Officer A paid attention to saving his strength without swimming, and maintained a strong attitude that he absolutely must survive, and when he noticed the loaded rescue boat, he began to swim in its direction.

(3) Situation of Abandon Ship for Crewmembers

Master and crewmembers, at the time of the accident, did not put on immersion suits, and then three crewmembers out of four crewmembers recovered in the Vessel interior had not put on life jackets. (See Table 17)

When whistling the general emergency signal for abandon ship, N. Officer A did not move to the master station and did not take the two-way wireless telephone which was his article to carry in emergency stations outside the Vessel.

Table 17　Condition of the Dead Crewmembers, etc. when Discovered

Location	Number	Condition of wearing life jacket
Crewmembers at sea	3 persons Boatswain, Oiler B and Oiler C	Wearing: 3 persons
Crewmembers in the Vessel interior	5 persons N. Officer B, Engineer, Able Seaman, Ordinary Seaman and Chief Cook	Wearing: 1 person Not wearing: 3 persons Unknown: 1 person

2.13 Information on Influence on Marine Environment Due to Oil Spill and Control of Oil Spill

According to the statements by the persons in charge of fisheries of Kanagawa Prefectural Government and Chiba Prefectural Government, the replies to the questionnaires of Kanto Regional Development Bureau and Kyushu Regional Development Bureau of MLIT, Port Bureau of Yokosuka City and the insurance company (hereafter referred to as "Company D") which had made a contract with Company C, and the information of JCG, an oil spill from the FO tanks, etc. of the Vessel occurred around the accident location after the accident, and then oil spill prevention measures were conducted by JCG, etc.

2.13.1 Influence on Marine Environment Due to Oil Spill

At around 18:30 on October 13, drifting oil discharged from the Vessel was confirmed around the center of Tokyo Wan, and the coastline of Kisarazu City, Chiba Prefecture and Yokosuka City offing, Kanagawa Prefecture.

(1)　JCG

On October 18, the relevant persons of JCG, the Vessel's parties concerned (Surveyor, etc.), Related Administrative Organizations, Fishery Cooperative, etc. held the Marine Accident Liaison Meeting for the Vessel Foundering, and promoted information sharing regarding the summary of the marine accident, the response actions after the accident occurred, etc., as the result, they confirmed the role of oil pollution prevention measures, etc. each other.

Still more, at around 06:30 on October 18, the circumstance of spill oil was as follows;

(i)　The point where the spilled oil was gushing out was discovered around Higashi-Ogi Island offing of Keihin Port.　The drifting oil was in striated form, with a length of approximately 1,700 meters and width of approximately 20 meters.

(ii)　Spilled oil washed up ashore and drifting trash became oily at the US Navy base, three seaside parks and some facilities in the seaside parks in Yokosuka City.

(iii)　Drifting trash became oily along Futtsu coast, Futtsu City, Chiba Prefecture.

(2)　Kanagawa Prefecture

As of November 14, the circumstances of oil pollution concerning the fishery in Kanagawa Prefecture were confirmed as oil contents adhering to the following facilities, and there was no direct damage to marine products.

(i)　Some parts of wakame seaweed aquaculture facilities and the ropes of seaweed aquaculture facilities on the Hashirimizu Coast in Yokosuka City

(ii)　Ropes of seaweed aquaculture facilities in Kaneda Wan, Miura City

(3) Chiba Prefecture

As of November 13, the circumstances of oil pollution concerning the fishery in Chiba Prefecture were confirmed as oil contents adhering to the following facilities and the coastlines had become oily, and there was no direct damage to marine products.

(i) The frames and buoys of seaweed aquaculture facilities around the Futtsu coast; the season for setting seaweed nets was delayed.

(ii) Trash with adhered oil contents was arriving at the sandy beach on the Futtsu coast which is the habitat of "Asari" short-necked clams.

(See Annex Table 1 Situation of Oil Pollution around the Accident Location, Annex Table 3 Circumstances of Oil Pollution by Spilled Oil (Yokosuka Port, Yokosuka City))

2.13.2 Control of Oil Spill

(1) Prevention Measures for the Oil Spill

On October 14 and 15, JCG divers conducted temporary measures by divers to prevent oil spilling from the air vents of the FO tanks, lub. oil tanks, bilge tank, etc. of the Vessel. Subsequently, on October 17, the divers of the other salvage company (hereafter referred to as "Company E"), which made a contract with Company D, conducted spilled oil prevention measures by wrapping the above-mentioned air vents and the filling lines of lub. oil using plastic bags, etc.

After the measures, it seemed that the spilled oil gushing out was not from the FO tanks, etc. and was the remaining oil from the engine room interior.

(2) Recovery Works and Diffusion Work for Spilled Oil

(i) After the confirmation of drifting oil around the center of Tokyo Wan, the patrol vessels, patrol boats, vessels belonging to the Regional Development Bureaus and the working boat which was arranged by Company C conducted the following oil pollution prevention works.

a) JCG

On October 13, the patrol vessels and patrol boats conducted recovery for spilled oil using oil skimming nets, and subsequently, from October 14 to 18, conducted water diffusion and ship sailing diffusion.

b) Kanto Regional Development Bureau and Kyushu Regional Development Bureau, MLIT

From October 13 to 18, a sea surface cleaning and oil recovery vessel (hereafter referred to as "the COR vessel") recovered spilled oil using oil adsorbing mats and conducted agitation operations using water gun devices, and then on October 14, a suction hopper dredger and oil recovery vessel (hereafter referred to as "the DOR vessel") departed from Kitakyusyu Port, Fukuoka Prefecture and on October 18, conducted diffusion for spilled oil with a jet spraying device.

(See Annex Table 2 Prevention Works for Spilled Oil around the Accident Location)

c) Kanagawa Prefecture and Chiba Prefecture

Related administrative organizations of ports and fisheries in both prefectures removed drifting oil using oil adsorbing materials, and subsequently recovered trash with adhered oil contents that had washed ashore in seaside park facilities and around the coast.

(See Annex Table 3 Circumstance of Oil Pollution Due to Spilled Oil (Yokosuka Port, Yokosuka City))

(ii) From November 29 to December 9, Company D conducted oil draining work from the FO tanks, etc. of the Vessel, and thereby there was no longer a fear that a lot of spilled oil would be discharged from the Vessel after completing this work.

3 ANALYSIS

3.1 Situation of the Accident

3.1.1 Course of the Events

According to 2.1.3, 2.6.2, 2.6.3, 2.6.5, 2.8 and 2.9, it is considered probable that the course of events involving the Vessel was as follows:

(1) At around 19:00 on October 12, Master ordered the crewmembers to assemble in the stand-by station, and subsequently commanded maneuvering the Vessel himself and directed the heading of the Vessel against the wind and waves under the condition of rolling and pitching due to her hull receiving winds and waves that had increased due to the typhoon approaching.

(2) At around 20:00, she was receiving strong winds and waves more than item (1), and her rolling was increasing.

(3) At around 21:00, she was receiving strong winds and waves from the south-south-west more than item (2), at around 21:23, No.2 diesel generator engine stopped and lost electric power, and then her steering was uncontrollable and she was swept away to the east-south-east direction, and subsequently Master tried to maneuver the Vessel and was stabilizing her attitude only using the main engine.

(4) Chief Engineer and Engineer started No.1 generator and recovered electric power in the Vessel, but her generators stopped three times in succession, and subsequently electric power of the Vessel was recovered by the work of the crewmembers.

(5) At around 21:30, the Vessel received winds and waves from the south-west and her hull was swinging, and then was swept away to the north-west direction, and subsequently heeled to the starboard side, rolled over to the starboard side and thereby foundered.

3.1.2 Situation of the Vessel Foundering

According to 2.1.3 and 2.9, it is considered probable that at the time of the accident, the Vessel was in a situation in which sea water washing up to the upper deck became the Retained Water and flooding due to taking on sea water into the interior of the cargo holds began, after which there was rolling between 10° and 20° and pitching movement. At around 21:34, she heeled to the starboard side by approximately 5° due to receiving winds and waves from her port fore side and came to roll on that heeling angle; furthermore, she was gradually increasing to heel to the starboard side by approximately 30°, and thereby she lost her stability and rolled, as a result of which she proceeded to be flooded due to taking on sea water into her hull interior and foundered.

3.1.3 Date, Time and Location of the Accident Occurrence

According to 2.1 and 2.3, it is considered highly probable that the date and time of occurrence of the accident was around 21:39 on October 12, 2019, and the location was around 137°, 1 M from the lighthouse on the Kawasaki Higashi-Ogi Island breakwater.

3.1.4 Situation of Casualties and Injuries to Persons

According to 2.1.3 and 2.2, it is considered highly probable that N. Officer B, Engineer, Boatswain, Able Seaman, Ordinary Seaman, Oiler B, Oiler C and Chief Cook were drowned.

3.1.5 Damage to the Vessel

According to 2.3, it is considered highly probable that the Vessel foundered in a condition of her port side being upward and grounded in a condition of heeling to her starboard side.

3.2 Causal Factors of the Accident

3.2.1 Situation of Crew Members

According to 2.4, the situation of the crewmembers was as follows:

(1) Master

Master possessed a legally valid certificate of competence and was assigned as a master on the Vessel for the first time. However, he has had a boarding career as a navigation officer in the past and experience for sailing vessels in storms and rough seas, and therefore obtained recognition of his skill by the crewmembers of the deck department.

It is considered highly probable that he was in good health.

(2) Chief Engineer

The Chief Engineer possessed a legally valid certificate of competence.

It is considered highly probable that he was in good health.

(3) N. Officer A

N. Officer A possessed a legally valid certificate of competence.

It is considered highly probable that he was in good health.

(4) Oiler A

Oiler A possessed a legally valid certificate of competence.

It is considered highly probable that he was in good health.

(5) Other crewmembers

It is considered probable that they were in good health.

3.2.2 Situation of the Vessel

According to 2.1.3, 2.5.2, 2.5.3, 2.10, 2.11.3 and 2.11.5, it is considered probable that situation of the Vessel was as follows:

(1) There was no malfunction or failure with the Vessel’s hull, engine or machinery in usual ship operation, but she did not maintain weather-tightness for the hatch covers themselves of the cargo holds due to some part of the Panels of the hatch cover being deformed and the Receivers being partially broken with holes in rusty condition. Moreover, distress signals from the Vessel were not dispatched at the time of the accident.

(2) The Vessel had loaded steel scrap in Keihin Port, her draft became deeper in position and her dry draft was approximately 1 meter due to conducting bunkering at K1 anchorage, and moreover, waves increased due to the typhoon approaching washed up on the upper deck and the Retained Water occurred, because her dry draft was further reducing.

(3) The cargo holds were in the following condition, because the dry draft of the Vessel was further decreasing when the Retained Water on the deck and flooding from taking on sea water into the interior of the cargo holds occurred.

i) The lids of opening parts of the ventilation cylinders for the cargo holds were in an open condition.

ii) There were broken holes in parts of the Receivers which were at the connection parts between the Panels and some clearance in parts between the Panels and the hatch coaming due to being deformed, involving approximately one fourth of all of the Panels, and therefore the hatch cover of the cargo holds was not secured to be weather-tight.

(4) At around 16:00 on October 12, a crewmember of the engine department conducted the Discharging Operation as routine work before the accident and confirmed that there was no ingress water in the MDO tank, because ingress water infiltrated into the MDO tank interior after that time.

(5) At the time of the accident, when the Vessel was heeled to the port side in excess of 13° to 16° due to the ship's condition, or had the Retained Water to a height of more than approximately 0.7 m, then it is considered somewhat likely that the air vents of the MDO tank were submerged, and subsequently sea water infiltrated into the MDO tank interior.

(6) Ingress water pooled at the bottom of the MDO tank with MDO was supplied to the diesel generator engines through the FO line, because the diesel generator engines experienced combustion failure or misfire, and thereby stopped.

3.2.3 Weather and Sea Conditions

According to 2.6 and 2.9, the weather and sea conditions were as follows:

(1) It is certain that at the time of the accident, local weather warnings such as a high wave warning, storm warning and emergency heavy rain warning for Yokohama City and Kawasaki City had been issued and these warnings continued to be in effect.

(2) It is considered probable that at around K1 anchorage where the Vessel anchored, between 20:00 and her foundering on October 12, the weather condition was rain, the wind was blowing from the south-east to south-south-west at an average wind speed of between 18.0 m/s and 32.3 m/s and maximum instantaneous wind of approximately 42.7 m/s, and that at around 21:00 before the accident, the wind factor of blowing from the south to the north was at its maximum and at that timing the wind factor had been changing from the east to the west. The air temperature was approximately 24 degrees Celsius, sea water temperature was approximately 24 degrees Celsius and visibility was poor.

(3) It is considered probable that at the time of the accident, the wave height was from 4.0 to 5.0 m and the wave frequency was approximately 7 seconds.

3.2.4 Situation of Safety Management Aboard the Vessel

According to 2.1.3, 2.5.2, 2.5.3, 2.7.2, 2.7.3, 2.9, 3.1.1 and 3.2.2, it is considered probable that Company C had produced the SMS and implemented it by formulating procedure documents, and the management status in the SMM was as follows:

(1) Implementation of Critical Operations in SMS

(i) It is considered probable that Master recognized that closing opening parts on the exposed deck, etc. was important as a measure of preparation based on the SMS against stormy weather as the typhoon was approaching, and therefore he instructed the crewmembers to take these measures; however, these measures were not conducted reliably before the accident, because some lids for opening parts of the ventilation cylinders were in an open condition.

(ii) It is considered probable that the Vessel conducted bunkering in Keihin Port after loading cargo according to the direction from Company C, and thereby her dry draft was decreased, and subsequently at the time of the accident, the Retained Water was caused on the upper deck, because Master could not help to conduct critical operations of the SMS in the situation of her dry draft further decreasing and her stability decreasing.

(2) Weather-tightness for the Cargo Holds

(i) It is considered somewhat likely that the staff of Company C had confirmed deformation of the hatch covers of the cargo holds when visiting for the Vessel's inspection; however, they recognized that weather-tightness of the hatch covers would be maintained by covering them with the tarpaulin sheets, and furthermore this measure for weather-tightness had also been recognized as a temporary measure in PSC, because the cargo holds were not kept weather-tight in compliance with the relevant regulation.

(ii) It is considered somewhat likely that even though Company C had produced maintenance processes and inspections in the SMM which should be conducted to satisfy the relevant regulations, etc., because using the tarpaulin sheets on the hatch covers was recognized as shown in item (i), thereby Company C did not conduct repairment regarding the defective hatch covers of the cargo holds.

3.2.5 Analysis of Hull's Stability, Rolling Over and Foundering

According to 2.1.3, 2.5.3, 2.6.2, 2.6.3, 2.8, 2.9, 2.11.2 to 2.11.5, 3.1.1, 3.1.2, 3.2.2 and 3.2.3, it is considered probable that at the time of the accident, the Vessel was as follows:

(1) At 19:00 on October 12, the Vessel was receiving winds blowing from between the east-south-east and south-east, and waves with a wave height from 2.0 to 3.0 m, in a condition of rolling by approximately 5° in addition to pitching movement. Even though she was stabilizing her attitude, she was in a condition in which discharging sea water came not to continue significantly through the discharging holes, and then the cargo holds came to be in the condition of 3.2.2 (3), because she began to be flooded due to beginning to take on sea water into the interior of the cargo holds.

The Vessel was able to secure stability if it was only the Retained Water on the upper deck; however, she had begun to be flooded due to taking on sea water into the interior of the cargo holds, because her stability was gradually decreasing.

When she had the Retained Water in both passages on the upper deck, in the case of the Retained Water being at 75 %, the dry draft being at approximately 0.9 meters, and then she was heeling in the condition in which the discharging holes of the bulwark were submerged at approximately 8° and the top of the bulwark was submerged at approximately 16°.

The angle of the bulwark being submerged decreased as the volume of the Retained Water and ingress water into the interior of the cargo holds increased, and thereby discharging of the Retained Water was obstructed due to the discharging holes being submerged and the Vessel was difficult to stabilize due to the top of the bulwark being submerged when her hull was heeling.

(2) At around 20:00, winds and waves were stronger than in the condition of item (1), and the Vessel was heeling between 10° and 20° due to receiving waves with a wave height of 3.0 m to 4.0 m, and subsequently wave uprush coming heavily from her fore side and both sides caused the Retained Water on the deck and the Vessel was covered with spraying sea water to a height of between 0.2 m and 0.5 m on the hatch covers of the cargo holds. This situation continued until the time of the accident, and her stability progressively decreased. In addition, wave uprush on the deck further increased, because her dry draft had been

decreasing due to ingress water into the cargo holds and the Retained Water.

(3) At around 21:00, the Vessel began to receive winds from the south-south-west which were stronger than in the condition of item (2). Average wind speed was approximately 30 m/s and maximum instantaneous wind more than approximately 40 m/s, and furthermore there was wave uprush with a wave height from 4.0 to 5.0 m. Subsequently, at around 21:23, the Vessel's steering was uncontrollable and it was difficult to stabilize her attitude, and she was then sweeping away to the east-south-east direction and was difficult to maneuver such as directing her heading against winds and waves, and thereby receiving winds and wave uprush from the port fore side.

(4) At around 21:34, the Vessel was receiving winds which were changing wind direction due to blowback wind after passing of the typhoon and furthermore heavier waves from the port fore side to port side, and then the lateral moment was acting, after which her hull heeled to the starboard side at approximately 5°, and she came to be rolling on that heeling angle and heeled to the starboard side by approximately 20°. At that time, she continued to be flooded due to taking on sea water into the interior of the cargo holds, and subsequently heeled to the starboard side more and more and did not stabilize, and thereby heeled to starboard by approximately 30°.

In this situation, the submerged bulwark was dragging subject to the weight of sea water, because the Vessel fell into a condition of being difficult to stabilize, and subsequently was continuously receiving waves with a wave height from 4.0 to 5.0 m.

(5) The height of metacenter was decreased due to the Retained Water and ingress water into the cargo holds, in addition to stability having reduced, because the Vessel was heeling to the starboard side by approximately 30° to 45°, after which she rolled over and flooding was progressing due to taking on sea water into the interior of the cargo holds, with the result being that she foundered.

(6) After the Vessel was receiving further increased winds and wave uprush from the port fore side to port side, she heeled to the starboard side due to receiving winds and waves and came to roll on that angle, and then heeling to the starboard side gradually increased due to receiving strong wind such as an average wind speed of approximately 30 m/s and maximum instantaneous wind of more than approximately 40 m/s and heavy waves due to the typhoon. After she attained the angle of stability in maximum condition (approximately 30°), and subsequently the lateral heeling angle increased due to continuous waves, this thereby led to the lateral heeling angle attaining the angle of loss of residual stability (approximately 45°) and she rolled over to the starboard side.

3.2.6 Analysis of the Accident Occurrence

According to 2.1.3, 2.5.2 to 2.5.4, 2.6.1 to 2.6.3, 2.7.2, 2.8, 2.9, 2.10, 2.11.2 to 2.11.5, 3.1.1 to 3.1.3 and 3.2.2 to 3.2.5, it is considered probable that the Vessel was as follows:

(1) The Vessel was under a condition of rolling and pitching due to receiving winds and waves that had increased due to the typhoon approaching while the Vessel was anchoring in the nighttime. At around 19:00 on October 12, Master ordered the crewmembers to assign the stand-by station, and then was conducting maneuvering of the Vessel himself using the steering and the main engine, and was stabilizing her to direct her heading against the winds and waves.

In that time, the Retained Water was caused on the Vessel due to sea water washing up on the upper deck, because her dry draft was decreasing, and she began to be flooded due to taking on sea water into the interior of the cargo holds because the lids for opening parts of the ventilation cylinders of the cargo holds were in an open condition.

The Vessel would have been able to secure stability if there was only the Retained Water on the upper deck; however, she had begun to be flooded due to taking on sea water into the interior of the cargo holds, because her stability was gradually decreasing.

(2) At around 20:00, the Vessel was receiving strong winds and waves with a wave height from 3.0 to 4.0 m, and then the bulwark began to submerge when her hull heeled greatly. Sea water washed up on the upper deck and caused the Retained Water, and furthermore covered the hatch covers of the cargo holds, and the Vessel did not maintain weather-tightness of the hatch covers, because her flooding was further increasing due to taking on sea water into the interior of the cargo holds, and thereby her stability was progressively decreasing. In addition, wave uprush on the deck further increased, because her dry draft had been decreasing due to ingress water into the cargo holds and the Retained Water.

(3) At around 21:00, the Vessel was receiving strong winds from the south-south-west that were stronger than the condition of item (2), with an average wind speed of approximately 30 m/s and maximum instantaneous wind speed of more than approximately 40 m/s, and furthermore waves with a wave height from 4.0 to 5.0 m. At around 21:23, a generator engine stopped and she lost electric power, and then she was in a state in which her steering was uncontrollable and it was difficult to stabilize her attitude, and subsequently she was sweeping away to the east-south-east direction and was difficult to maneuver such as directing her heading against winds and waves, and thereby she was receiving winds and wave uprush from the port fore side.

(4) Even though electric power in the Vessel was recovered, she was in a difficult situation for directing her heading against winds and waves. At around 21:34, she was receiving winds the wind direction of which was changing due to blowback wind after passing of the typhoon, and furthermore heavier waves from the port fore side to port side, and she then greatly heeled to the starboard side and continued to be flooded due to taking on sea water into the interior of the cargo holds, and moreover was heeling to the starboard side and the starboard bulwark was submerged. Subsequently, she rolled over due to her decreasing stability and the progress of flooding due to taking on sea water into the interior of the cargo holds, with the result being that she foundered.

(5) After the Vessel was receiving further increased winds and wave uprush from the port fore side to port side, she heeled to the starboard side due to receiving winds and waves and came to roll on that angle, and then heeling to the starboard side gradually increased due to receiving strong wind and heavy waves due to the typhoon. After she attained the angle of stability in maximum condition and subsequently the lateral heeling angle increased due to continuous waves, this thereby led to the lateral heeling angle attaining the angle of loss of residual stability and she rolled over to the starboard side.

(6) Under the circumstances of the rolling and pitching of the Vessel's hull in stormy weather and rough seas, ingress water that pooled in the MDO tank interior with MDO was supplied to the diesel generator engines with MDO through the FO line, as a result of which the diesel generator engines experienced combustion failure or misfiring, and subsequently stopped, and thereby the blackout occurred.

3.3 Analysis of Measures to Alleviate Damage

3.3.1 Circumstances of Survival Techniques at Sea

According to 2.1.3 and 2.12, it is considered probable that Master and three crewmembers who were the survivors performed the following activities while they were drifting in the sea.

(1) Not swimming and saving their strength.

(2) Swallowing sea water into their stomach without drawing it into their respiratory organs if sea water got into their mouth.

(3) Continuing to face down by grabbing a life buoy with their arms because waves did not strike their faces directly.

(4) Having a strong attitude to survive and cheering up their surviving partner among crewmembers who were drifting.

(5) Using a life jacket light effectively to make their position known to the rescue team.

3.3.2 Illustrative Cases of Not Practicing Techniques for Abandon Ship

According to 2.1.3 and 2.12, it is considered probable that the illustrative cases in the accident were as follows:

(1) Some crewmembers did not evacuate from the Vessel interior and did not put on life jackets.

(2) Even though the abandon ship station was announced and the signal was whistling, some crewmembers hesitated to move to the master station on the boat deck and did not take out the two-way radio telephone as an item to carry in emergency stations.

(3) When the abandon ship station was announced, some crewmembers took off their clothing and jumped into the sea, and therefore it is somewhat likely that they suffered hypothermia until they were rescued.

3.4 Situation of Influence on Marine Environment Due to Oil Spill and Control of Oil Spill

According to 2.1.3 and 2.13, the situation was as follows:

(1) It is considered to be highly probable that an oil spill from the Vessel occurred after the accident occurred. There was drifting oil around the accident location, and drifting oil and trash that had become oily washed up along the coast, etc. in Kanagawa Prefecture and Chiba Prefecture. Drifting oil was recovered and agitated by the patrol vessels, patrol boats, COR vessel and DOR vessel, and drifting oil and trash that had become oily and had washed up along the coast, etc. were recovered by Local Government organizations, etc.

(2) It is certain that temporary measures were conducted on the Vessel to prevent oil spilling from her air vents of the FO tanks, etc. by JCG, etc., due to which the oil spill that was gushing out from the Vessel would be limited, and that, at a later date, oil draining work from the FO tanks, etc. was conducted on the Vessel, and subsequently she was raised and was recovered by a crane vessel around the accident location, because there is no oil spill at the present time.

4 CONCLUSIONS

4.1 Findings

It is considered probable that the accident occurred because the Vessel foundered due to the fact that the Retained Water on the deck began flooding due to taking on sea water in the interior of the cargo holds, and then her steering was uncontrollable and she was receiving winds and wave uprush from the port fore side to port side, and furthermore her hull greatly heeled to the starboard side and she continued to be flooded due to taking on sea water in the interior of the cargo holds, and she subsequently rolled over due to her stability having been decreasing and flooding due to taking on sea water into the interior of the cargo holds progressed, with the result being that she foundered. This situation began while the Vessel was anchoring in the nighttime under conditions of rolling and pitching due to receiving winds and waves that had increased due to the typhoon approaching the area of K1 anchorage.

It is considered probable that the Retained Water on the deck began flooding due to taking on sea water in the interior of the cargo holds because the lids for opening parts of the ventilation cylinders of the cargo holds were in an open condition, and the Receivers at the connection parts between the Panels had a number of broken holes and some parts of the Panels were deformed, and thereby the hatch covers were not securely weather-tight. In addition, it is considered probable that wave uprush on the deck further increased because her dry draft had been decreasing due to ingress water into the interior of the cargo holds and the Retained Water.

It is considered probable that the Vessel was in a state in which her steering was uncontrollable because ingress water that infiltrated into the MDO tank interior through air vents on the upper deck was supplied to the diesel generator engines with MDO through the FO line, and then the diesel generator engines experienced combustion failure or misfiring, and subsequently stopped, and thereby the blackout occurred.

It is considered probable that after the steering of the Vessel was uncontrollable and she was receiving further increased winds and wave uprush from the port fore side to port side, she heeled to the starboard side due to receiving winds and waves and came to roll on that angle, and then heeling to the starboard side gradually increased due to receiving strong wind and heavy waves due to the typhoon. It is considered probable that after she attained the angle of stability in maximum condition, and subsequently the lateral heeling angle increased due to continuous waves, because this thereby led to the lateral heeling angle attaining the angle of loss of residual stability and she rolled over to the starboard side.

4.2 Other Findings of Safety Relating to Issues

It is considered probable that the Vessel had the possibility to promote measures to prevent recurrence of a similar accident and to reduce the damage by taking the following measures.

(1) The Vessel conducted the bunkering in a condition of loading the cargo mostly full, and then when the Retained Water on the deck occurred, her dry draft was decreasing and it was difficult for her to discharge sea water on the deck, because her loading capacity and the timing of the bunkering should have been considered.

(2) Ingress water that pooled in the MDO tank interior after infiltrating due to rolling and pitching was supplied to the diesel generator engines through the FO line, so at the time of stormy weather, the crewmembers should conduct the Discharging Operation appropriately in addition to routine work.

Also, sea water infiltrated into the MDO tank interior though the air vents, so it is desirable for piping construction to be remodeled to automatically prevent water infiltration, such as an automatic opening and closing-type air vent head at the top of the pipe head or drain pipe.

(3) With regard to the crewmembers, refresher training should be conducted for survival techniques at sea for getting ready for abandon ship, such as taking out belongings, escape behavior from the Vessel interior, putting on a life jacket and immersion suit, dressing warmly, etc.

5 SAFETY ACTIONS

It is considered probable that the accident occurred because the Vessel foundered due to the fact that the Retained Water on the deck began flooding due to taking on sea water in the interior of the cargo holds, and then her steering was uncontrollable and she was receiving winds and wave uprush from the port fore side to port side, and furthermore her hull greatly heeled to the starboard side and continued to be flooded due to taking on sea water in the interior of the cargo holds, and she subsequently rolled over due to her stability having been decreasing and flooding due to taking on sea water into the interior of the cargo holds progressed, with the result being that she foundered. This situation began while the Vessel was anchoring in the nighttime under conditions of rolling and pitching due to receiving winds and waves that had increased due to the typhoon approaching the area of K1 anchorage.

Implementation of the following measures is necessary to prevent recurrence of a similar accident, etc.

(1) Masters should have crewmembers reliably carry out closing of opening parts on exposed decks such as lids of opening parts of the ventilation cylinders of cargo holds, etc. in case that stormy weather and rough seas are expected.

(2) Masters should secure significant dry draft in any sea condition, and therefore should have crewmembers carry out adjustment of the ship's condition, and arrange loading capacity and the timing of bunkering with the Management company.

(3) Masters should direct crewmembers to have them carry out the Discharging Operation for fuel oil tanks not only periodically as routine work, but also on a timely basis in a condition of rolling and pitching in stormy weather and rough seas so as not to supply fuel oil with infiltrated water into the FO lines of generator engines, etc.

(4) Masters should conduct refresher training for crewmembers concerning survival techniques at sea for getting ready for abandon ship, such as taking out belongings, escape behavior from the interior of the vessel, putting on a life jacket and immersion suit, dressing warmly, etc.,

(5) Masters should take measures to inform JCG, etc. immediately in case of a vessel for which there is a fear such as foundering, etc.

(6) The Management company and the Owner should implement necessary maintenance including the Receivers to secure weather-tightness of the hatch cover of the cargo holds themselves. Moreover, it is desirable that the air vent pipe construction of vessels managed by the Management company and the Owner be remodeled to automatically prevent the infiltration of water such as an automatic opening and closing-type air vent head at the top of a pipe head or drain discharging pipe.

Based on the results of investigation of this fatal marine accident, the Japan Transport Safety Board shall cause this marine accident investigation report to be widely disseminated to contribute to the prevention of recurrence of a similar marine accident and to reduce damage with the cooperation of the Maritime Bureau of MLIT, Japan Distributor Association, etc., the flag state and the substantially interested states of the JIA DE, namely Panama, China, Myanmar and Vietnam.

6 SAFETY RECOMMENDATIONS

It is considered probable that the accident occurred because the cargo vessel JIA DE foundered due to the fact that sea water which was being retained due to wave uprush on the upper deck (hereafter referred to as "the Retained Water") began flooding due to taking on sea water in the interior of the cargo holds, and then her steering was uncontrollable and she was receiving winds and wave uprush from the port fore side to port side, and furthermore her hull greatly heeled to the starboard side and she continued to be flooded due to taking on sea water in the interior of the cargo holds, and she subsequently rolled over due to her stability having been decreasing and flooding due to taking on sea water into the interior of the cargo holds progressed, with the result being that she foundered. This situation began while JIA DE was anchoring in the nighttime under conditions of rolling and pitching due to receiving winds and waves that had increased due to the typhoon No.19 (Asian name "Hagibis") approaching the area of K1 anchorage point of Keihin Port.

It is considered probable that the Retained Water on the deck of JIA DE began flooding due to taking on sea water in the interior of the cargo holds because the lids for opening parts of the ventilation cylinders of the cargo holds were in an open condition, and the water receiver railings at the connection parts between the panels of the hatch covers of the cargo holds had a number of broken holes and some part of the panels of the hatch covers were deformed, and thereby the hatch covers were not securely weather-tight. In addition, it is considered probable that wave uprush on the deck further increased because her dry draft had been decreasing due to ingress water into the interior of the cargo holds and the Retained Water.

It is considered probable that JIA DE was in a state in which her steering was uncontrollable because ingress water that infiltrated into the marine diesel oil (MDO) tank interior through the vents on the upper deck was supplied to the diesel generator engines with MDO through the fuel oil supply line of the diesel generator engines, and then the diesel generator engines experienced combustion failure or misfiring, and subsequently stopped, and thereby the blackout occurred.

In view of the results of this accident investigation, the Japan Transport Safety Board recommends that the Panama Maritime Authority, the Republic of Panama (hereafter referred to as "Panama") as the flag state of JIA DE should take the following measures to prevent similar accidents and to reduce damage.

The Panama Maritime Authority should instruct the Owners and the Management Companies (hereafter referred to as "the Companies") of Panama flag vessels to engage in the following practices due to securing safety for crewmembers and vessels in stormy weather and rough seas.

(1) The Companies should instruct masters and crewmembers to reliably carry out closing of opening parts on exposed decks such as lids of opening parts of ventilation cylinders of cargo holds, etc. in case that stormy weather and rough seas are expected.

(2) The Companies should instruct masters and crewmembers to secure significant dry draft in

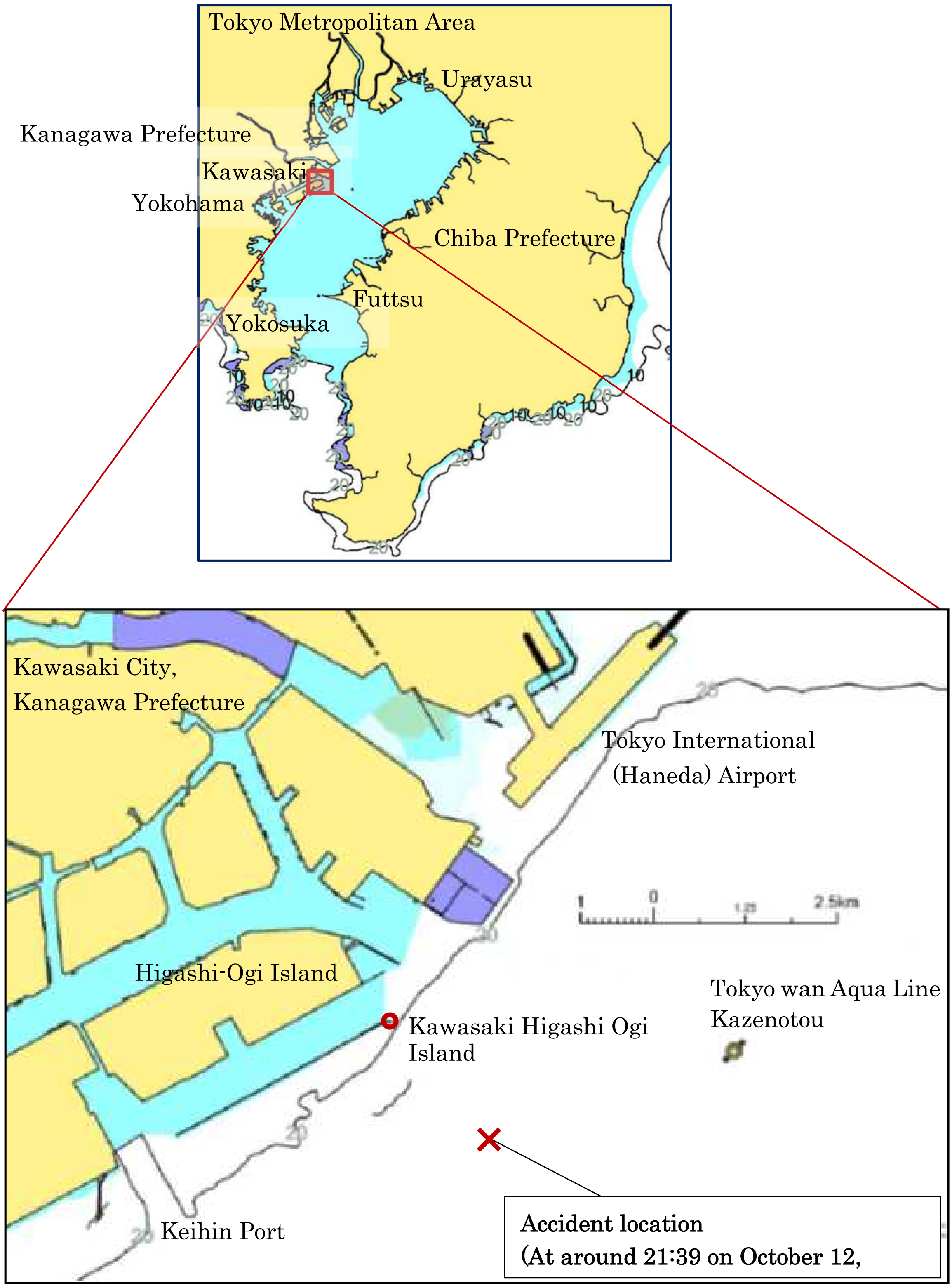
any sea condition, and therefore should crewmembers to carry out adjustment of the ship's condition.

(3) The Companies should instruct masters and crewmembers to carry out the drain discharging operation in which each drain valve of fuel oil tanks is operated not only periodically as routine work, but also on a timely basis in a condition of rolling and pitching in stormy weather and rough seas so as not to supply fuel oil with infiltrated water into the fuel oil supply lines of generator engines, etc. in case that air vent pipes of fuel oil tanks were not equipped automatic opening and closing-type air vent head, etc. to automatically prevent the infiltration of water.

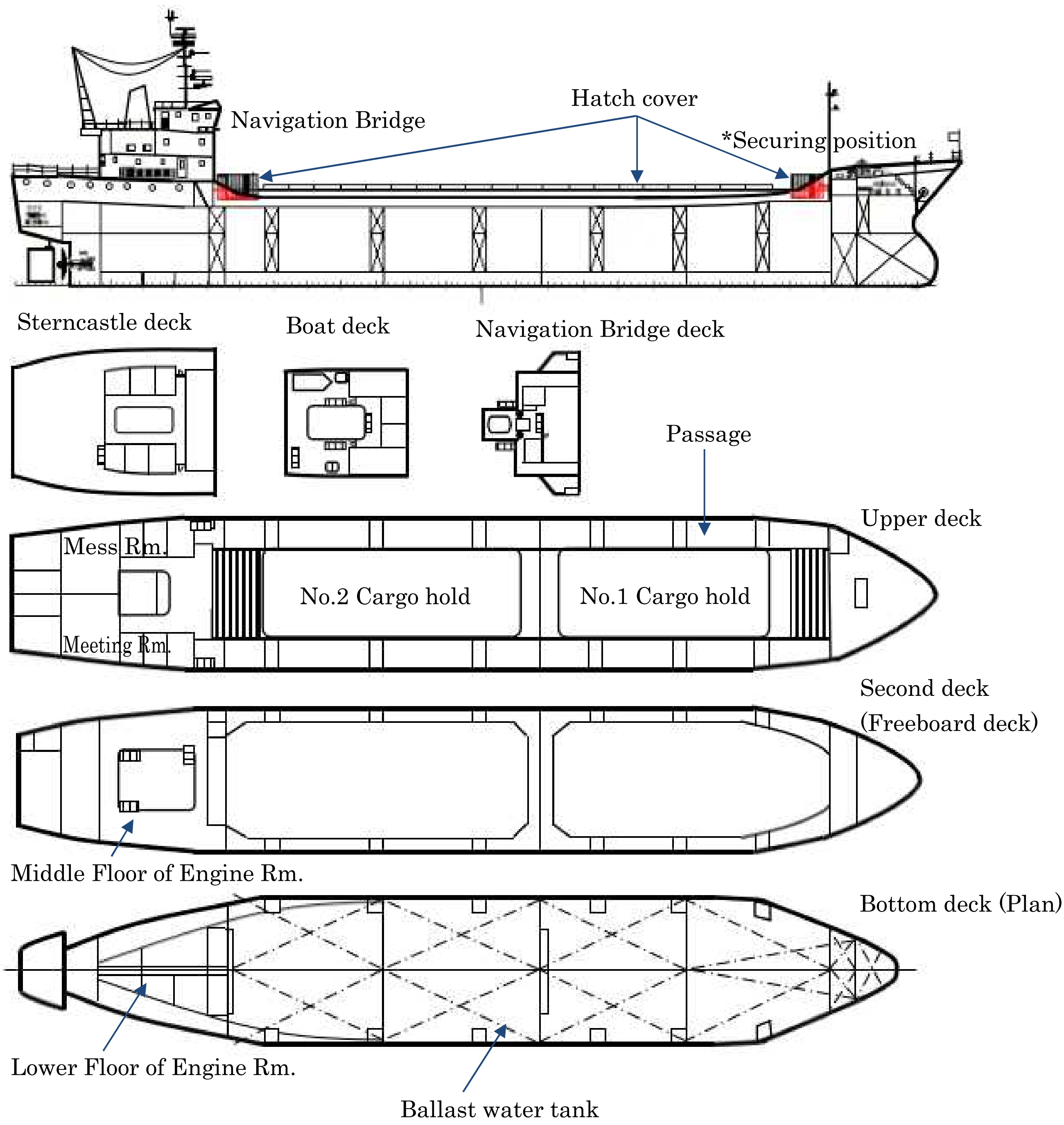
(4) The Companies should instruct masters and crewmembers to conduct refresher training for crewmembers concerning survival techniques at sea for getting ready for abandon ship, such as taking out belongings, escape behavior from the interior of vessel, putting on a life jacket and immersion suit, dressing warmly, etc.

(5) The Companies should implement maintenance necessary including the water receiver railings of the hatch cover to secure weather-tightness of the hatch cover of the cargo holds themselves with regard to vessels managed and owned by the Companies.

Annex Figure 1　Schematic Diagram of the Accident Location



Annex Figure 2 General Arrangement Plan



Annex Table 1 Situation of Oil Pollution around the Accident Location

Provided by The 3rd District Coast Guard Headquarters, JCG

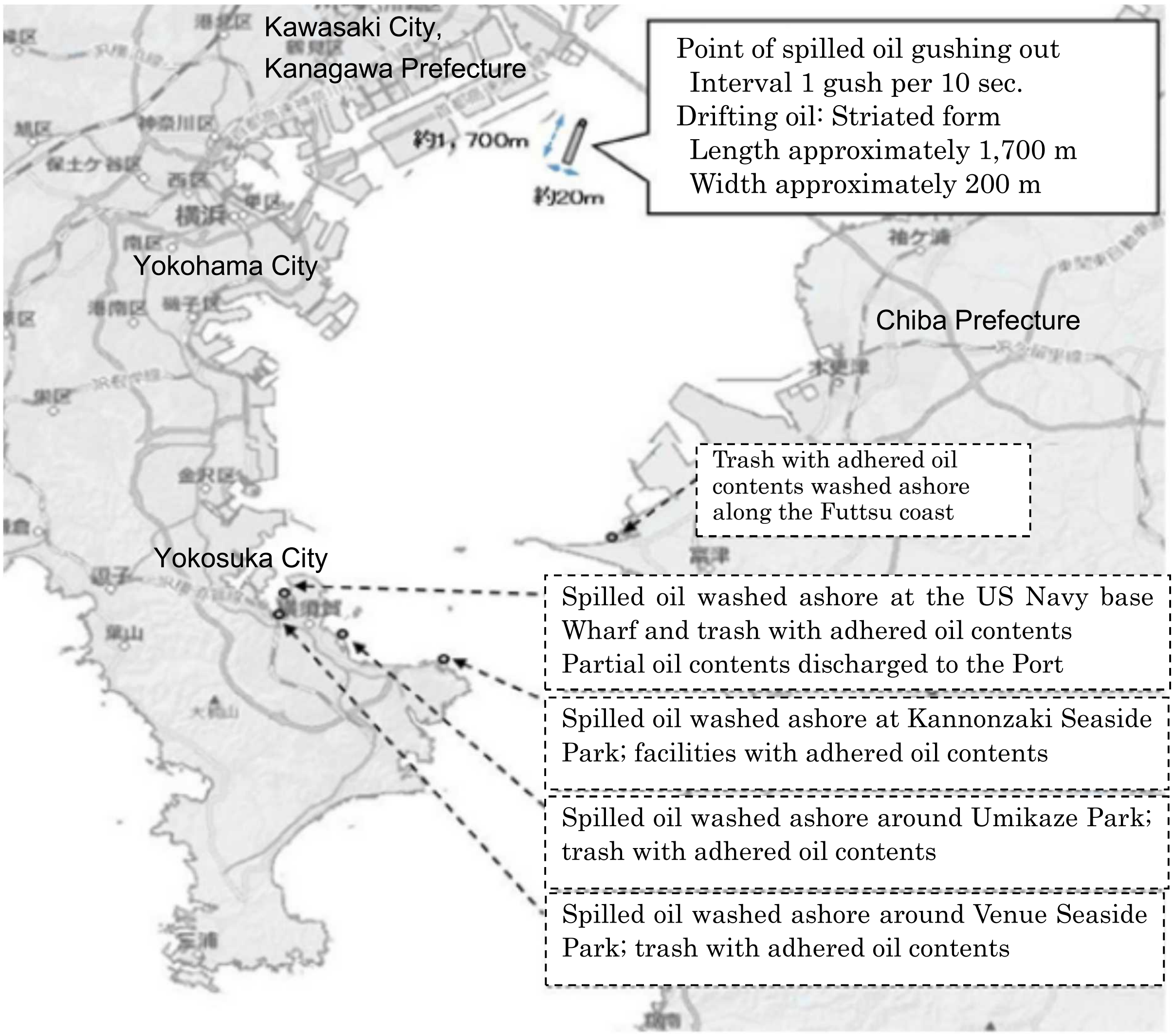
Materials (extract) of Marine Accident Liaison Meeting for M.V. JIA DE Foundering issued by the 3rd District Coast Guard Headquarters

Circumstances of the accident location

At around 09:00 on October 13

At around 06:35 on October 18

Circumstances of drifting oil in Tokyo wan   Time & Date: Around 06:35, October 18

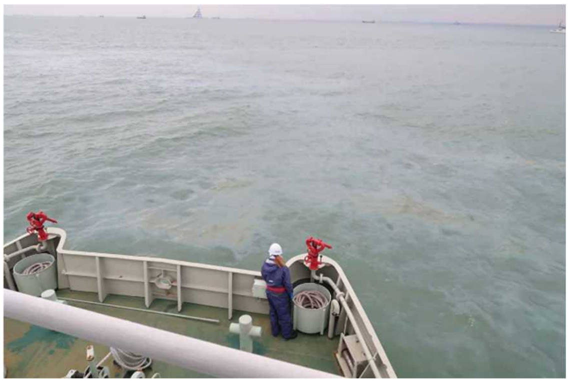


Annex Table 2 Prevention Works for Oil Spill around the Accident Location

Provided by Kanto Regional Development Bureau and Kyushu Regional Development Bureau

Circumstances of drifting oil at around the accident location (i)

Circumstances of drifting oil at around the accident location (ii)



Oil agitation operation by water jet gun

Recovery of spilled oil using oil adsorption materials

Oil agitation operation by jet spraying device of DOR Vessel

Annex Table 3　Circumstances of Oil Pollution Due to Spilled Oil (Yokosuka Port, Yokosuka City)

Provided by Port Bureau, Yokosuka City

ANNNEX

Analysis and Investigation Report on the Foundering of Cargo Vessel A

March 2020

National Maritime Research Institute (NMRI)

English Translation by
Japan Transport Safety Board (JTSB)

Table of Contents

Introduction

This report summarizes the results and findings of the contract study entitled Analysis and Investigation on Foundering (Foundering Accident of Cargo Vessel A) (hereafter referred to as the "Analysis") conducted by the National Maritime Research Institute (hereafter referred to as the "NMRI").

The project involved the following steps:

(1) Estimation of Cargo Vessel A's stability at the time of the accident

Since no stability-related data was available concerning Cargo Vessel A, the Analysis used an analogous cargo vessel's data as instructed by the marine accident investigator of the Japan Transport Safety Board (hereafter referred to as the "JTSB") to estimate Cargo Vessel A's stability immediately before the accident assuming different volumes of Retained Water in both passages on the upper deck. Furthermore, the stability was also estimated for the case where the cargo holds were flooded in addition to both passages on the upper deck.

(2) Consideration of Cargo Vessel A's progressive heeling that led to the foundering

Based on the results of item (1), the condition of ingress water and heeling that led to Cargo Vessel A's foundering was estimated by estimating the vessel's stability assuming that it had been rolling due to winds and waves from the port fore side when it was hit by a gust of wind and heeled further to the starboard.

(3) Preparation of the report

The NMRI worked closely with the JTSB in implementing the project in order to ensure its smooth execution. The analysis and investigation were mainly carried out by the following person:

Dr. TAGUCHI Harukuni, Fluids Engineering and Vessel Performance Evaluation Department, NMRI

If you have any questions, please contact him at: taguchi@m.mpa.go.jp

1. Estimation of Stability at the Time of the Accident

As per instructions of the marine accident investigator of the JTSB (hereafter referred as the "Investigator"), the stability of Cargo Vessel A at the time of the accident was estimated based on the following data immediately before the accident:

[1] Weight and loading position of the loads
[2] Quantity of the loaded fuel oil and fresh water
[3] Area and height of sea water retained on the upper deck
[4] Area and depth of ingress water in the cargo holds
[5] Winds and waves

Since detailed hull form data of Cargo Vessel A (hereafter referred as the "Vessel") (gross tonnage: 1,925 tons; length: 82.65 m; width: 13.00 m; depth: 6.60 m) was unavailable, the analysis was conducted with the hull form data of an analogous cargo vessel (gross tonnage: 1,915 tons; length: 86.15 m; width: 12.80 m; depth: 6.70 m) selected by the Investigator. The analysis used both of the two heights of the center of gravity under the light loading condition (KG_L) estimated in the data of the analogous cargo vessel (4.49 m and 4.82 m).

1.1 Estimation of Stability Immediately before the Accident

1.1.1 Hull Form Data

A draft survey was conducted with the Vessel before the accident in order to determine its displacement and the tonnage of the loads. As a result of calculating the analogous cargo vessel's displacement using its hull form data, it was found that almost the same value as the Vessel's displacement determined in the draft survey can be obtained if the analogous vessel's length between perpendiculars (LPP) (79.80 m) was corrected to that of the Vessel (74.50 m). Therefore, it was decided that the Vessel's stability was to be considered using the analogous cargo vessel's hull form data with only the LPP corrected for this analysis.

1.1.2 Estimation of Stability When There Is No Retained Water in Both Passages on Upp. Deck (Initial Condition)

The Vessel's stability before there was any Retained Water in both passages on the upper deck (Initial Condition) was estimated based on the provided loading data and the Vessel's draft measured while at anchor on the day of the accident (draft fore: 5.30 m; draft aft: 5.80 m).

1) Setting of the Center of Gravity

The displacement and the longitudinal and the vertical position of the center of gravity under the Initial Condition were set as follows:

[1] The displacement (W) and longitudinal position of the center of gravity of the whole vessel (mid-G) were calculated with the draft data on the day of the accident. In doing so, it was estimated that the longitudinal position of the center of gravity coincides with the longitudinal position of the center of buoyancy.

[2] The displacement under the light loading condition (1,105.7 t) was determined by subtracting the weight of load items (i) to (vii) in Tables 1 and 2 (3,319.1 t in total) from the displacement calculated using the draft (4,424.8 t). The height of the center of gravity under the light loading condition (KG_L) was set at two values: 4.49 m and 4.82 m.

[3] The height of the center of gravity of load items (i) to (vi) was calculated with the following formula: $Volume\ of\ each\ item/Area\ of\ the\ bottom\ of\ the\ cargo\ hold\ or\ tank \times \frac{1}{2}$

In addition, the height of the center of gravity of the constant (item (vii)) was estimated to be the same as the height of the vessel's center of gravity under the light loading condition.

[4] The height of the center of gravity of the whole vessel (KG) was determined by dividing the total gravity moment by the displacement, in the same manner as the normal weight and balance calculation.

Tables 1 and 2 show the Vessel's calculated weight and center of gravity under the Initial Condition. The height of the center of gravity under the light loading condition KG_L is 4.49 m in Table 1 and 4.82 m in Table 2. The displacement (W = 4,424.8 tf) and the longitudinal position of the center of gravity of the whole Vessel (mid-G = -0.29 m) (stern side) are the same in both tables; only the heights of the center of gravity are different at 3.88 m (Table 1: KG_L = 4.49 m) and 3.97 m (Table 2: KG_L = 4.82 m). Table 3 shows the ballast water measurements from the draft survey. On the day of the accident, ballast water was remaining in six ballast tanks.

Table 1 Weight and the Center of Gravity under the Initial Condition (KG_L=4.49 m)

	W (tf)	mid-G (m)	Gravity moment (tf-m)	KG (m)	Gravity moment (tf-m)
Light loading condition	1,105.7			4.49	4,964.5
Loading objects					
i) Cargo					
No.1 Cargo Hold	1,348.9			3.80	5,126.6
No.2 Cargo Hold	1,696.1			3.62	6,137.9
ii) MDO	17.9			5.67	101.5
iii) HFO	61.9			3.54	218.8
iv) Lub. Oil	2.6			1.78	4.6
v) Fresh Water	67.0			2.28	153.0
vi) Ballast Water	24.8			0.05	1.2
vii) Constant	100.0			4.49	449.0
Subtotal	3,319.1				12,192.6
Total	4,424.8	-0.29	-1261.1	3.88	17,157.1

Table 2 Weight and the Center of Gravity under the Initial Condition (KG_L=4.82 m)

	W (tf)	Mid-G (m)	Gravity moment (tf-m)	KG (m)	Gravity moment (tf-m)
Light loading condition	1,105.7			4.82	5,329.3
Loading objects					
i) Cargo					
No.1 Cargo Hold	1,348.9			3.80	5,126.6
No.2 Cargo Hold	1,696.1			3.62	6,137.9
ii) MDO	17.9			5.67	101.5
iii) HFO	61.9			3.54	218.8
iv) Lub. Oil	2.6			1.78	4.6
v) Fresh Water	67.0			2.28	153.0
vi) Ballast Water	24.8			0.05	1.2
vii) Constant	100.0			4.82	449.0
Subtotal	3,319.1				12,225.6
Total	4,424.8	-0.29	-1,261.1	3.97	17,555.0

Table 3 Weight of Ballast Water (Unit: tf)

No.1 B.W.T. (P)	0.0
No.1 B.W.T. (S)	1.6
No.2 B.W.T. (P)	10.7
No.2 B.W.T. (S)	0.0
No.3 B.W.T. (P)	3.0
No.3 B.W.T. (S)	9.2
No.4 B.W.T. (P)	0.1
No.4 B.W.T. (S)	0.2
Total	24.8

2) Calculated Stability

Figure 1 shows the Vessel's stability under the Initial Condition calculated using the values of the weight and the center of gravity in Tables 1 and 2. Table 4 shows the calculated metacentric height (GM), draft (da: draft aft; df: draft fore, dm: draft mid), and trim (τ: positive when trimmed by the stern) calculated taking into account free water effects. GM1 and GM2 denote the metacentric height for when the height of the center of gravity under the light loading condition KG_L is estimated at 4.49 m (Table 1) and 4.82 m (Table 2), respectively.

When the height of the center of gravity under the light loading condition KG_L is 4.49 m, the Vessel's metacentric height (GM1) under the Initial Condition is 1.44 m, the maximum stability (GZ_{max}) is approximately 0.44 m, and the lateral heeling angle at which the maximum stability occurs (φ_{max}) is approximately 26 deg. The free water effects of any liquids other than the ballast water were not considered in this calculation, because the volumes of the tanks containing those liquids were unknown. Meanwhile, treating the free water effect of the ballast water as a virtual rise of the center of gravity may result in an overestimation of the free water effect at higher lateral heeling angles, because the amount of ballast water was relatively small compared to the volume of the ballast tanks (Table 3).[1)] For this reason, the free water effect of water in each ballast tank was taken into account as a change (due to heeling) in the center of gravity of water contained in a hypothetical tank that has a plane with the same length and area as the plane of the actual tank (i.e. a hypothetical tank that has an approximate rectangular plane). The plane shape and height of each actual tank were determined based on the general arrangement plan.

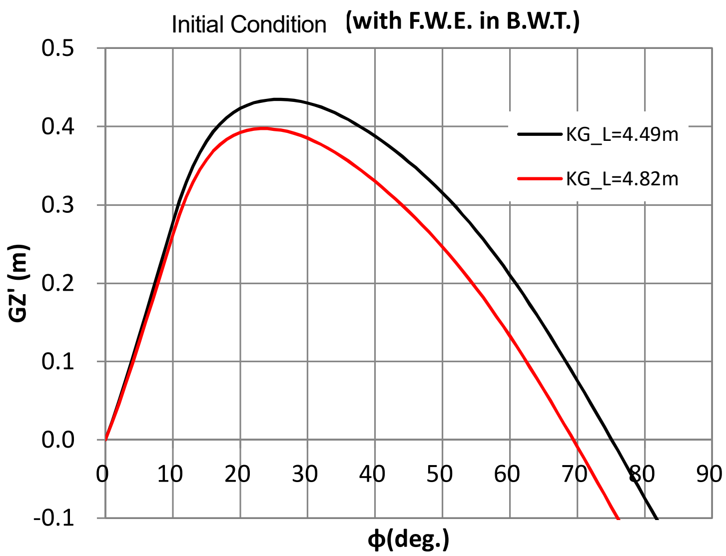


Figure 1 Stability Curve (Initial Condition)

Table 4 Calculated Metacentric Height, Draft, and Trim (Initial Condition)

GM1 (m)	GM2 (m)	da (m)	df (m)	dm (m)	τ (m)
1.44	1.35	5.80	5.30	5.55	0.50

1.1.3 Effects of Retained Water in Both Passages on Upp. Deck

It was reported that the passages (length: 54.85 m; width: 2.46 m; height of the bulwark: 1.0 m) on the port and starboard sides of the upper deck were flooded by sea water and eventually filled up to the top when the accident occurred. To examine the effects of the sea water retained in the passages (hereinafter referred to as the "Retained Water"), the Vessel's stability was estimated with different volumes of Retained Water (i.e. with different ratios of the volume of Retained Water to the volume of the passages (hereinafter referred to as the "RW ratios")).

The volume of the passages is the actual volume net of the stern structures and was calculated based on the data provided by the Investigator. The weight of Retained Water (W_S': weight of water retained on one of the passages) and the position of its center of gravity (C_{SL}: longitudinal position; C_{SV}: vertical position) were determined at different RW ratios, assuming that the water was retained on the upper deck according to the trim under the Initial Condition (0.50 m trim by the stern (Table 4)) and ignoring the sheer of the Vessel (Table 5). In this table, the weight of Retained Water (W_S') was calculated using the specific gravity of sea water at the time of the draft survey (γ = 1.019). The baseline for the longitudinal position (C_{SL}) and the vertical position (C_{SV}) of the center of gravity are the rear end of the passage (Fr. 23) and the top surface of the upper deck, respectively.

Table 5 Retained Water (One of the Passages)

RW ratios	Weight of Retained Water W_S' (tf)	Longitudinal position and of Center of Gravity C_{SL} (m)	Vertical position of Center of Gravity C_{SV} (m)
25 %	26.2	19.29	0.129
50 %	52.4	23.36	0.218
75 %	78.7	24.71	0.316
100 %	104.9	25.39	0.416

Table 6 Conditions of Calculation (Effects of Retained Water in Both Passages on Upp. deck)

Condition	W (tf)	mid-G (m)	KG1 (m)	KG2 (m)	Retained Water ratio
Initial condition	4424.8	-0.285	3.877	3.967	0 %
Condition 1	4477.3	-0.344	3.911	4.000	25 %
Condition 2	4529.7	-0.307	3.946	4.033	50 %
Condition 3	4582.1	-0.271	3.982	4.069	75 %
Condition 4	4634.6	-0.236	4.020	4.105	100 %

Table 6 shows the displacement (W) and the position of the center of gravity (mid-G: longitudinal position; KG: vertical position) in the condition under which the Vessel's stability was calculated in order to examine the effects of the Retained Water. KG1 denotes the vertical position (height) of the center of gravity for when the height of the center of gravity under the light loading condition (KG_L) is 4.49 m, and KG2 denotes that for when KG_L is 4.82 m. The table also shows the values under the Initial Condition (i.e. no Retained Water) for reference.

The Vessel's calculated stability under each Condition is shown in Figures 2 (KG_L = 4.49 m) and 3 (KG_L = 4.82 m). Table 7 shows the calculated metacentric height (GM), draft (da: draft aft; df: draft fore, dm: draft mid), and trim (τ: positive when trimmed by the stern). In the same manner as Table 4, GM1 and GM2 denote the metacentric height when the height of the Vessel's center of gravity under the light loading condition (KG_L) is estimated at 4.49 m and 4.82 m, respectively. The values shown in these Figures and Tables were calculated taking into account the free water effect of the ballast water in the same manner as Section 1.1.2.

In the Analysis, the situation at the time of the accident where sea water was continually flowing onto the Vessel–was analyzed quasi-statically, which means that Retained Water discharged outboard (from the heel side) or onto the hatch covers due to the inclination of the hull and the free water effect of the Retained Water were ignored. The values shown in Figures 2 and 3 and Table 7 were calculated by deeming the Retained Water as a solid load that does not change in weight or shape loaded on the hull under the Initial Condition.

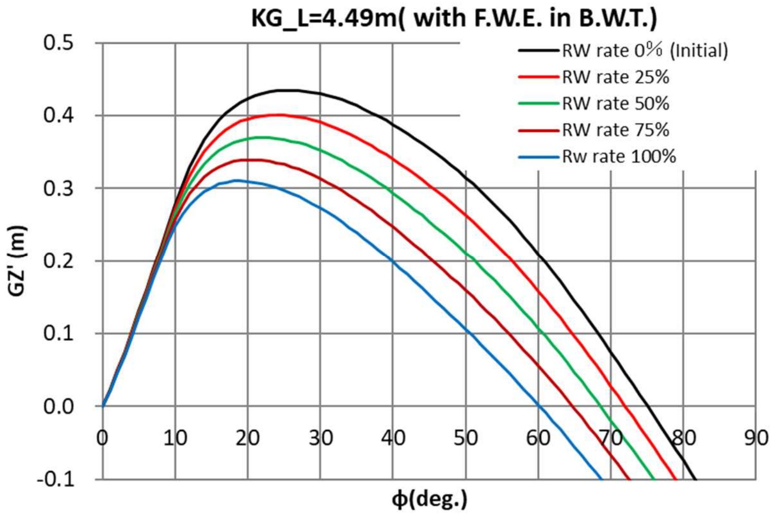


Figure 2 Stability Curve (Effects of Retained Water in Both Passages on Upp. Deck; KG_L = 4.49 m)

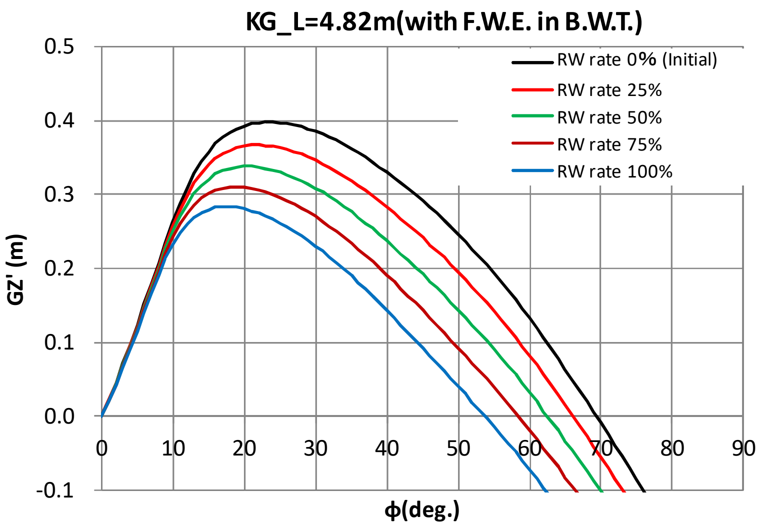


Figure 3 Stability Curve (Effects of Retained Water in Both Passages on Upp. Deck; KG_L = 4.82 m)

Table 7 Calculated Metacentric Height, Draft, and Trim (Effects of Retained Water in Both Passages on Upp. Deck)

Condition	GM1 (m)	GM2 (m)	da (m)	df (m)	dm (m)	τ (m)
Initial condition	1.44	1.35	5.80	5.30	5.55	0.50
Condition 1	1.42	1.33	5.88	5.34	5.61	0.54
Condition 2	1.39	1.31	5.91	5.41	5.66	0.50
Condition 3	1.37	1.28	5.95	5.49	5.72	0.45
Condition 4	1.34	1.25	5.98	5.57	5.78	0.41

Figures 2 and 3 and Tables 6 and 7 show that with increase in Retained Water, the vertical position of the Vessel's center of gravity rises and its longitudinal position shifts toward the center of the hull, which results in a decrease in the trim by the stern, metacentric height, and stability. However, even when the passages on the upper deck are filled with sea water to the top (Condition 4), the volume of Retained Water is only about 210 tf (approximately 5% of the displacement under the Initial Condition) and the metacentric height decreases only by about 7% (GM1 = 1.34 m and GM2 = 1.25 m under Condition 4, as compared to GM1 = 1.44 m and GM2 = 1.35 m under the Initial Condition).

Table 8 Calculated Submerged Angles of the Discharging Holes, Top of the Bulwark, and Air Vent Pipes (Effects of Retained Water in Both Passages on Upp. Deck) (Unit: deg.)

Condition	Discharging Holes	Top of Bulwark	Air Vent Pipes		
	Fr. 34	Fr. 34	Port i	Port ii	Starboard
Initial condition	9.2	17.0	29.6	31.3	29.4
Condition 1	8.6	16.4	28.9	30.5	28.7
Condition 2	8.2	15.9	28.4	30.1	28.3
Condition 3	7.8	15.5	27.0	29.6	27.8
Condition 4	7.4	15.1	27.5	29.2	27.3

Table 8 shows the calculated submerged angles of the discharging holes, the top of the bulwark, and fuel tanks' air vent pipes on the aft-deck (two on the port side, one on the starboard side) at Frame number of the Vessel's hull (Fr.) 34 under each Condition. The height of the discharging holes and that of the top of the bulwark above sea level become the lowest when the Vessel is upright at Fr. 34, since the Vessel is trimmed by the stern under all of the Conditions, as shown in Table 7.

Table 8 shows that the submerged angles of the discharging holes, the top of the bulwark, and air vent pipes are 9.2 deg., 17.0 deg., and 29.4-31.3 deg., respectively, when there is no Retained Water in both passages on the upper deck (Initial Condition). It is also found that the submerged angles decrease as the volume of Retained Water increases. In the case where the passages are filled with sea water to the top (Condition 4), the submerged angles of the discharging holes, top of the bulwark, and air vent pipes are 7.4 deg., 15.1 deg., and 27.3-29.2 deg., respectively, each decreasing by approximately 2 deg. compared to when there is no Retained Water (Initial Condition).

Note that this analysis did not consider the fact that the Retained Water below sea level can be deemed as sea water flowing back through the discharging holes (i.e. outboard sea water) when the heeling angle is equal to or greater than the submerged angle of the discharging holes.[2)] Also note that the two passages are connected in front of the sterncastle deck, meaning that Retained Water in the passages on both the heeling side and the opposite side gathers on the heeling side as the Vessel heels. For this reason, it is appropriate to say that all the Retained Water in the passages is essentially outboard sea water when the top of the bulwark is submerged, and thus the Vessel's stability should be deemed to recover to that under the Initial Condition (i.e. no Retained Water) in such a situation.[2)]

1.2 Estimation of the Vessel's Stability at the Time of Accident

It was reported that the cargo holds may also have been flooded when the accident occurred. To examine its effects, the Vessel's stability at the time of the accident was estimated with different volumes of ingress water in the cargo holds, assuming that the RW ratio was 75% (Condition 3) when it occurred. For reference, Appendix 1 shows the estimated stability for the case where the cargo holds are flooded while there is no Retained Water in both passages on the upper deck (Initial Condition).

The weight of ingress water (W_H') and the position of the center of gravity (C_{HL}: longitudinal position; C_{HV}: vertical position) were calculated with different ratios of the volume of ingress water to the volume of the cargo holds (hereinafter referred to as the "IW ratios"), assuming that ingress water is retained on the bottom (the inner bottom plating of the double bottom) of the cargo holds according to the trim under Condition 3 (0.45 m trim by the stern (Table 7)) (Tables 9 and 10). The weight of the ingress water (W_H') in Tables 9 and 10 was calculated using the specific gravity of sea water at the time of the draft survey (γ = 1.019). The baseline for the longitudinal position (C_{HL}) and the vertical position (C_{HV}) of the center of gravity are the rear bulkhead (Cargo Hold No. 1: Fr.74; Cargo Hold No. 2: Fr. 28) and the level of the inner bottom plating, respectively.

Table 9 Estimated Ingress Water in No.1 Cargo Hold

IW ratios	Weight of Retained Water W_S' (tf)	Longitudinal position of Center of Gravity C_{SL} (m)	Vertical position of Center of Gravity C_{SV} (m)
2 %	40.8	10.61	0.086
4 %	81.5	11.61	0.163
6 %	122.3	11.94	0.242
8 %	163.0	12.10	0.322
10 %	203.8	12.20	0.402

Table 10 Estimated Ingress Water in No.2 Cargo Hold

IW ratios	Weight of Retained Water W_S' (tf)	Longitudinal position of Center of Gravity C_{SL} (m)	Vertical position of Center of Gravity C_{SV} (m)
2 %	46.6	10.96	0.076
4 %	93.2	12.36	0.140
6 %	139.8	12.82	0.206
8 %	186.4	13.05	0.274
10 %	232.9	13.19	0.341

According to the Investigator, sea water is likely to have flowed into the cargo holds through the four ventilation cylinders (each has 0.2 m x 0.2 m square cross section) in each cargo hold (aft and fore, port and starboard), the clearances-in the hatch covers, and the bore parts of the water receiver railings installed in the cover panel connections. It was reported that sea water continued to flow into the cargo holds through the ventilation cylinders over approximately 160 minutes, from around 19:00 to the time of the accident, and through the clearances in the hatch covers and the water receiver railings of the hatch covers over approximately 100 minutes from 20:00 to the time of the accident.

Table 11　Conditions of Calculation (Effects of Ingress Water in the Cargo Holds)

Condition	W (t)	mid-G (m)	KG1 (m)	KG2 (m)	RW ratios + IW ratios
Condition 3	4582.1	-0.271	3.982	4.069	75 % + 0 %
Condition 11	4669.5	-0.233	3.929	4.003	75 % + 2 %
Condition 12	4756.8	-0.152	3.882	3.941	75 % + 4 %
Condition 13	4844.2	-0.073	3.838	3.882	75 % + 6 %
Condition 14	4831.5	0.002	3.799	3.827	75 % + 8 %
Condition 15	5018.9	0.075	3.763	3.776	75 % + 10 %

Table 11 shows the displacement (W) and the position of the center of gravity (mid-G: longitudinal position; KG: vertical position) under the condition with which the Vessel's stability was calculated in order to examine the effects of ingress water in the cargo holds. KG1 denotes the vertical position (height) of the center of gravity for when the height of the center of gravity under the light loading condition (KG_L) is 4.49 m, and KG2 denotes that for when KG_L is 4.82 m. The table also shows the values under Condition 3 (i.e. no ingress water in the cargo holds) for reference.

Meanwhile, when the IW ratio is in the range of 2-10 %, treating the free water effect of ingress water as a virtual rise of the center of gravity may result in an overestimation of the free water effect at higher lateral heeling angles.[1)] For this reason, it is necessary to accurately treat changes in the shape of ingress water in the same manner as the remaining ballast water (in other words, its effect should be treated as a heeling moment caused by free water). Accordingly, the free water effect of ingress water in each cargo hold was taken into account as a change (caused by heeling) in the center of gravity of water contained in a hypothetical cargo hold that has a plane with the same length and area as the plane of the actual cargo hold (i.e. a hypothetical cargo hold tank that has an approximate rectangular plane). The plane shape and height of each actual cargo hold were determined based on the general arrangement plan.[1)]

Figures 4 and 5 show the Vessel's calculated stability under each Condition. The stability generally decreases as ingress water increases. At the same time, the angle of loss of residual stability (φ_V) and the range of stability (φ_R), which define the characteristics of a vessel's stability, both decrease, while the maximum stability (GZ_{max}) and the lateral heeling angle at which the maximum stability occurs (φ_{max}) also decline. For example, when the height of the center of gravity under the light loading condition KG_L is 4.82 m and the IW ratio is 4% (Condition 12; weight of ingress water in Cargo Hold No. 1: 81.5 tf; weight of ingress water in Cargo Hold No. 2: 93.2 tf) (the green line in Figure 5), the angle of loss of residual stability (φ_V) is approximately 47 deg., the maximum stability GZ_{max} is approximately 0.15 m, and the lateral heeling angle at which the maximum stability occurs φ_{max} is approximately 17 deg., decreasing by about 20%, 50%, and 10%, respectively, compared to the condition where there is no ingress water in the cargo holds (Condition 3; $\varphi_V \cong 58$ deg., $GZ_{max} \cong 0.31$ m, $\varphi_{max} \cong 19$ deg.) (black line in Figure 5).

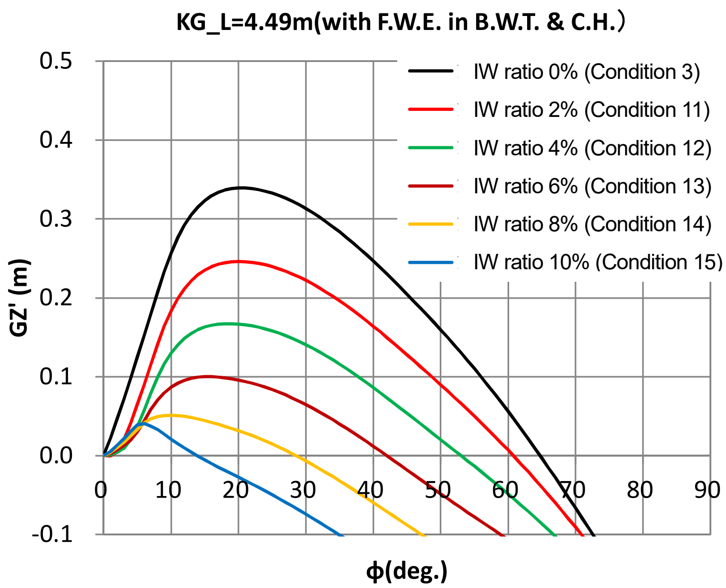


Figure 4 Stability Curve (Effects of Ingress Water in the Cargo Holds; KG_L = 4.49 m; RW Ratio: 75%)

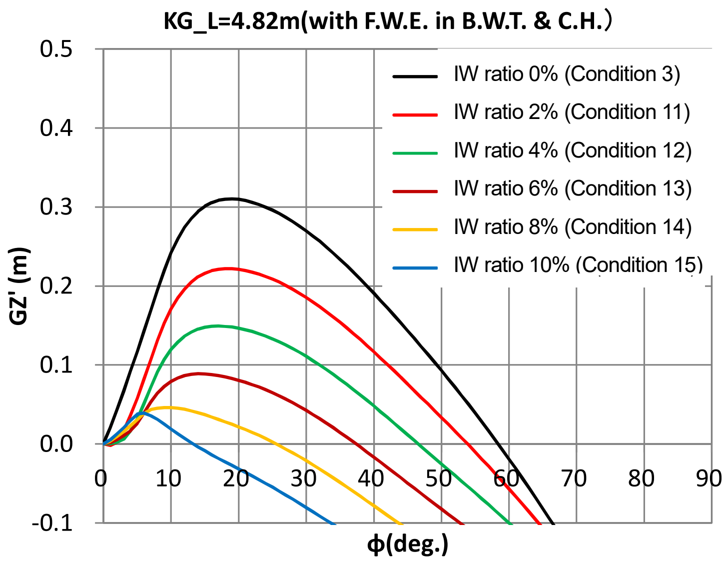


Figure 5 Stability Curve (Effects of Ingress Water in the Cargo Holds; KG_L = 4.82 m; RW Ratio: 75%)

Table 12 Calculated Metacentric Height, Draft, and Trim (Effects of Ingress Water in the Cargo Holds)

Condition	GM1 (m)	GM2 (m)	da (m)	df (m)	dm (m)	τ (m)
Condition 3	1.37	1.28	5.95	5.49	5.72	0.45
Condition 11	0.07	0.00	6.01	5.62	5.82	0.39
Condition 12	0.16	0.10	6.06	5.76	5.91	0.30
Condition 13	0.24	0.20	6.11	5.91	6.01	0.20
Condition 14	0.33	0.30	6.16	6.05	6.11	0.10
Condition 15	0.40	0.39	6.20	6.20	6.20	0.01

Table 12 shows the calculated metacentric height (GM), draft (da: draft aft; df: draft fore, dm: draft mid), and trim (τ: positive when trimmed by the stern), which were calculated taking into account the free water effects of water in the cargo holds and ballast tanks. It is known that the value of metacentric height corresponds to the slope of the tangent line of the stability curve at the origin (i.e. lateral heeling angle: 0 deg.),[3] and thus the same value will be obtained for the metacentric height regardless of whether the free water effects of ingress water in the cargo holds and ballast water are treated as changes in their center of gravity due to heeling, like in this analysis, or they are treated as a virtual rise in the Vessel's center of gravity.[1] Therefore, the metacentric height largely decreases under Conditions listed in Table 12 from that under Condition 3 (where there is no ingress water in the cargo holds), due to the large free water effect. For example, when KG_L = 4.49 m and the IW ratio is 2% (Condition 11; weight of ingress water in Cargo Hold No. 1: 40.8 tf; weight of ingress water in Cargo Hold No. 2: 46.6 tf), the metacentric height (GM1) is 0.07 m, which is about 5% of the metacentric height under Condition 3 (1.37 m). Note that the metacentric height (GM1 and GM2) is the lowest when the IW ratio is 2% (Condition 11) in Table 12. Major reasons are: [1] that the displacement volume (V) increases with increase in the volume of ingress water, which results in a smaller virtual rise in the center of gravity ($GG_0 = I/V$), because the moment of inertia of free surface is constant across the range of IW ratio assumed in this analysis; and [2] that the height of the Vessel's center of gravity (KG1 and KG2) decreases as ingress water increases (Table 11).

Meanwhile, the free water effect of ingress water is only significant at smaller lateral heeling angles, as this analysis assumes relatively small volumes of ingress water. For example, when KG_L = 4.82 m and the IW ratio is 2% (Condition 11), the metacentric height (GM2) calculated taking into account the free water effect is almost 0 m (Table 12); then, the pro-metacentric height starts to grow around a lateral heeling angle of 2 deg. and it becomes approximately 0.22 m at maximum, a significant stability value, at a lateral heeling angle of about 18 deg. (Figure 5).

Table 13 shows the calculated submerged angles of the discharging holes, top of the bulwark, and fuel tanks' vent pipes on the aft deck at Fr.34 under each Condition. The table shows that the submerged angles decrease as ingress water in the cargo holds increases. When the IW ratio is 10% (Condition 15), the submerged angles of the discharging holes, top of the bulwark, and air vent pipes are 4.5 deg., 11.9 deg., and 23.9-25.8 deg., respectively, each decreasing by 3-4 deg. from Condition 3 (i.e. no ingress water in the cargo holds). Note that, as discussed in Section 1.1.3, all the water retained in the passages on the upper deck is essentially outboard sea water when the top of the bulwark is submerged, and thus the Vessel's stability in such a situation should be deemed to recover to that under the condition where there is no Retained Water in both passages on the upper deck and only the cargo holds are flooded.

Table 13 Calculated Submerged Angles of the Discharging Holes, Top of the Bulwark, and Air Vent Pipes (Effects of Ingress Water in the Cargo Holds) (Unit: Deg.)

Condition	Discharging Holes	Top of Bulwark	Air Vent Pipes		
	Fr. 34	Fr. 34	Port i	Port ii	Starboard
Initial condition	7.8	15.5	28.0	29.6	27.8
Condition 11	7.0	14.7	27.1	28.8	26.9
Condition 12	6.4	14.0	26.4	28.1	26.2
Condition 13	5.8	13.3	25.6	27.3	25.5
Condition 14	5.1	12.6	24.8	26.6	24.7
Condition 15	4.5	11.9	24.0	25.8	23.9

References

1) MORITA Tomoharu, Senpaku-fukugenron : Kiso to Oyo (Theory of Stability, Basis and Application), pp. 84-94, Kaibundo, April 1985.
2) TAMIYA Shin, Free Water on Deck, Zosen Kyokai Ronbunshu No. 107, pp. 71-76, June 1960.
3) OGUSHI Masanobu, Riron Senpaku Kogaku (Jokan) (Theory of Marine Engineering (First Volume)) New Edition, p.163, Kaibundo, October 1984.

2. Consideration of the Vessel's Progressive Heeling That Led to the Foundering

Possible external forces that acted in the process leading up to the Vessel's foundering include waves and strong winds caused by the typhoon that was passing near the anchorage. It is considered that the Vessel had been rolling due to waves when it was hit by a gust of wind from the port side to heel greatly to the starboard side and eventually rolled over and foudered. The effective stability (i.e. residual stability) of a vessel heeling due to winds can be obtained by subtracting the heeling couple of the force due to winds from the initial stability, in an analogous manner as a vessel whose center of gravity has shifted transversely due to a collapse of vessel containers.[1)] As the heeling couple of the force due to winds increases, the steady heeling angle grows larger and the residual stability becomes smaller. The Vessel may have rolled over as the heeling angle, which had been growing larger due to rolling, exceeded the angle of loss of residual stability.

In Section 1.2, the Vessel's stability is estimated under six Conditions with different IW ratios (0-10%), assuming that the RW ratio was 75% (Table 14). Below, the heeling monents and lateral heeling angles due to winds at designated wind velocities and directions and headings were estimated under these six Conditions, in order to consider the status of the Vessel's progressive heeling that led to the accident. In addition, the process leading up to the large heeling to starboard and the resulting rolling over was also considered based on the Vessel's residual stability calculated taking into account the heeling couple of the force due to winds.

Table 15 shows the relative wind velocities and directions corresponding to the designated wind velocities and directions and the Vessel's headings. Since the speed of the Vessel at the time of the accident is set at 0, the relative wind velocities are the same as the designated wind velocities. Note that the Vessel received the winds on the port side in all the cases.

Table 14 Calculated Vessel Condition

Condition	W (t)	da (m)	df (m)	dm (m)	τ (m)	RW ratios + IW ratios
Condition 3	4582.1	5.95	5.49	5.72	0.45	75 % + 0 %
Condition 11	4615.0	6.01	5.62	5.82	0.39	75 % + 2 %
Condition 12	4680.7	6.06	5.76	5.91	0.30	75 % + 4 %
Condition 13	4598.6	6.11	5.91	6.01	0.20	75 % + 6 %
Condition 14	4746.5	6.16	6.05	6.11	0.10	75 % + 8 %
Condition 15	4910.8	6.20	6.20	6.20	0.01	75 % + 10 %

Table 15 Conditions of Calculation (Wind Velocity and Direction and the Vessel's Heading (co.))

Wind speed (m/s)	Wind direction (°)	Heading of the Vessel (°)	Ship speed (kn)	Relative speed (m/s)	Relative wind direction (°)
30.0	202.5 SSW	225.0 SW	0.0	30.0	22.5
35.0				35.0	
40.0				40.0	
30.0		270.0 West		30.0	67.5
35.0				35.0	
40.0				40.0	

2.1 Estimated Lateral Heeling Angle Due to Winds at the Time of the Accident

The lateral heeling angle due to winds at the time of the accident was estimated for the six Conditions (Table 14) for which the Vessel's stability at the time of the accident was estimated assuming that ingress water in the cargo holds occurred when the RW ratio was 75%. For reference, Appendix 1 shows the estimated lateral heeling angle due to winds for the case where the cargo holds are flooded while there is no Retained Water in both passages on the upper deck (Initial Condition).

2.1.1 Calculation of the Heeling Moment Due to Winds

The heeling moment due to winds K_A was obtained with Formula (1).

$$K_A = C_K q_A A_L H_L \tag{1}$$

C_K is the coefficient of the heeling moment due to winds and was estimated based on Fujiwara's formula (Appendix 2).[2] q_A is the dynamic pressure, defined by Formula (2), where ρ_A is air density and U_A is relative wind speed. A_L is the lateral projected area of the above-water hull and superstructure, and H_L is the average height of the sides of the above-water hull and superstructure ($H_L = A_L/L_{OA}$). These values were determined based on the general arrangement plan, in relation to the part above the draft line at the time of the accident (Table 14: draft aft (da) and draft fore (df)).

$$q_A = \frac{1}{2}\rho_A U_A^2 \tag{2}$$

Table 16 shows the eight parameters for the Vessel's appearance that are used in Fujiwara's formula. L_{OA} is the length, B is the width, A_F is the frontal projected area of the above-water hull and superstructure, A_{OD} is the lateral projected area of the superstructure, C is the longitudinal coordinate from the center of the hull to the center of the lateral area (positive on the fore side), H_C is the height from the draft line to the center of the lateral area, and H_{BR} is the height from the draft line to the highest point of the main structure (bridge).

Table 16 Parameters Used for Estimation of Heeling Moments Due to Winds

Condition	L_{OA}(m)	B(m)	AF(m^2)	A_L (m^2)	A_{OD} (m^2)	C (m)	H_C (m)	H_{BR} (m)
Condition 3	82.65	13.00	141.76	314.11	143.15	-3.88	2.80	15.48
Condition 11			138.16	306.18		-4.07	2.71	15.37
Condition 12			134.08	298.30		-4.34	2.62	15.24
Condition 13			129.82	290.22		-4.63	2.53	15.11
Condition 14			125.74	282.34		-4.93	2.45	14.98
Condition 15			121.65	274.46		-5.25	2.37	14.85

Table 17 shows the coefficient of the estimated heeling moment due to winds (C_K) and heeling moment due to winds (K_A) estimated using Fujiwara's formula concerning each Condition. In this table, D_W is the heeling couple of the force lever calculated using the heeling moment ($D_W = K_A/W$). Under the Conditions assumed in this analysis, the heeling moment due to winds coefficient (C_K) increases with increase in IW ratio. On the other hand, as ingress water increases, the draft becomes deeper and the lateral projected area of the above-water hull and superstructure A_L and its average height H_L (= A_L/L_{OA}) decreases (Table 16), which means that the heeling moment due to winds K_A obtained in Formula (1) and the heeling couple of the force lever D_W also decline (Table 17).

Figures 6 to 11 show the comparison of the Vessel's calculated stability and the calculated heeling couple of the force lever due to winds under each Condition. In the legends, the figures in the brackets are the Vessel's heading and the wind velocity (e.g. "DW (225, 30)" denotes the heeling couple of the force lever when the Vessel's heading is 225 deg. and the wind velocity is 30 m/s). For reference, the Figures also show the lateral heeling angle at which the maximum stability occurs (φ_{max}) and the value of lateral heeling angle at the intersection of the stability curve and the line of DW(270, 40) (i.e. the heeling couple of the force lever when the Vessel's heading is 270 deg. and the wind velocity is 40 m/s) (φ_{wind} and $\varphi_{wind\text{-}2}$; φ_{wind} is further discussed in Section 2.1.2).

While, as mentioned above, both the Vessel's stability (GZ') and the heeling couple of the force lever (D_W) decrease as the IW ratio increases, the former decreases more rapidly. Figures 6 to 11 show that the residual stability ($GZ'_{\_R}$), which corresponds to the stability curve (GZ') represented by the solid line above the line of the heeling couple of the force lever (D_W) parallel to the lateral axis, drops rapidly as the IW ratio increases. In particular, in Figure 11, where the IW ratio is 10% (Condition 15), when the Vessel's heading is 270 deg. and the wind velocity is 40 m/s (heeling couple of the force lever: green dash-dotted line), the effective stability is almost null even when the height of the center of gravity under the light loading condition KG_L is 4.49 m (black solid line).

Table 17 Estimated Heeling Moment Due to Winds

Wind Force m/s	Wind Direction °	Heading of the Vessel °	Condition 3 RW ratio 75% + IW ratio 0%			Condition 11 RW ratio 75% + IW ratio 2%			Condition 12 RW ratio 75% +IW ratio 4%		
			C_K	K_A tf*m	D_w M	C_K	K_A tf*m	D_w m	C_K	K_A tf*m	D_w m
30.0	202.5 SSW	225.0 SW	0.750	53.10	0.012	0.763	51.32	0.011	0.774	49.42	0.010
35.0				72.27	0.016		69.85	0.015		67.26	0.014
40.0				94.40	0.021		91.23	0.020		87.86	0.018
30.0		270.0 West	1.902	134.73	0.029	1.946	130.98	0.028	1.987	126.94	0.027
35.0				183.39	0.040		178.27	0.038		172.78	0.036
40.0				239.52	0.052		232.85	0.050		225.68	0.047

Wind Force m/s	Wind Direction °	Heading of the Vessel °	Condition 13 RW ratio 75%+IW ratio 6%			Condition 14 RW ratio 75%+IW ratio 8%			Condition 15 RW ratio 75%+IW ratio 10%		
			C_K	K_A tf*m	D_w m	C_K	K_A tf*m	D_w m	C_K	K_A tf*m	D_w m
30.0	202.5 SSW	225.0 SW	0.785	47.45	0.010	0.796	45.53	0.009	0.806	43.60	0.009
35.0				64.58	0.013		61.97	0.013		59.35	0.012
40.0				84.35	0.017		80.94	0.016		77.52	0.015
30.0		270.0 West	2.030	122.71	0.025	2.072	118.55	0.024	2.114	114.33	0.023
35.0				167.02	0.034		161.37	0.033		155.62	0.031
40.0				218.15	0.045		210.76	0.043		203.26	0.040

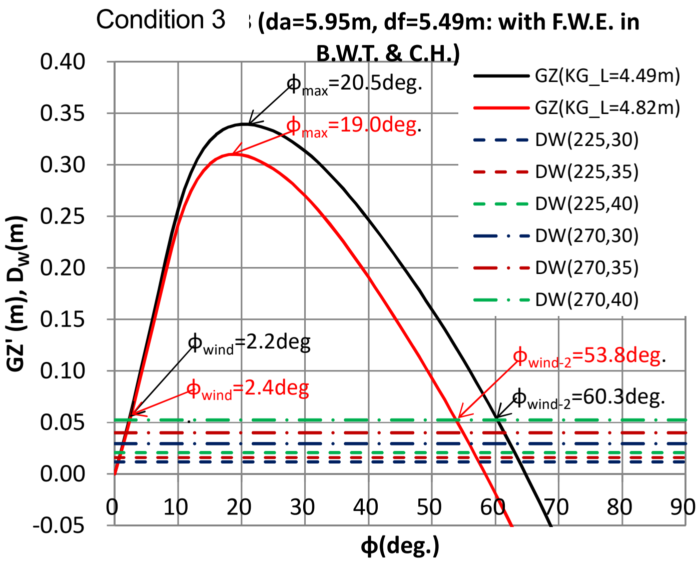


Figure 6 Stability and Heeling Couple of the Force Lever due to Winds (Condition 3 - IW Ratio: 0%)

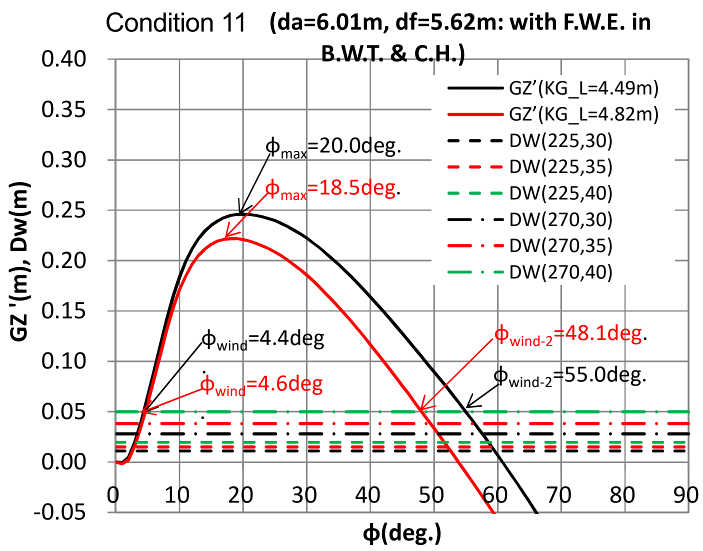


Figure 7 Stability and Heeling Couple of the Force Lever due to Winds (Condition 11 - IW Ratio: 2%)

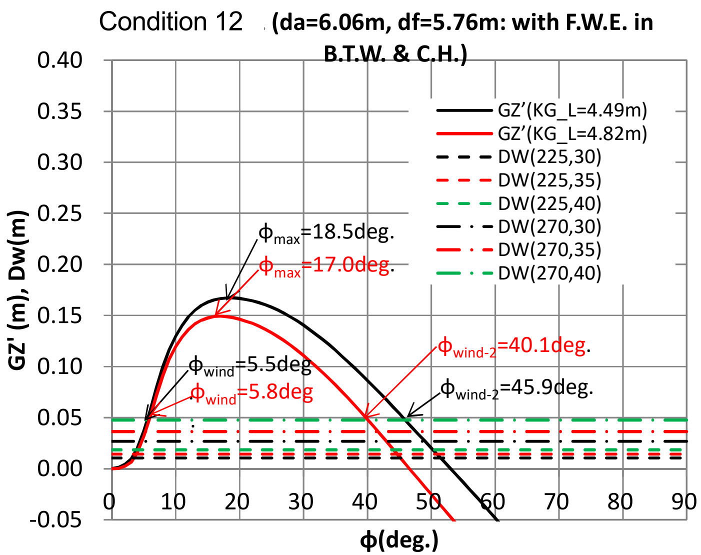


Figure 8 Stability and Heeling Couple of the Force Lever due to Winds (Condition 12 - IW Ratio: 4%)

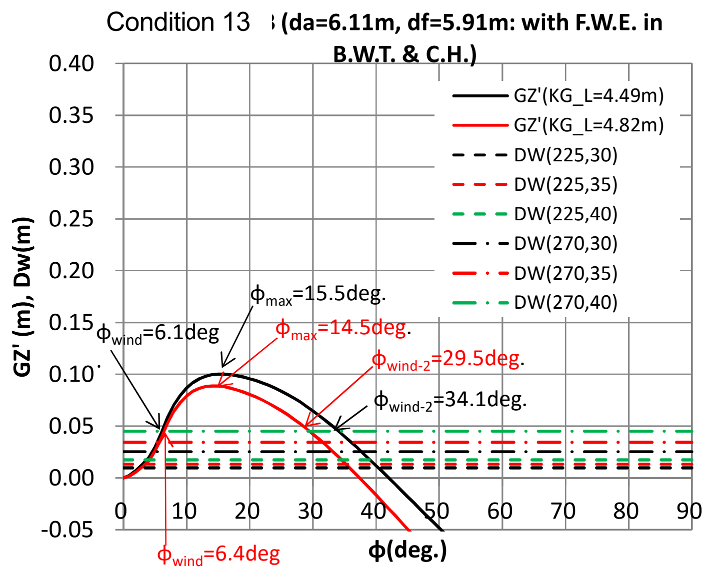


Figure 9 Stability and Heeling Couple of the Force Lever due to Winds (Condition 13 - IW Ratio: 6%)

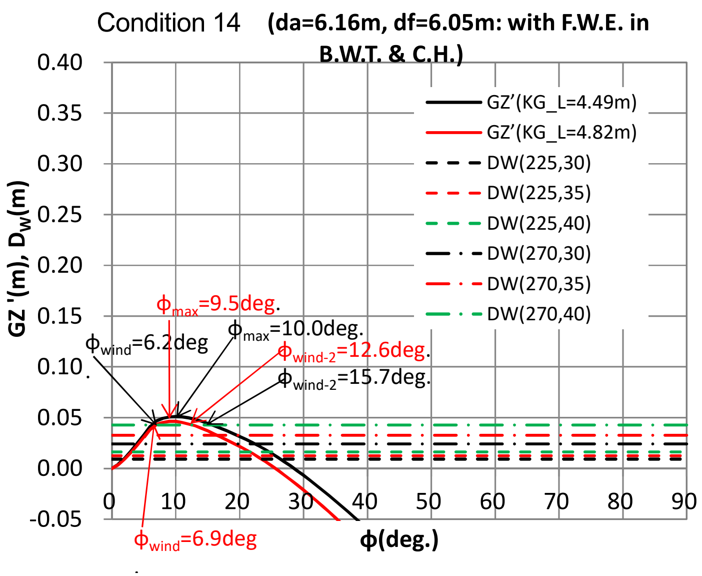


Figure 10 Stability and Heeling Couple of the Force Lever due to Winds (Condition 14 - IW Ratio: 8%)

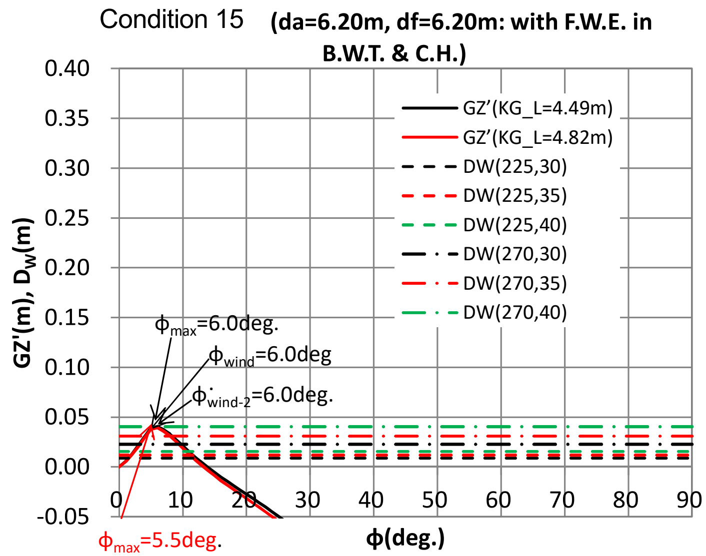


Figure 11 Stability and Heeling Couple of the Force Lever due to Winds (Condition 15 - IW Ratio: 10%)

2.1.2 Lateral Heeling Angle Due to Winds

In Figures 6 to 11, the lateral heeling angle due to winds (φ_{wind}) corresponds to the smallest of the heeling angles at the intersections of the stability curve (GZ') and the line of the heeling couple of the force lever (D_W) (Formula (3)).

$$GZ'(\phi_{wind}) = D_W \left(= \frac{K_A}{W}\right) \quad (3)$$

Table 18 shows the estimated lateral heeling angle due to winds when the height of the center of gravity under the light loading condition (KG_L) is 4.49 m, and Table 19 shows that for when KG_L is 4.82 m. In addition, the estimated lateral heeling angle due to winds is plotted on the ordinate and the IW ratio is plotted on the abscissa in Figures 12 (KG_L = 4.49 m) and 13 (KG_L = 4.82 m). When KG_L = 4.82 m and the IW ratio is 10% (Condition 15), there is no intersection between the stability curve and the line of the heeling couple of the force lever due to winds at a heading of 270 deg. and a wind velocity of 40 m/s (a heeling angle at which the heeling couple of the force equals the stability).

Based on Tables 18 and 19 and Figures 12 and 13, it is found that: [1] the lateral heeling angle due to winds at a heading of 270 deg. where the relative wind direction is close to lateral is about 1.4-3.5 times greater than that at a heading of 225 deg.; and [2] the lateral heeling angle due to winds becomes 5 deg. or greater only when the heading is 270 deg. and the IW ratio is 4% or greater.

Under the Conditions assumed in this analysis, the lateral heeling angle due to winds increases with the volume of ingress water up to 4% (Condition 12) if the heading and the wind velocity stay the same. If the IW ratio is greater than 4%, the lateral heeling angle may decrease as ingress water increases, depending on the combination of the heading and the wind velocity, since the stability (GZ') and the heeling couple of the force due to winds (D_W) decrease at different rates against the increase in ingress water.

In Tables 18 and 19, the lateral heeling angles due to winds that are greater than the submerged angles of the discharging holes are highlighted in yellow. It is considered that the water retained in both passages on the upper deck exceeds the value set in this Chapter (an RW ratio of 75%) in these cases, since water discharge will be inhibited when the discharging holes are submerged.

Table 18 Estimated Lateral Heeling Angle Due to Winds (KG_L = 4.49 m)

Heading of the Vessel	225.0			270.0		
Wind Force	30.0	35.0	40.0	30.0	35.0	40.0
Condition 3	0.5	0.7	0.9	1.3	1.7	2.2
Condition 11	2.4	2.7	3.0	3.4	3.9	4.4
Condition 12	3.1	3.4	3.8	4.4	5.0	5.5
Condition 13	2.4	3.1	3.7	4.6	5.3	6.1
Condition 14	1.9	2.3	2.9	3.9	4.9	6.2
Condition 15	1.4	1.9	2.3	3.2	4.1	6.0

Table 19 Estimated Lateral Heeling Angle Due to Winds (KG_L = 4.82 m)

Heading of the Vessel	225.0			270.0		
Wind Force	30.0	35.0	40.0	30.0	35.0	40.0
Condition 3	0.6	0.8	1.0	1.4	1.9	2.4
Condition 11	2.6	2.9	3.2	3.6	4.1	4.6
Condition 12	3.4	3.8	4.1	4.7	5.2	5.8
Condition 13	2.8	3.5	4.1	4.9	5.6	6.4
Condition 14	2.0	2.5	3.1	4.1	5.2	6.9
Condition 15	1.5	1.9	2.4	3.2	4.2	–

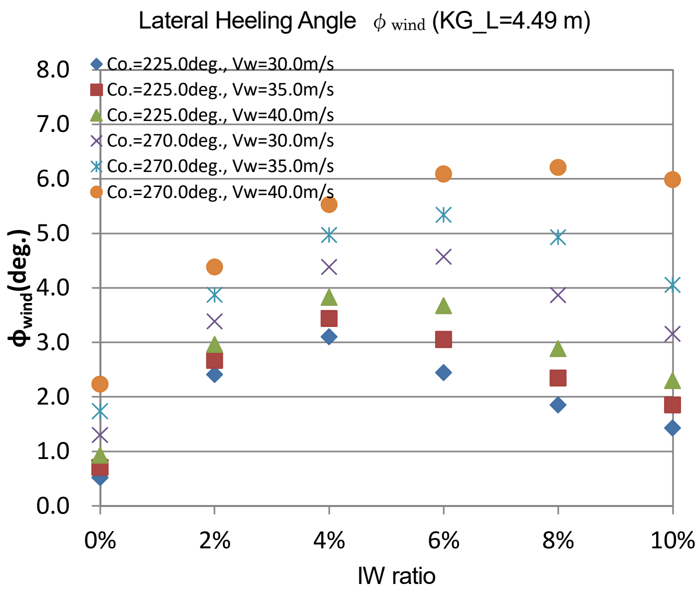


Figure 12 Lateral Heeling Angle Due to Winds
(Effects of Ingress Water in the Cargo Holds; KG_L = 4.49 m)

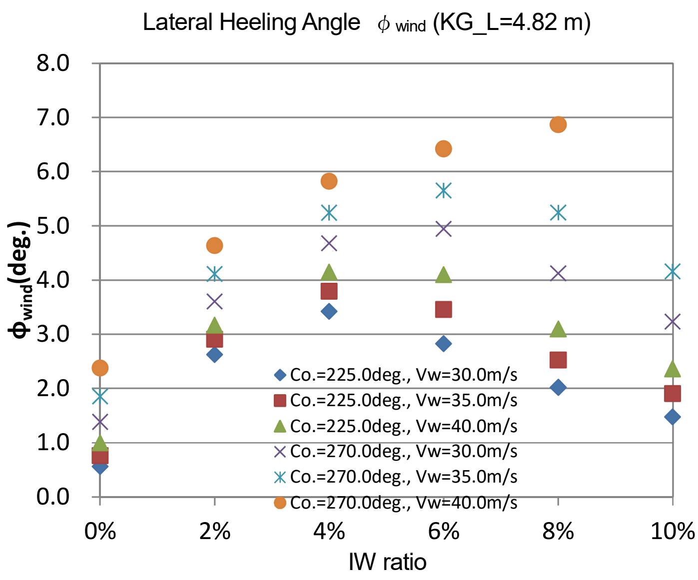


Figure 13 Lateral Heeling Angle Due to Winds
(Effects of Ingress Water in the Cargo Holds; KG_L = 4.82 m)

2.2 The Vessel's Progressive Heeling That Lead to the Foundering

The Vessel's progressive heeling that led to the accident was consdiered based on the residual stability estimated taking into account the heeling couple of the force due to winds. Below, the process leading up to the large heel to starboard and rolling over is discussed.

2.2.1 Assumption of an Accident Scenario

Table 20 summarizes the weather and sea conditions, the Vessel's rolling and heeling status, and the condition of water flowing onto and retained in the Vessel from 19:00 to the time of the accident, which have been reported by the Investigator, events that are estimated to have occurred based on interviews, and the Conditions assumed in previous Sections.

As shown in the table, the Vessel rolled and heeled increasingly higher degrees in the following manner: [1] the Vessel was rolling about 5 deg. due to waves from around 18:00 on the day of the accident; [2] with increase in wave height, the rolling degree reached 10-20 deg. around 20:00; [3] in addition, the Vessel began to heel about 5 deg. due to winds; [4] the heeling angle increased to about 30 deg. around 21:34; and [5] the Vessel rolled over after its heeling angle reached about 45 deg. around 21:39.

Table 20　Situation at the Time of the Accident occurred (Extract)

<table>
<tr><th>Time</th><th>Wave Height (m)</th><th>Wave Direction (deg.)</th><th>Wind Velocity (Ave./Max.) (m/s)</th><th>Wind Direction (Mean/Max.)</th><th>Heading (deg.)</th><th>Wave Angle of encounter (deg.)</th><th>Rolling Angle (deg.)</th><th>Heeling Angle (deg.)</th><th>Uprush Wave (UW), Retained Water (RW)</th><th>Condition of Ingress Water (IW) into Cargo Holds</th><th colspan="2">Responding Estimated Condition
*Bulwark: BW</th></tr>
<tr><td>18:00</td><td>1.0-1.5</td><td>-</td><td>14.6/18.5</td><td>ESE/SE</td><td>-</td><td>-</td><td>5</td><td>-</td><td>UW form the fore
No RW in passages</td><td></td><td colspan="2">Initial Condition</td></tr>
<tr><td>19:00</td><td>2.0-3.0</td><td>-</td><td>15.8/22.1</td><td>SE/SE</td><td>-</td><td>-</td><td>5</td><td>-</td><td>UW form the fore
RW ratio in passages 25%-100%</td><td>IW from four ventilation cylinders</td><td colspan="2">Condition 1 (RW ratio 25%)
– Condition 4 (RW ratio 100%)
to Condition 11 (IW ratio 2%:RW ratio 75%)</td></tr>
<tr><td>20:00</td><td>3.0-4.5</td><td>-</td><td>18.0/24.7</td><td>SE/SE</td><td>-</td><td>-</td><td>10-20</td><td>-</td><td>UW from the fore
Inflow and outflow due to rolling at large angle
(Change RW in passages)
RW on hatch covers (0.2-0.5m)</td><td>IW from four ventilation cylinders
IW from clearances of hatch covers</td><td rowspan="3">Heeling to discharging holes of BW
Condition 11 to Condition 15
IW ratio increasing from 2% to 10% with time</td><td rowspan="3">Heeling to top of BW

Condition 21 to Condition 25
IW ratio increasing IW ratio increasing from 2% to 10% with time</td></tr>
<tr><td>21:00</td><td>4.5-5.0</td><td>190</td><td>34.6/43.7</td><td>SSE/SSE</td><td>-</td><td>-</td><td>Ditto</td><td>-</td><td>Ditto</td><td>Ditto</td></tr>
<tr><td>21:30</td><td>ditto</td><td>201</td><td>28.9/38.6</td><td>SSW/South</td><td>225-270</td><td>111-156</td><td>Ditto</td><td>5</td><td>Ditto-</td><td>Ditto</td></tr>
<tr><td>21:34</td><td>ditto</td><td>202</td><td>Ditto</td><td>Ditto</td><td>Ditto</td><td>112-157</td><td>Ditto</td><td>30</td><td>-</td><td>Ditto</td><td>Heeling to discharge holes of BW
Condition 14/15
(IW ratio 8%/10%)</td><td>Heeling to top of BW

Condition 24/25
(IW ratio 8%/10%)</td></tr>
<tr><td>21:39</td><td>ditto</td><td>204</td><td>23.1/30.3</td><td>SSW/SSW</td><td>Ditto</td><td>114-159</td><td>Ditto</td><td>45</td><td>-</td><td>Ditto</td><td colspan="2">Condition 24/25
(IW ratio 8%/10%:RW ration in passages 100%)</td></tr>
</table>

Based on the process described in [3] to [5] above, the following Accident Scenario can be assumed.

(i) The Vessel was rolling 10-20 degrees due to waves while the mean RW ratio was 75%.

(ii) Around 21:30, the Vessel heeled about 5 deg. to the starboard side due to winds with an average velocity of 30 m/s (because of a change in the heading) and it started to roll 10-20 deg. around that heeling angle.

(iii) Around 21:34, the Vessel began to move back to the leeward side (starboard side) due to a gust of wind (40 m/s) while rolling a maximum degree on the windward side (port side).

(iv) The lateral heeling angle to starboard exceeded the submerged angle of the top of the bulwark (i.e. the water retained in the passages on the upper deck was now essentially outboard water) and reached the degree at which the maximum stability occurs (approximately 30 deg.) (which was greater than it had been).

(v) The Vessel came to be in an unstable condition[3)] in that the stability curve was negative, and furthermore, it was in a condition of being difficult to stabilize due to the submerged bulwark dragging, subject to the weight of sea water. As a result, the lateral heeling angle continued to grow due to waves, and the lateral heeling angle eventually reached about 45 deg. (which corresponds to the angle of loss of residual stability calculated taking into account the heeling couple of the force lever due to winds at the mean wind velocity), which resulted in the Vessel's rolling over to starboard.

2.2.2 Calculation Based on the Accident Scenario

Below, the situation at the time of the accident is considered by calculation using specific values at the accident in the context of the Accident Scenario assumed in Section 2.2.1.

1) Stability Curve

As discussed in Section 1.1.3, all the water retained in the passages on the upper deck is essentially outboard sea water when the top of the bulwark is submerged, and thus the Vessel's stability in such a situation should be deemed to recover to that under the condition where there is no Retained Water in both passages on the upper deck and only the cargo holds are flooded.

Figure 14 shows the stability curve when the IW ratio is 8%. The submerged angle of the top of the bulwark (φ_B) is 12.6 deg. when the RW ratio is 75% and the IW ratio is 8% (Condition 14) (Table 13). According to the logic discussed above, when $0 \leqq \varphi \leqq \varphi_B$ (φ denotes the lateral heeling angle), the Vessel's stability equals that estimated in Condition 14 (RW ratio: 75%); when $\varphi_B \leqq \varphi$, it is equal to that estimated under the condition where the RW ratio is 0% and the IW ratio is 8% (Appendix 1; Condition 24). In Figure 14, the red dotted line is the stability curve under Condition 24 (an RW ratio of 0%) when $0 \leqq \varphi \leqq \varphi_B$, and the green dotted line is the stability curve under Condition 14 (an RW ratio of 75%) when $\varphi_B \leqq \varphi$.

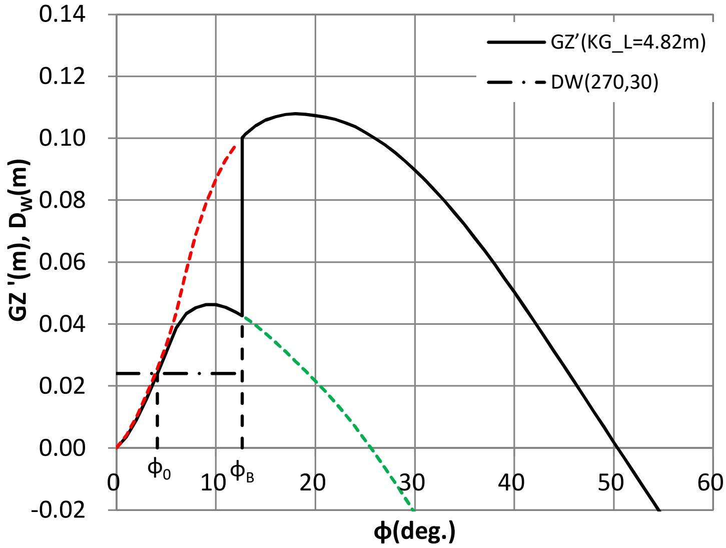


Figure 14 Stability Curve at the Time of the Accident occurred (Conditions 14 and 24; KG_L = 4.82 m) and the Heeling Couple of the Force Lever due to Winds
(Heading: 270 deg.; Wind Velocity: 30 m/s; Condition 14)

If the Vessel rolls 10-20 deg. under this condition ((i) in the Accident Scenario), the stability may significantly change as the lateral heeling angle can exceed the submerged angle of the top of the bulwark (12.6 deg.) (φ_B), depending on the rolling degree. However, this situation would still not produce a steady heeling, which means that the Vessel rolls symmetrically centered on its upright position (i.e. the rolling amplitude is equal on the port and starboard sides).

2) Heeling Angle Due to Winds and Roll Amplitude

The estimated heeling angle due to winds at the time of the accident shown in Tables 18 and 19 corresponds to φ_0, the angle at which the stability GZ' equals the heeling couple of the force lever due to winds Dw in Figure 14. Figure 14 shows the stability GZ' when the height of the center of gravity under the light loading condition KG_L is 4.82m (solid line) and the heeling couple of the force lever due to winds Dw (270, 30) (i.e. the heeling lever at a heading of 270 deg. and a wind velocity of 30 m/s) (dash-dotted line). Here, φ_0 is 4.1 deg. (Table 19), a heel to starboard.

If the Vessel rolls due to waves when it is heeled φ_0 degrees due to winds (steady heeling), the roll amplitudes to port and starboard sides may become asymmetric, depending on the characteristics of the stability curve. Under the Vessel Inspection Guidelines,[4] the roll amplitudes under such condition are calculated with Formulas (4) and (5), where φ_0 is the center of rolling.

$$\int_{\phi_{1p}}^{\phi_0}(D_w - \overline{GZ'})d\phi = \int_{\phi_0}^{\phi_{1s}}(\overline{GZ'} - D_w)d\phi \quad (4)$$

$$|\phi_{1p} - \phi_0| + |\phi_{1s} - \phi_0| = 2 \cdot \phi_a \quad (5)$$

φ_{1p} denotes the maximum heeling angle on the port side, φ_{1s} denotes that on the starboard side, and φ_a denotes the roll amplitude due to estimated waves. The first term on the left side of Formula (5) is the roll amplitude to port and the second term is roll amplitude to starboard.

Under the condition shown in Figure 14, if a roll amplitude (φ_a) of 15 deg. (the median of 10-20 deg.) ((ii) of the Accident Scenario) is applied to Formulas (4) and (5), the maximum heeling angle to the port side φ_{1p} is 11.1 deg. and the maximum heeling angle to the starboard side φ_{1s} is 18.9 deg. (Figure 15). Note that Formula (4) was calculated based on an assumption that the Vessel's stability and heeling couple of the force due to winds shift to those under Condition 24 (the condition where only the cargo holds are flooded and there is no Retained Water in the passages) when the lateral heeling angle exceeds the top of the bulwark's submerged angle (φ_B) (=12.6 deg.).

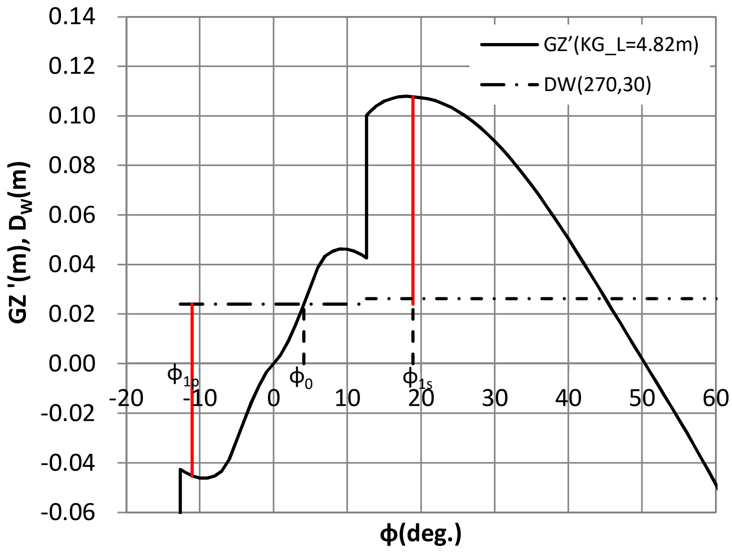


Figure 15 Calculated Roll Amplitude When the Vessel Has a Steady Heeling
(Conditions 14 and 24; KG_L=4.82 m; Center of Rolling (φ_0): 4.1 deg.; Wave Roll Amplitude: 15 deg.)

3) Calculation of Maximum Lateral Heeling Angle to the Starboard Side

The maximum lateral heeling angle to the starboard side φ_ℓ when the Vessel returns to the leeward side (starboard side) after receiving a gust of wind (wind velocity: 40 m/s) while rolling a maximum degree towards the waves (to the port side) ($\varphi = \varphi_{1p}$) ((iii) and (iv) of the Accident Scenario) can be obtained using the same approach based on energy balance as the C coefficient standard described in the Rules on Vessel Stability.

The heeling energy to the starboard side (a) can be expressed by Formula (6), where Dwg is the heeling couple of the force lever due to a gust of wind and φ_2 is the lateral heeling angle when the gust of wind acts quasi-statically. The maximum lateral heeling angle (φ_ℓ) to the starboard side satisfies Formula (7), based on the above approach concerning energy balance. The whole dynamic stability (b) that absorbs the heeling energy can be expressed by Formula (8), where φ_3 is the angle of loss of residual stability obtained taking account of the heeling couple of the force due to the gust of wind. With these, the ratio of the dynamic stability to the heeling energy can be obtained, which corresponds to the C coefficient as defined under the Rules on Vessel Stability (c=b/a).

$$a = \int_{\phi_{1p}}^{\phi_2} (D_{wg} - \overline{GZ'})d\phi \tag{6}$$

$$\int_{\phi_2}^{\phi_l} (\overline{GZ'} - D_{wg})d\phi = a \tag{7}$$

$$b = \int_{\phi_2}^{\phi_3} (\overline{GZ'} - D_{wg})d\phi \tag{8}$$

Figure 16 was used for the calculation of the energy balance. Assuming that the heeling couple of the force lever due to a gust of wind (Dwg) is equivalent to the heeling couple of the force lever due to winds at a heading of 270 deg. and a wind velocity of 40 m/s (Dw (270,40)), the lateral heeling angle φ_2 is 6.9 deg. when the gust of wind acts quasi-statistically (Table 19). By applying the maximum heeling angle to the port side calculated in 2) (φ_{1p} = -11.1 deg.) to Formulas (6) to (8), the maximum heeling angle to the starboard side (φ_ℓ) is 29.2 deg. and the ratio of the dynamic stability to the heeling energy (c = b/a) is 1.29. Note that Formulas (7) and (8) were calculated based on an assumption that the Vessel's stability and heeling couple of the force due to winds shift to those under Condition 24 (the condition where only the cargo holds are flooded and there is no Retained Water in the passages) when the lateral heeling angle exceeds the top of the bulwark's submerged angle (φ_B) (12.6 deg.).

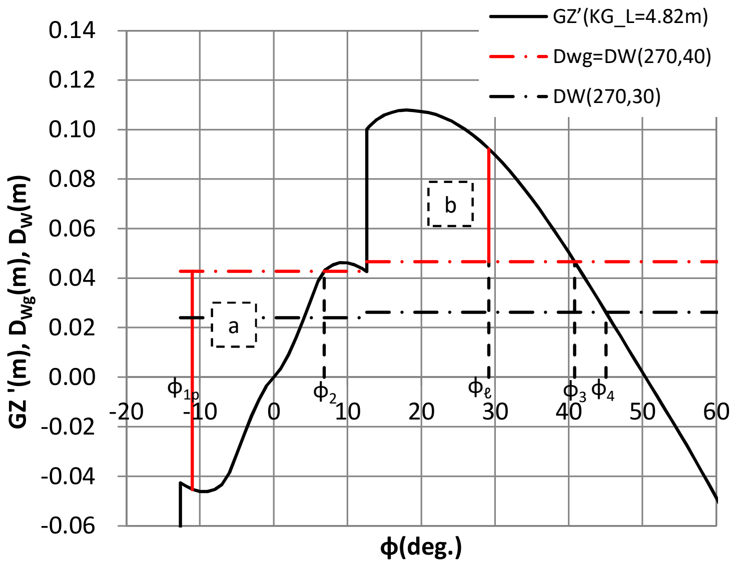


Figure 16 Calculated Energy Balance

(Conditions 14 and 24; KG_L=4.82m; Heading: 270 deg.;

Wind Velocity: 40 m/s; Maximum Lateral Heeling Angle to the Port Side φ_{1p}: -11.1 deg.)

4) Comparison between the Maximum Lateral Heeling Angle to the Starboard Side and the Heeling Angle at Which the Maximum Stability Occurs

As discussed in 3), the results of calculations based on the Accident Scenario show that the maximum heeling angle to the starboard side is 29.2 deg. when the center of gravity under the light loading condition (KG-L) is 4.82 m, the RW ratio is 75%, the IW ratio is 8%, the heading is 270 deg., the average wind velocity is 30 m/s, and the Vessel had been rolling 30 deg. when it was hit by a gust of wind with a velocity of 40 m/s.

Meanwhile, the heeling angle at which the maximum stability occurs is approximately 18 deg. At the maximum heeling angle to the starboard side (29.2 deg.), the slope of the stability curve is negative (Figure 16). This means that the Vessel was unstable at the maximum heeling angle to the starboard side.[3] At the same time, the stability was undermined due to the the submerged bulwark dragging, subject to the weight of sea water. In this situation, the continuous effects of waves could have further increased the lateral heeling angle ((v) of the Accident Scenario). The angle of loss of residual stability φ_4 is calculated to be 45.1 deg. when the average wind velocity is 30 m/s under the condition assumed in Figure 16.

5) Summary of Calculations Based on the Accident Scenario

Tables 21 to 24 show the results of the calculations described in 1) to 3) above for the combinations of the two heights of the center of gravity (4.49m and 4.82m), six IW ratios (0-10 % in 2% increments), and two headings (225 and 270 deg.). In Tables 21 and 22, the heading is 225 deg. The height of the center of gravity under the light loading condition KG_L is 4.49 m in the former and 4.82 m in the latter. In Tables 23 and 24, the heading is 270 deg. The height of the center of gravity under the light loading condition KG_L is 4.49 m in the former and 4.82 m in the latter. Each table shows the results calculated with the six IW ratios. The cells are highlighted in yellow when the maximum heeling angle to the starboard side caused by a gust of wind exceeds the heeling angle at which the maximum stability occurs.

Table 21 Results of Energy Balance Calculation (KG_L = 4.49 m; Heading: 225 deg.)

IW Rate	ϕ_0 (deg.)	ϕ_{1p} (deg.)	ϕ_2 (deg.)	ϕ_B (deg.)	ϕ_ℓ (deg.)	ϕ_{max} (deg.)	ϕ_3 (deg.)	ϕ_4 (deg.)	a (deg.)	b (deg.)	c (deg.)
0%	0.5	-14.4	0.9	15.5	16.2	25.5	73.6	74.3	2.87	19.38	6.75
2%	2.4	-14..4	3.0	14.7	16.5	26.0	72.3	73.1	1.99	14.44	7.24
4%	3.1	-14..3	3.8	14.0	16.8	25.5	69.1	70.0	1.45	10.04	6.94
6%	2.4	-14.3	3.7	13.3	17.2	23.5	63.1	64.3	1.06	6.10	5.75
8%	1.9	-14.0	2.9	12.6	18.2	20.5	51.5	53.2	0.79	2.92	3.70
10%	1.4	-13.3	2.3	11.9	21.5	11.0	35.2	37.1	0.57	0.88	1.94

Table 22 Results of Energy Balance Calculation (KG_L = 4.82 m; Heading: 225 deg.)

IW Rate	ϕ_0 (deg.)	ϕ_{1p} (deg.)	ϕ_2 (deg.)	ϕ_B (deg.)	ϕ_ℓ (deg.)	ϕ_{max} (deg.)	ϕ_3 (deg.)	ϕ_4 (deg.)	a (deg.)	b (deg.)	c (deg.)
0%	0.6	-14.4	1.0	15.5	16.3	23.5	67.9	68.5	2.70	15.93	5.90
2%	2.6	-14.4	3.2	14.7	16.6	24.0	66.5	66.5	1.86	11.63	6.26
4%	3.4	-14.3	4.1	14.0	16.9	23.5	63.2	64.2	1.34	7.96	5.95
6%	2.8	-14.2	4.1	13.3	17.4	22.0	57.2	58.5	0.98	4.78	4.89
8%	2.0	-13.9	3.1	12.6	18.5	18.0	46.7	48.3	0.73	2.33	3.19
10%	1.5	-13.2	2.4	11.9	22.2	10.5	33.4	35.2	0.54	0.75	1.38

Table 23 Results of Energy Balance Calculation (KG_L = 4.49 m; Heading: 270 deg.)

IW Rate	ϕ_0 (deg.)	ϕ_{1p} (deg.)	ϕ_2 (deg.)	ϕ_B (deg.)	ϕ_ℓ (deg.)	ϕ_{max} (deg.)	ϕ_3 (deg.)	ϕ_4 (deg.)	a (deg.)	b (deg.)	c (deg.)
0%	1.3	-13.7	2.2	15.5	18.3	25.5	71.3	73.0	3.11	17.00	5.47
2%	3.4	-13.4	4.4	14.7	19.0	26.0	69.6	71.6	2.27	12.26	5.41
4%	4.4	-13.1	5.5	14.0	20.1	25.5	65.9	68.2	1.74	8.10	4.65
6%	4.6	-12.5	6.1	13.3	22.0	23.5	58.6	61.9	1.34	4.45	3.31
8%	3.9	-11.4	6.2	12.6	26.8	20.5	45.2	49.7	1.01	1.69	1.67
10%	3.2	-8.2	6.0	11.9	-	11.0	27.2	33.2	0.66	0.14	0.22

Table 24 Results of Energy Balance Calculation (KG_L = 4.82 m; Heading: 270 deg.)

IW Rate	ϕ_0 (deg.)	ϕ_{1p} (deg.)	ϕ_2 (deg.)	ϕ_B (deg.)	ϕ_ℓ (deg.)	ϕ_{max} (deg.)	ϕ_3 (deg.)	ϕ_4 (deg.)	a (deg.)	b (deg.)	c (deg.)
0%	1.4	-13.6	2.4	15.5	18.5	23.5	65.5	67.2	2.94	13.75	4.68
2%	3.6	-13.3	4.6	14.7	19.4	24.0	63.6	65.7	2.13	9.65	4.52
4%	4.7	-12.9	5.8	14.0	20.7	23.5	59.7	62.3	1.64	6.21	3.79
6%	4.9	-12.3	6.4	13.3	22.9	22.0	52.1	55.8	1.27	3.33	2.63
8%	4.1	-11.1	6.9	12.6	29.2	18.0	40.8	45.1	0.96	1.24	1.30
10%	3.2	-	-		-	-	-	-	-	-	-

The tables show that, as far as this analysis concerns,: [1] the maximum heeling angle ϕ_ℓ to the starboard side due to a gust of wind exceeds the heeling angle ϕ_{max} at which the maximum stability occurs only when the IW ratio is 6% or greater; [2] in the Accident Scenario from Section 2.2.1, the angle of loss of residual stability φ_4 becomes about 45 deg. when the IW ratio is 8%; and [3] when the heading is 270 deg. and the cargo holds's IW ratio is 10%, the Vessel rolls over when it is hit by a gust of wind while it is rolling to the port side to the maximum extent (KG_L = 4.49 m) (Table 23) or due to a gust of wind alone when the Vessel lacks balance (KG_L = 4.82 m) (Table 24). In summary, the conditions that led to the rolling over of the Vessel included a height of the center of gravity under the light loading condition (KG_L) of 4.82 m, an IW ratio of 8%, and a heading of 270 deg.

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2) FUJIWARA Toshifumi, UENO Michio, IKEDA Yoshiho, A New Estimation Method of Wind Forces and Moments Acting on Ships on the Basis of Physical Component Models, Journal of the Japan Society of Naval Architects and Ocean Engineers, Vol. 2, pp. 243-255, October 2005.

3) WATANABE Yoshiro, Some Considerations on the Instability of Asymmetric Rolling at the Large Inclination of a Ship, Journal of the West-Japan Society of Naval Architects, No. 34, pp. 59-71, July 1967.

4) Supervised by the Maritime Technology and Safety Bureau of the Ministry of Transport, edited by the Society for the Study of the Provisions of the Ship Safety Act: Interpretations of the Rules Related to the Ship Safety Act Based on the Ship Inspection Guidelines, p. 507, Seizando, February 2000.

Appendix 1 Consideration of the Case Where There Is No Retained Water in Both Passages on Upp. Deck

So far, the Vessel's stability at the time of the accident (Section 1.2) and the lateral heeling angle due to winds (Section 2.1) were estimated and their effects were examined with different volumes of ingress water in the cargo holds, assuming that the RW ratio was 75% at the time (Condition 3), as it was reported that the cargo holds may have been flooded when the accident occurred. Below, the results of the same analysis assuming an RW ratio of 0% (Initial Condition: no Retained Water) are summarized.

(1) Stability at the Time of the Accident

The Vessel's stability at the time of the accident was estimated, assuming that the cargo holds were flooded while the RW ratio was 0% (Initial Condition) to examine the effects of ingress water in the cargo holds.

The weight of ingress water (W_H') and the position of the center of gravity (C_{HL}: longitudinal position; C_{HV}: vertical position) were calculated with various IW ratios, assuming that ingress water was retained on the bottom (the inner bottom plating of the double bottom) of the cargo holds according to the trim under the Initial Condition (0.50 m trim by the stern (Table 7)) (Tables A1-1 and A1-2). The weight of the ingress water (W_H') in Tables A1-1 and A1-2 was calculated using the specific gravity of sea water at the time of the draft survey (γ = 1.019). The baseline of the longitudinal position (C_{HL}) and the vertical position (C_{HV}) of the center of gravity is the rear bulkhead (Cargo Hold No. 1: Fr.74; Cargo Hold No. 2: Fr. 28) and the level of the inner bottom plating, respectively. Compared to the previous analysis, where the RW ratio was 75% (Tables 9 and 10), the longitudinal position of the center of gravity (C_{HL}) is 0.04-0.29 m closer to the stern due to the difference in the estimated trims, while the weight of the ingress water (W_H') for each estimated ingress water ratio is the same. Meanwhile, there was no significant difference in the vertical position of the center of gravity between the analysis assuming an RW ratio of 0% and the one assuming that of 75%.

Table A1-1 Estimated Ingress Water in No. 1 Cargo Hold

IW ratios	Weight of Ingress Water W_S' (tf)	Longitudinal position and of Center of Gravity C_{SL} (m)	Vertical position of Center of Gravity C_{SV} (m)
2 %	40.8	10.41	0.087
4 %	81.5	11.50	0.164
6 %	122.3	11.87	0.243
8 %	163.0	12.05	0.322
10 %	203.8	12.16	0.402

Table A1-2　Estimated Ingress Water in No. 2 Cargo Hold

IW ratios	Weight of Ingress Water W_S' (tf)	Longitudinal position and of Center of Gravity C_{SL} (m)	Vertical position of Center of Gravity C_{SV} (m)
2 %	46.6	10.67	0.078
4 %	93.2	12.21	0.141
6 %	139.8	12.72	0.207
8 %	186.4	12.98	0.274
10 %	232.9	13.13	0.342

Table A1-3　Conditions of Calculation (Effects of Ingress Water in the Cargo Holds)

Condition	W (tf)	mid-G (m)	KG1 (m)	KG2 (m)	RW ratios + IW ratios
Initial Conditio	4424.8	-0.285	3.877	3.967	75 % + 0 %
Condition 21	4512.2	-0.250	3.825	3.901	75 % + 2 %
Condition 22	4599.5	-0.165	3.778	3.839	75 % + 4 %
Condition 23	4686.9	-0.084	3.735	3.781	75 % + 6 %
Condition 24	4774.2	-0.006	3.696	3.726	75 % + 8 %
Condition 25	4861.6	0.070	3.661	3.674	75 % + 10 %

Table A1-3 shows the displacement (W) and the position of the center of gravity (mid-G: longitudinal position; KG: vertical position) under the condition with which the Vessel's stability was calculated in order to examine the effects of ingress water in the cargo holds. KG1 denotes the vertical position (height) of the center of gravity for when the height of the center of gravity under the light loading condition (KG_L) is 4.49 m, and KG2 denotes that for when KG_L is 4.82 m. The table also shows the values under the Initial Condition (i.e. no ingress water in the cargo holds) for reference.

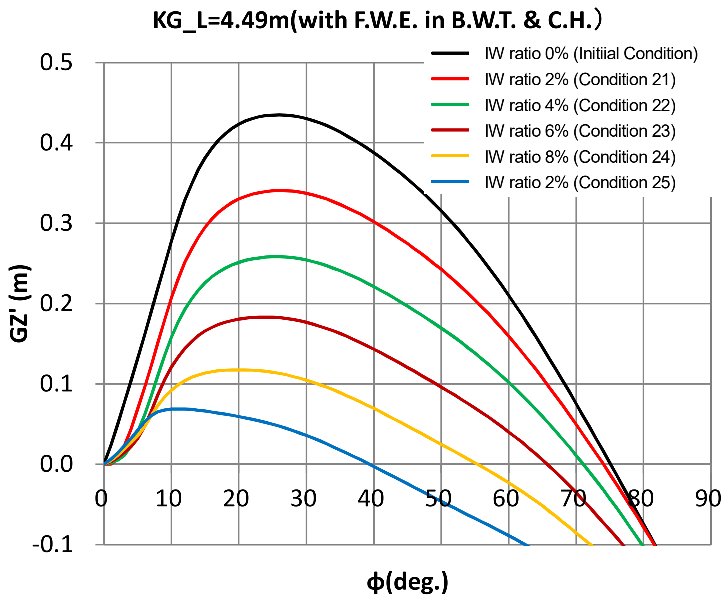

Figure A1-1　Stability Curve (Effects of Ingress Water in the Cargo Holds; KG_L = 4.49 m)

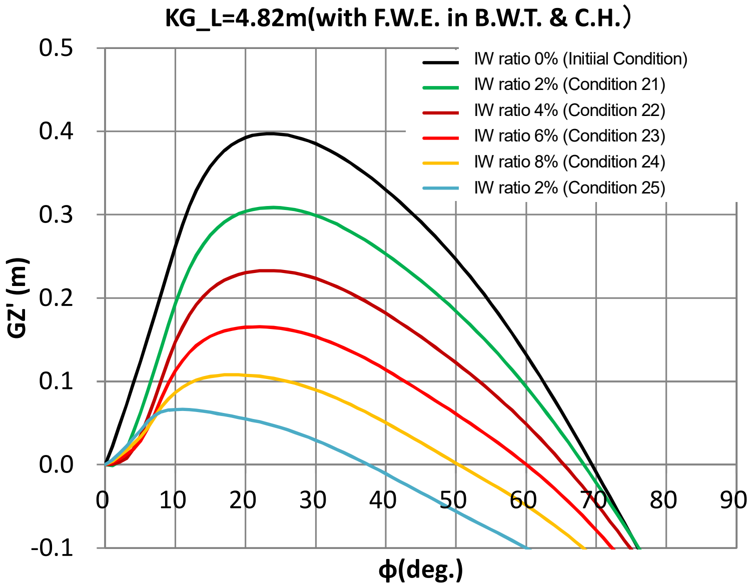

Figure A1-2 Stability Curve (Effects of Ingress Water in the Cargo Holds; KG_L = 4.82 m)

The Vessel's calculated stability for each condition is shown in Figures A1-1 and A1-2. In the same manner as Section 1.2, the free water effect of ingress water in each cargo hold was taken into account as a change (caused by heeling) in the center of gravity of water contained in a hypothetical cargo hold that has a plane with the same length and area as the plane of the actual cargo hold (i.e. a hypothetical cargo hold tank that has an approximate rectangular plane).[1)]

The stability generally decreases as ingress water increases. At the same time, the angle of loss of residual stability (φ_V) and the range of stability (φ_R), which define the characteristics of a vessel's stability, both decrease, while the maximum stability (GZ_{max}) and the lateral heeling angle at which the maximum stability occurs (φ_{max}) also decline. For example, when the height of the center of gravity under the light loading condition KG_L is 4.49 m and the IW ratio is 4% (Condition 22; weight of ingress water in No. 1 Cargo Hold: 81.5 tf; weight of ingress water in No. 2 Cargo Hold: 93.2 tf) (the green line in Figure A1-1), the angle of loss of residual stability (φ_V) is approximately 72 deg., the maximum stability GZ_{max} is approximately 0.26 m, and the lateral heeling angle at which the maximum stability occurs φ_{max} is approximately 26 deg. While the maximum stability is lower by approximately 40%, there is no significant difference in the angle of loss of residual stability or the lateral heeling angle at which the maximum stability occurs, compared to the case where there was no ingress water in the cargo holds (Initial Condition; $\varphi_V \cong$ 75 deg., $GZ_{max} \cong$ 0.43 m, $\varphi_{max} \cong$ 26 deg.) (black line in Figure A1-1).

Table A1-4 Calculated Metacentric Height, Draft, and Trim (Effects of Ingress Water in the Cargo Holds)

Condition	GM1 (m)	GM2 (m)	da (m)	df (m)	dm (m)	τ (m)
Initial condition	1.45	1.36	5.80	5.30	5.55	0.50
Condition 21	0.10	0.02	5.87	5.42	5.65	0.45
Condition 22	0.19	0.13	5.92	5.56	5.74	0.36
Condition 23	0.27	0.23	5.97	5.71	5.84	0.26
Condition 24	0.36	0.33	6.01	5.85	5.93	0.16
Condition 25	0.43	0.42	6.06	6.00	6.03	0.06

Table A1-4 shows the calculated metacentric height (GM), draft (da: draft aft; df: draft fore, dm: draft mid), and trim (τ: positive when trimmed by the stern), which were calculated taking into account the free water effects of water in the cargo holds and ballast tanks. It is known that the value of metacentric height corresponds to the slope of the tangent line of the stability curve at the origin (i.e. lateral heeling angle: 0 deg.),[2] and thus the same value will be obtained for the metacentric height regardless of whether the free water effects of ingress water in the cargo holds and ballast water are treated as changes in their center of gravity due to heeling, like in this analysis, or they are treated as a virtual rise in the Vessel's center of gravity.[1] Therefore, the metacentric height largely decreases under Conditions listed in Table A1-4 from that under the Initial Condition (where there is no ingress water in the cargo holds), due to the large free water effect. For example, when KG_L = 4.49 m and the IW ratio is 2% (Condition 21; weight of ingress water in No. 1 Cargo Hold: 40.8 tf; weight of ingress water in No. 2 Cargo Hold: 46.6 tf), the metacentric height (GM1) is 0.10 m, which is about 7% of the metacentric height under the Initial Condition (1.45 m).

Meanwhile, the free water effect of ingress water is only significant at smaller lateral heeling angles, as the estimated volumes of ingress water are low in this analysis. For example, when KG_L = 4.82 m and the IW ratio is 2% (Condition 21), the metacentric height (GM2) calculated taking into account the free water effect is very small, at 0.02 m (Table A1-4); then, the pro-metacentric height starts to grow around a lateral heeling angle of 2 deg. and it becomes approximately 0.31 m at maximum, a significant stability value, at a lateral heeling angle of about 24 deg. (Figure A1-2).

Table A1-5 shows the calculated submerged angles of the discharging holes, top of the bulwark, and fuel tanks' vent pipes on the aft deck at Fr.34 under each Condition. The table shows that the submerged angles decrease as ingress water in the cargo holds increases. When the IW ratio is 10% (Condition 25), the submerged angles of the discharging holes, top of the bulwark, and air vent pipes are 5.9 deg., 13.4 deg., and 25.8-27.6 deg., respectively, each decreasing by 3-4 deg. from the Initial Condition (i.e. no ingress water in the cargo holds).

Table A1-5 Calculated Submerged Angles of the Discharging Holes, Top of the Bulwark, and Air Vent Pipes (Effects of Ingress Water in the Cargo Holds)

Condition	Discharging Holes	Top of Bulwark	Air Vent Pipes		
	Fr. 34	Fr. 34	Port i	Port ii	Starboard
Initial condition	9.2	17.0	29.6	31.3	29.4
Condition 21	8.5	16.2	28.8	30.4	28.6
Condition 22	7.8	15.5	28.1	29.8	27.9
Condition 23	7.2	14.9	27.4	29.1	27.3
Condition 24	6.5	14.1	26.6	28.4	26.5
Condition 25	5.9	13.4	25.9	27.6	25.8

(2) Lateral Heeling Angle Due to Winds at the Time of the Accident

The Vessel's stability was estimated under six Conditions with different IW ratios (0-10%), assuming that the RW ratio was 75% (Table A1-6). Below, the heeling monents and lateral heeling angles due to winds at the designated wind velocities and directions and headings (Table A1-7 (recitation of Table 15)) were estimated under these six Conditions.

Table A1-6 Calculated Vessel Condition

Condition	W (t)	da (m)	df (m)	dm (m)	τ (m)	RW ratios + IW ratios
Condition 3	4424.8	5.80	5.30	5.55	0.50	0 % + 0 %
Condition 11	4457.7	5.87	5.42	5.65	0.45	0 % + 2 %
Condition 12	4523.4	5.92	5.56	5.74	0.36	0 % + 4 %
Condition 13	4441.2	5.97	5.71	5.84	0.26	0 % + 6 %
Condition 14	4589.1	6.01	5.85	5.93	0.16	0 % + 8 %
Condition 15	4589.1	6.06	6.00	6.03	0.06	0 % + 10 %

Table A1-7 Conditions of Calculation (Wind Velocity and Direction and the Vessel's Heading (co.))

Wind speed (m/s)	Wind direction (˚)	Heading of the Vessel (˚)	Ship speed (kn)	Relative speed (m/s)	Relative wind direction (˚)
30.0	202.5 SSW	225.0 SW	0.0	30.0	22.5
35.0				35.0	
40.0				40.0	
30.0		270.0 West		30.0	67.5
35.0				35.0	
40.0				40.0	

(i) Calculation of Heeling Moment Due to Winds

The heeling moment due to winds K_A was obtained with Formula (A1-1) (recitation of Formula (1)).

$$K_A = C_K q_A A_L H_L \tag{A1-1}$$

C_K is the heeling moment due to winds coefficient and is estimated based on Fujiwara's formula (Appendix 2).[3] q_A is the dynamic pressure, defined by Formula (A1-2) (recitation of Formula (2)), where ρ_A is air density and U_A is relative wind speed. A_L is the lateral projected area of the above-water hull and superstructure, and H_L is the average height of the sides of the above-water hull and superstructure ($H_L = A_L/L_{OA}$). These values were determined based on the general arrangement plan, in relation to the part above the draft line at the time of the accident (Table 12: draft aft (da) and draft fore (df)).

$$q_A = \frac{1}{2}\rho_A U_A^2 \tag{A1-2}$$

Table A1-8 Parameters Used for the Estimation of Heeling Moments Due to Winds

Condition	L_{OA} (m)	B (m)	A_P (m^2)	A_L (m^2)	A_{OD} (m^2)	C (m)	H_C (m)	H_{BR} (m)
Initial Condition	82.65	13.00	147.28	327.98	143.15	-3.65	2.98	15.67
Condition 21			143.88	320.23		-3.81	2.88	15.56
Condition 22			139.79	312.39		-4.06	2.79	15.43
Condition 23			135.56	304.30		-4.33	2.69	15.30
Condition 24			131.48	296.42		-4.61	2.61	15.17
Condition 25			127.22	286.34		-4.92	2.52	15.04

Table A1-8 shows the eight parameters for the Vessel's appearance that are used in Fujiwara's formula. L_{OA} is the length, B is the width, A_F is the frontal projected area of the above-water hull and superstructure, A_{OD} is the lateral projected area of the superstructure, C is the longitudinal coordinate from the center of the hull to the center of the lateral area (positive on the fore side), H_C is the height from the draft line to the center of the lateral area, and H_{BR} is the height from the draft line to the highest point of the main structure (bridge). Compared to the case from Section 2.1, where the RW ratio was 75% (Table 16), the projected areas (A_L, A_F) and height-related parameters (H_C, H_{BR}) are larger due to the shallower draft. Meanwhile, the longitudinal coordinate from the center of the hull to the center of the lateral area (C) has shifted closer to the center of the hull.

Table A1-9 shows the estimated coefficient of the heeling moment due to winds (C_K) and heeling moment due to winds (K_A) estimated using Fujiwara's formula concerning each Condition. In this table, D_W is the heeling couple of the force lever calculated using the heeling moment ($D_W = K_A/W$). Under the Conditions assumed in this analysis, the heeling moment due to winds coefficient (C_K) increases as ingress water in the cargo holds increases. On the other hand, as ingress water increases, the draft becomes deeper and the lateral projected area of the above-water hull and superstructure A_L and its average height H_L (= A_L/L_{OA}) decreases (Table A1-8), which means that the heeling moment due to winds K_A and the heeling couple of the force lever D_W also decline (Table A1-9).

Figures A1-3 to A1-10 show a comparison of the Vessel's calculated stability and the calculated heeling couple of the force lever due to winds under each Condition. While, as mentioned above, both the Vessel's stability (GZ') and the heeling couple of the force lever (D_W) decrease as the IW ratio increases, the former decreases more rapidly. Figures A1-3 to A1-10 show that the residual stability ($GZ'_{\_R}$), which corresponds to the stability curve (GZ') represented by the solid line above the line of the heeling couple of the force lever (D_W) parallel to the lateral axis, drops rapidly as the IW ratio increases. In particular, when the IW ratio is 10% (Condition 25), the Vessel's heading is 270 deg., and the wind velocity is 40 m/s (heeling couple of the force lever: green dash-dotted line), the range of residual stability is about 22 deg. even when the height of the center of gravity under the light loading condition KG_L is 4.49 m (black solid line).

Table A1-9 Estimated Heeling Moment Due to Winds

Wind Force m/s	Wind Direction °	Heading of the Vessel °	Initial Condition IW ratio 0%			Condition 21 IW ratio 2%			Condition 22 IW ratio 4%		
			C_K	K_A tf*m	D_w M	C_K	K_A tf*m	D_w m	C_K	K_A tf*m	D_w m
30.0	202.5 SSW	225.0 SW	0.725	56.00	0.013	0.738	54.30	0.012	0.748	52.42	0.011
35.0				76.22	0.017		73.91	0.016		71.35	0.016
40.0				99.56	0.022		96.54	0.021		93.19	0.020
30.0		270.0 West	1.823	140.81	0.032	1.865	137.27	0.030	1.903	133.34	0.029
35.0				191.65	0.043		186.85	0.041		181.49	0.039
40.0				250.32	0.057		244.04	0.054		237.05	0.052

Wind Force m/s	Wind Direction °	Heading of the Vessel °	Condition 23 IW ratio 6%			Condition 24 IW ratio 8%			Condition 25 IW ratio 10%		
			C_K	K_A tf*m	D_w M	C_K	K_A tf*m	D_w m	C_K	K_A tf*m	D_w m
30.0	202.5 SSW	225.0 SW	0.759	50.47	0.011	0.770	48.57	0.010	0.781	46.59	0.010
35.0				68.69	0.015		66.11	0.014		63.42	0.013
40.0				89.72	0.019		86.34	0.018		82.83	0.017
30.0		270.0 West	1.944	129.22	0.028	1.984	125.16	0.026	2.026	120.91	0.025
35.0				175.88	0.038		170..36	0.036		164.57	0.034
40.0				229.72	0.049		222.51	0.047		214.95	0.044

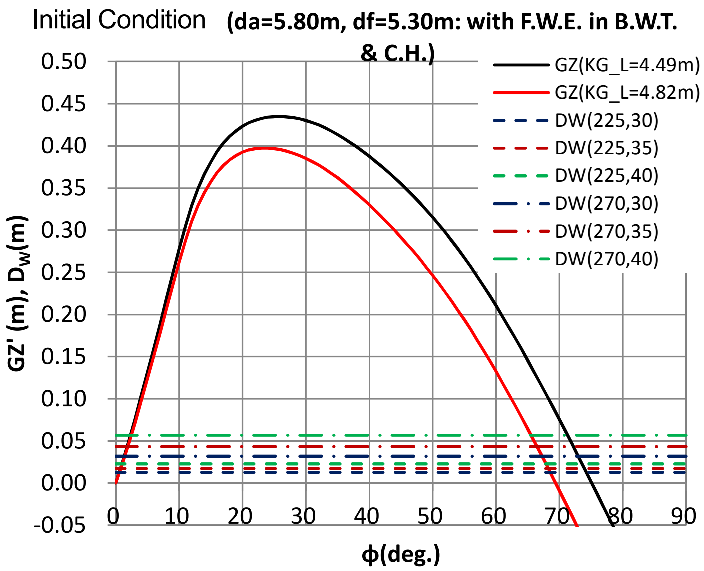

Figure A1-3 Stability and Heeling Couple of the Force Lever due to Winds (Initial Condition - IW Ratio: 0%)

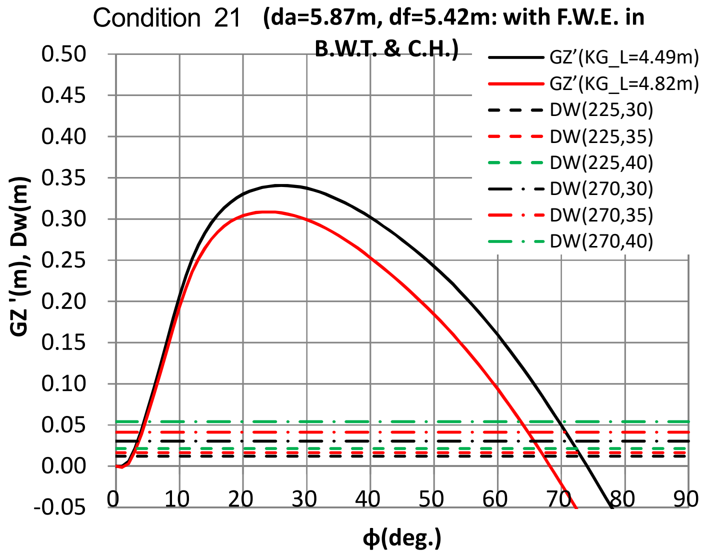

Figure A1-4 Stability and Heeling Couple of the Force Lever due to Winds (Condition 21 - IW Ratio: 2%)

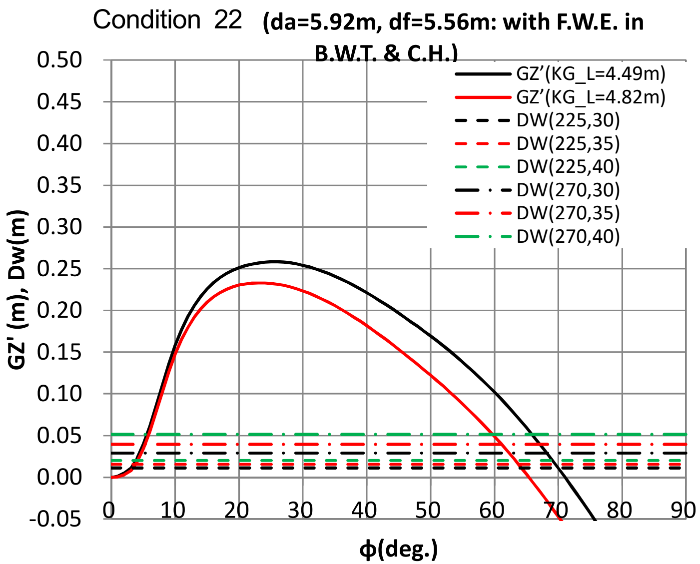

Figure A1-5 Stability and Heeling Couple of the Force Lever due to Winds (Condition 22 - IW Ratio: 4%)

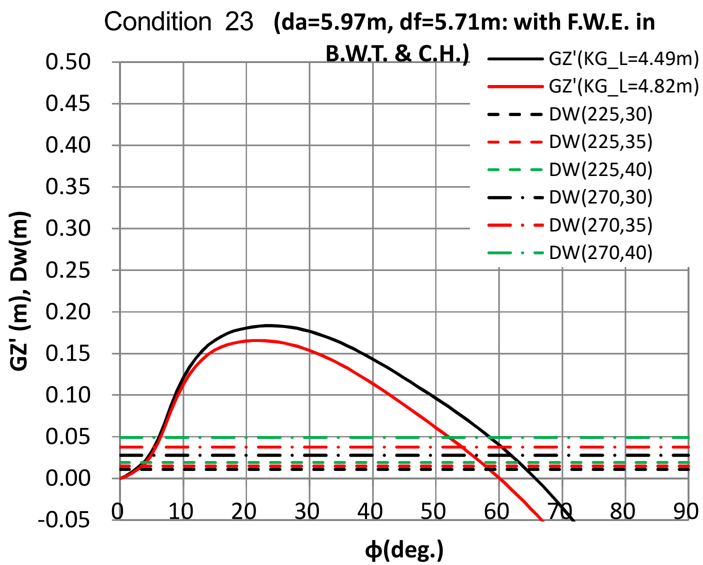

Figure A1-6 Stability and Heeling Couple of the Force Lever due to Winds (Condition 23 - IW Ratio: 6%)

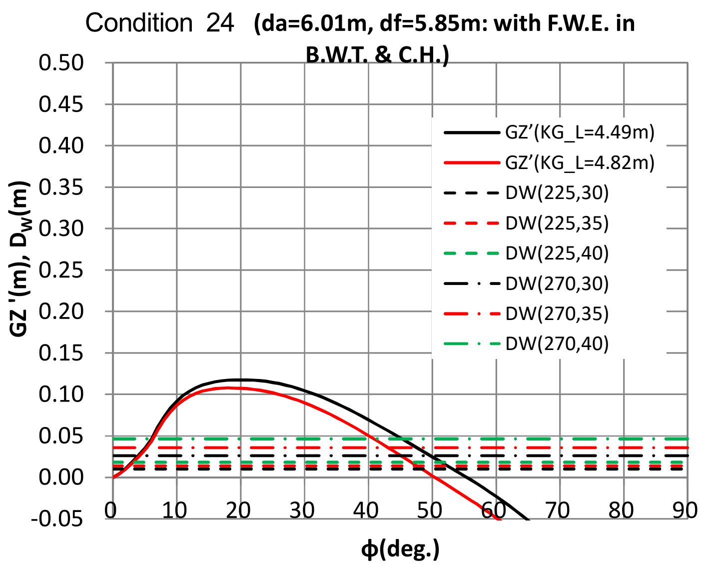

Figure A1-7 Stability and Heeling Couple of the Force Lever due to Winds (Condition 24 - IW Ratio: 8%)

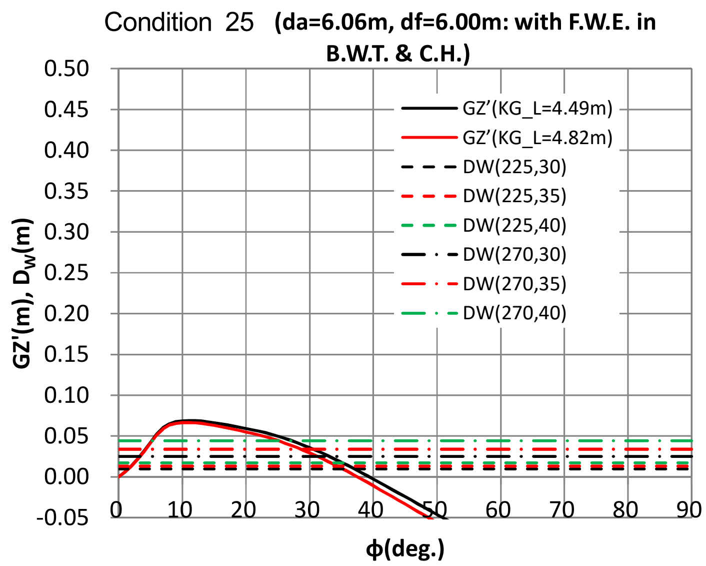

Figure A1-8 Stability and Heeling Couple of the Force Lever due to Winds (Condition 25 - IW Ratio: 10%)

(ii) Lateral Heeling Angle Due to Winds

In Figures A1-3 to A1-8, the lateral heeling angle due to winds (φ_{wind}) corresponds to the heeling angle at the intersections of the stability curve (GZ') and the line of the heeling couple of the force lever (D_W) (Formula (A1-3)).

$$GZ'(\phi_{wind}) = D_W\left(=\frac{K_A}{W}\right) \quad \text{(A1-3)}$$

Table A1-10 shows the estimated lateral heeling angle due to winds when the height of the center of gravity under the light loading condition (KG_L) is 4.49 m, and Table A1-11 shows that for when KG_L is 4.82 m. In addition, the estimated lateral heeling angle due to winds is plotted on the ordinate and the IW ratio is plotted on the abscissa in Figures A1-9 (KG_L = 4.49 m) and A1-10 (KG_L = 4.82 m).

Table A1-10 Estimated Lateral Heeling Angle Due to Winds (KG_L = 4.49 m)

Heading of the Vessel	225.0			270.0		
Wind Force	30.0	35.0	40.0	30.0	35.0	40.0
Condition 3	0.5	0.7	1.0	1.3	1.8	2.3
Condition 11	2.4	2.7	3.0	3.4	3.9	4.4
Condition 12	3.1	3.4	3.8	4.4	5.0	5.5
Condition 13	2.4	3.1	3.7	4.6	5.4	6.1
Condition 14	1.9	2.4	2.9	3.9	5.0	6.0
Condition 15	1.4	1.9	2.4	3.2	4.2	5.2

Table A1-11 Estimated Lateral Heeling Angle Due to Winds (KG_L = 4.82 m)

Heading of the Vessel	225.0			270.0		
Wind Force	30.0	35.0	40.0	30.0	35.0	40.0
Condition 3	0.6	0.8	1.0	1.4	1.9	2.4
Condition 11	2.6	2.9	3.2	3.6	4.1	4.7
Condition 12	3.4	3.7	4.1	4.7	5.2	5.8
Condition 13	2.8	3.4	4.1	4.9	5.7	6.4
Condition 14	2.0	2.5	3.1	4.2	5.3	6.2
Condition 15	1.5	2.0	2.4	3.3	4.2	5.3

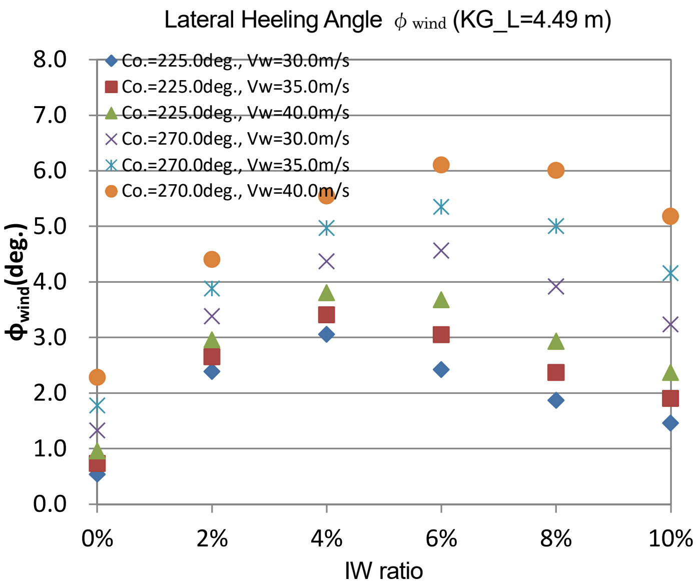

Figure A1-9 Lateral Heeling Angle Due to Winds
(Effects of Ingress Water in the Cargo Holds; KG_L = 4.49 m)

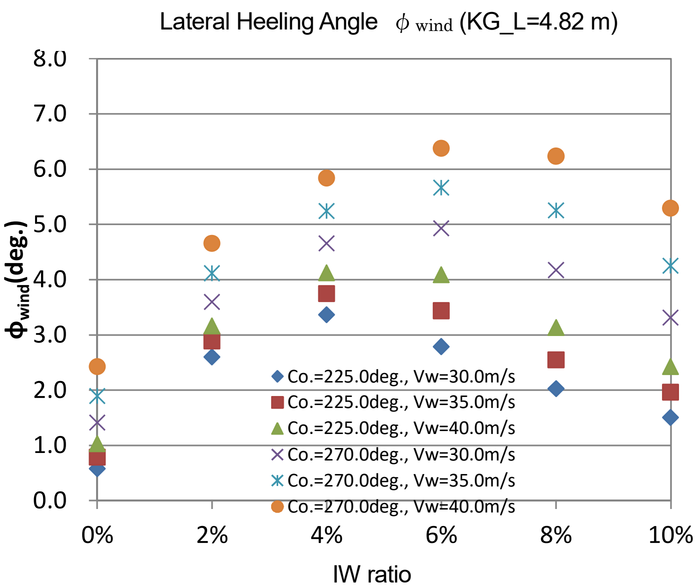

Figure A1-10 Lateral Heeling Angle Due to Winds
(Effects of Ingress Water in the Cargo Holds; KG_L = 4.82 m)

Under the Conditions assumed in this analysis, the lateral heeling angle due to winds increases with the volume of ingress water up to 4% (Condition 22) if the heading and the wind velocity stay the same. If the IW ratio is greater than 4%, the lateral heeling angle may decrease as ingress water increases, depending on the combination of the heading and the wind velocity, since the stability (GZ') and the heeling couple of the force due to winds (D_W) decrease at different rates against the increase in ingress water. Also, when the IW ratio is greater than 6%, the lateral heeling angle decreases with the increase in ingress water with any combinations of the headings and wind velocities.

Note that Tables A1-5, A1-10, and A1-11 show that the lateral heeling angle due to winds does not exceed the submerged angle of the discharging holes when there is no Retained Water in the passages on the upper deck, unlike in the situation assumed in Section 2.1 where the RW ratio was 75%.

References

1) MORITA Tomoharu, Senpaku-fukugenron: Kiso to Oyo (Theory of Stability, Basis and Application), pp. 84-94, Kaibundo, April 1985.
2) OGUSHI Masanobu, Riron Senpaku Kogaku (Jokan) New Edition, p.163, Kaibundo, October 1984.
3) FUJIWARA Toshifumi, UENO Michio, IKEDA Yoshiho, A New Estimation Method of Wind Forces and Moments Acting on Ships on the Basis of Physical Component Models, Journal of the Japan Society of Naval Architects and Ocean Engineers, Vol. 2, pp. 243-255, October 2005.

Appendix 2 Estimation of the Heeling Moment Coefficient (C_K) Due to Winds

Heeling Moment Coefficient (C_K) Due to Winds

The heeling moment due to winds coefficient C_K can be expressed by Formula (A2-1).

$$C_K = C_Y(L_K + L_d) \tag{A2-1}$$

C_Y denotes the cross wind pressure coefficient, L_K denotes the dimensionless value of the heeling moment lever due to winds acting on the above-water hull, and L_d denotes the dimensionless value of the heeling moment lever due to winds acting on the underwater hull due to fluid reaction (lateral force). C_Y and L_K were estimated using Fujiwara's formula (1). L_d was calculated assuming that the virtual point of action of the lateral force acting on the underwater hull is at half of the draft (d/2).

Crosswind Pressure Coefficient (C_Y) and Heeling Moment Lever (L_K) Due to Winds

The crosswind pressure coefficient C_Y is expressed by Formula (A2-2) as a function of the relative wind angle Ψ_A, assuming that it is composed of the cross-flow drag and the lateral components of the lift and induced drag forces.

$$C_Y(\Psi_A) = C_{CF}\sin^2\Psi_A + C_{YLI}\left(\cos\Psi_A + \frac{1}{2}\sin^2\Psi_A\cos\Psi_A\right)\sin\Psi_A\cos\Psi_A \tag{A2-2}$$

C_{CF} denotes the cross-flow drag coefficient and C_{YLI} denotes the lateral component coefficient of lift and induced drag forces. C_{CF} and C_{YLI} at the time of the accident were estimated by applying the parameters listed in Table 2 to Formulas (A2-3) and (A2-4), respectively.

$$C_{CF} = 0.404 + 0.368\frac{A_F}{BH_{BR}} + 0.902\frac{H_{BR}}{L_{OA}} \tag{A2-3}$$

$$C_{YLI} = \pi\frac{A_L}{L_{OA}^2} + C_{YM}$$

$$C_{YM} = 0.116 + 3.345\frac{A_F}{L_{OA}B} \tag{A2-4}$$

The heeling moment due to winds lever L_K is assumed to be almost constant regardless of the wind direction angle.[1] L_K under the condition at the time of the accident was estimated by Formula (A2-5).

$$L_K = 0.0737\left(\frac{H_C}{L_{OA}}\right)^{-0.821} \tag{A2-5}$$

Reference

1) FUJIWARA Toshifumi, UENO Michio, IKEDA Yoshiho, A New Estimation Method of Wind Forces and Moments Acting on Ships on the Basis of Physical Component Models, Journal of the Japan Society of Naval Architects and Ocean Engineers, Vol. 2, pp. 243-255, October 2005.