MA2025-10

MARINE ACCIDENT
INVESTIGATION REPORT

October 30, 2025

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.

RINOIE Kenichi
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.

《Reference》

The terms used to describe the results of the analysis in "3. ANALYSIS" of this report are as follows.

i) In case of being able to determine, the term "certain" or "certainly" is used.
ii) In case of being unable to determine but being almost certain, the term "highly probable" or "most likely" is used.
iii) In case of higher possibility, the term "probable" or "more likely" is used.
iv) In a case that there is a possibility, the term "likely" or "possible" is used.

MARINE ACCIDENT INVESTIGATION REPORT

Vessel Type and Name: Roll-on/roll-off cargo vessel Byakko
Vessel Number: 143784
Gross Tonnage: 11,454 tons

Vessel Type and Name: Chemical tanker ULSAN PIONEER
IMO Number: 9730969
Gross Tonnage: 2,696 tons

Accident Type: Collision
Date and Time: Around 23:53:38, May 27, 2021 (local time, UTC+9 hours)
Location: Off the north–northeast coast of Kajitori-no-Hana, Imabari City, Ehime Prefecture (near the west entrance of the Kurushima Kaikyo Traffic Route)
Around 285° true bearing, 1.4 nautical miles from Ikada Iso Lighthouse
(Coordinates approximately 34°09.1′ N, 132°54.4′ E)

September 17, 2025
Adapted by the Japan Transport Safety Board
Chairperson RINOIE Kenichi
Member ITO Hiroyasu
Member UENO Michio
Member SODA Hisako
Member TAKAHASHI Akiko

SYNOPSIS

<Summary of the Accident>

On May 27, 2021, at around 23:53:38, the roll-on/roll-off cargo vessel Byakko, manned with a master and 11 crew members, had exited the west entrance of the Kurushima Kaikyo Traffic Route and was proceeding southwest toward the Akinada Minami Koro. At the same time, the chemical tanker ULSAN PIONEER, manned with a master and 12 crew members, was navigating northeast toward the same entrance. The two vessels collided off the north–northeast coast of Kajitori-no-Hana, Imabari City, Ehime Prefecture.

Byakko sustained a breach midship along its port side and subsequently foundered. The Master and two crew members lost their lives, and five others were injured. ULSAN PIONEER experienced damage, with its bow severely crushed and bulbous bow bent; however, no fatalities or injuries occurred on board.

<Probable Causes>

(1) Probable Causes of the Collision

The Japan Transport Safety Board concludes that the probable causes of the collision are as follows.

It is probable that this accident occurred at night during the period when navigation in the Kurushima Kaikyo Traffic Route is designated for the southerly current. Byakko was heading southwest from the west entrance of the route, while ULSAN PIONEER was heading northeast from the Akinada Minami Koro toward the west entrance of the Kurushima Kaikyo Traffic Route. As the two vessels approached each other on crossing courses, Byakko judged that there was no risk of collision with ULSAN PIONEER even if it altered course to the Akinada Minami Koro after departing from the Kurushima Kaikyo Traffic Route. Shortly after departing, when the vessels were approximately 1 nautical mile (M) apart, Byakko changed course 30° to port to set a heading of 230° (true bearing, hereinafter the same) without communicating its maneuvering intentions to ULSAN PIONEER by radio. Consequently, Byakko came close to ULSAN PIONEER, which was heading north near the west entrance, intending to pass the stern side of Byakko. Confusion arose on ULSAN PIONEER's bridge due to the sudden and unexpected course change by Byakko. The officer on duty of Byakko, without the master of ULSAN PIONEER's approval, communicated with Byakko via VHF, expressing a desire to pass "Port to Port" (a passing method in which each vessel passes on the other's port side). Although Byakko agreed and turned starboard, it is probable that ULSAN PIONEER, following the master of ULSAN PIONEER's order to "Hard port," did not maintain the agreed "Port to Port" passing arrangement. It is probable that this divergence in maneuvers ultimately resulted in the collision between Byakko and ULSAN PIONEER.

It is more likely that Byakko did not communicate its intention to maneuver to ULSAN PIONEER when it altered course 30° to port toward the Akinada Minami Koro because the officer on duty of Byakko, having conducted a trial maneuver using the radar function prior to the course change, judged that a Port-to-Port passage would be possible with a CPA of approximately 0.2 M, and therefore did not perceive a risk of collision. It is likely that the passing distance between Byakko and ULSAN PIONEER assumed by the officer on duty of Byakko was insufficient, and that he did not fully comprehend the implications of the small CPA value indicated by the results of the trial maneuver.

It was not possible to determine the master of ULSAN PIONEER 's intention when he issued the command "Hard port", however, it was likely that, at the time Byakko set a course of 230°, the distance between the two vessels was only approximately 0.5 M, and Byakko's outline was rapidly approaching ULSAN PIONEER at a relative speed of over 30 kn. Under such circumstances, it is possible that the master of ULSAN PIONEER was unable to maneuver based on calm and rational judgment.

Contributing factors to the accident are as follows.

It is probable that it is involved in the occurrence of the accident, although Byakko was navigating near the west entrance of the Kurushima Kaikyo Traffic Route, the master of Byakko was not present in the bridge. As a result, Byakko was not in a position to properly maintain a lookout, judgment of the surrounding conditions, or communicate with ULSAN PIONEER via radio.

In addition, it is probable that it is involved in the occurrence of the accident, although ULSAN PIONEER had initially planned to transit the Kurushima Kaikyo Traffic Route during a north-flowing current, it did not adjust its speed accordingly and instead altered its course only after approaching the route while the current was flowing south. This led to a situation in which it came into close proximity with Byakko near the west entrance of the route. Furthermore, it is probable that it is involved in the occurrence of the accident, although the officer on duty of ULSAN PIONEER did not necessarily have sufficient seagoing service experience, there was a delay in the arrival time of the master of ULSAN PIONEER in the bridge to assume command. This delay adversely affected ULSAN PIONEER’s lookout and judgment of the surrounding conditions.

(2) Factors Contributing to Damage Increase

It is likely that the number of human casualties to the crew members of Byakko could have been reduced that, the crew members of Byakko possessed a better understanding of Byakko's damage stability, and recognized the necessity of making an early decision to abandon ship depending on the location of the damage sustained in the collision.

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1 PROCESS AND PROGRESS OF THE INVESTIGATION

1.1 Summary of the Accident

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1.2 Outline of the Accident Investigation

1.2.1 Setup of the Investigation

On May 28, 2021, the Japan Transport Safety Board (JTSB) appointed an investigator-in-charge and two additional investigators to conduct an investigation into the accident.

1.2.2 Collection of Evidence

Collection of questionnaires: May 28, June 7, 14, and 24, July 24, August 15, September 30, October 1 and 4, and December 6, 2021; February 2, 3, 7, and 24, April 15, May 19, June 22, October 11 and 24, November 8, 10, and 25, and December 1, 2022; January 13, 16, 27, 30, and 31, March 23, and July 25, 2023

Interviews: May 29, 2021; May 10, October 31, and December 7, 2022; January 10 and February 1, 2023

On-site investigation and interviews: May 30, 2021

Interviews and collection of questionnaires: November 15 and December 5, 2022

On-site investigation: November 1, 2023

1.2.3 Tests and Research by Other Institutes

In investigating this accident, the JTSB commissioned the National Maritime Research Institute, a division of the National Institute of Maritime, Port and Aviation Technology, to conduct specialized analysis. These included evaluating the collision risk factors between Byakko and ULSAN PIONEER, assessing Byakko's stability characteristics, and examining the specific circumstances that resulted in Byakko's capsizing and subsequent foundering.

1.2.4 Interim Report

On May 26, 2022, the JTSB submitted an interim report to the Minister of Land, Infrastructure, Transport and Tourism, based on the findings available at that time, and released it to the public.

1.2.5 Opinions of Parties Relevant to the Cause

Opinions on the draft report were invited from parties relevant to the cause of the accident.

1.2.6 Comments from the Flag State

Comments on the draft report were invited from the flag State of ULSAN PIONEER.

2 FACTUAL INFORMATION

2.1 Information on the Kurushima Strait and Surrounding Waters

Located in the central part of the Seto Inland Sea, the Kurushima Strait connects Hiuchi Nada and Aki Nada. It is a critical maritime traffic route, traversed daily by numerous vessels, including passenger ships, cargo ships, ferries, and fishing boats. The strait is divided into four narrow channels - Kurushima-no-Seto, Nishi Suido, Naka Suido, and Higashi Suido - by islands such as O Shima, Uma Shima, and Nakato Shima. Each channel has a limited navigable width, is winding, and has poor visibility. The area is also subject to strong tidal currents, with complex flow patterns and speeds that can reach up to 10 knots (kn), making it one of the most difficult navigation routes in Japan. (see Figure 1)

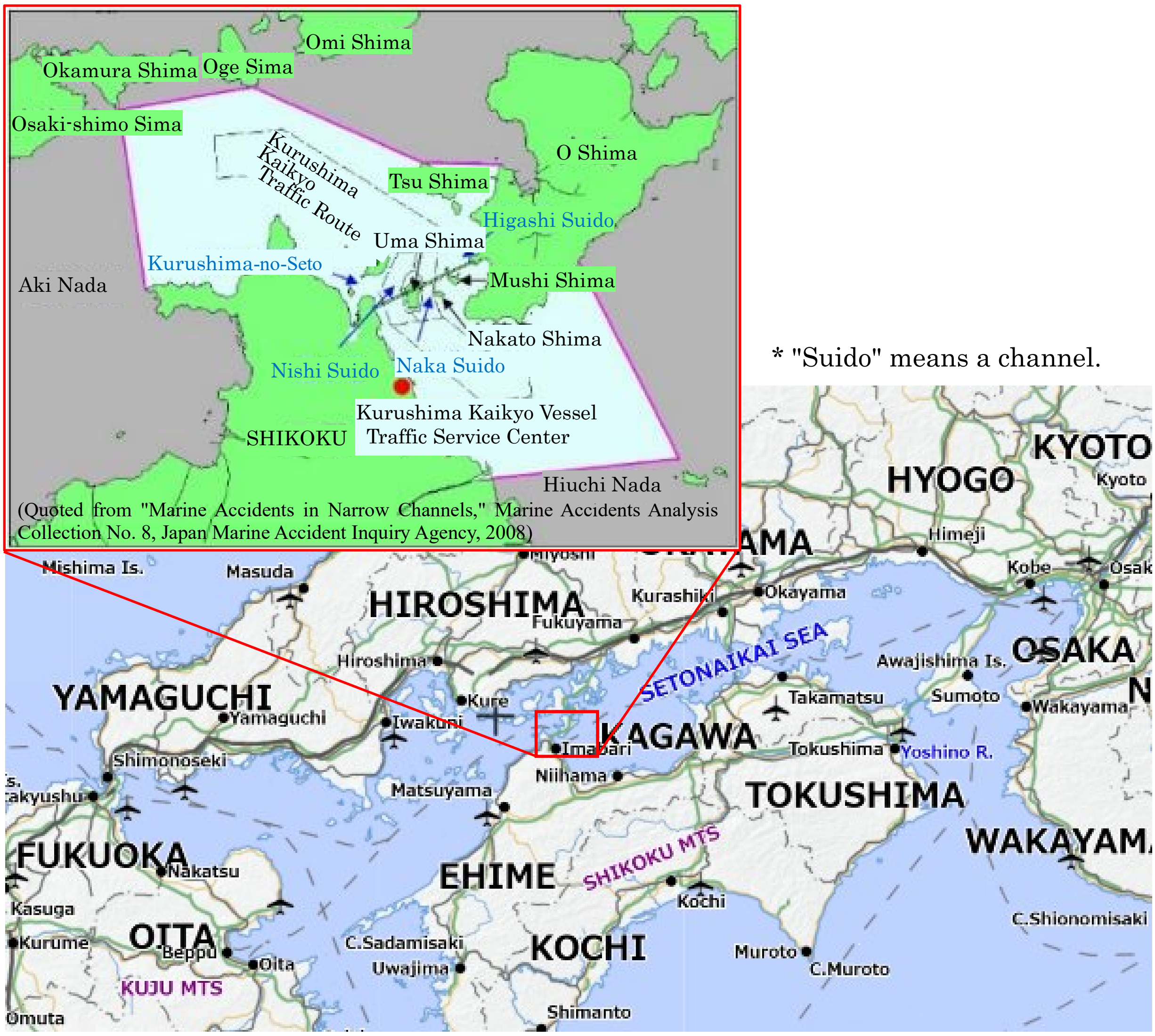


Figure 1 Seto Inland Sea and the Kurushima Strait (using a 1:2,000,000 light-colored map from the Geospatial Information Authority of Japan)

2.1.1 Sea Areas Applied by the Maritime Traffic Safety Act and the Kurushima Kaikyo Traffic Route

The Seto Inland Sea falls under the jurisdiction of the Maritime Traffic Safety Act (Act No.115 of 1972), which is intended to ensure safe navigation in areas with heavy maritime traffic.

In the Kurushima Strait, the "Kurushima Kaikyo Traffic Route" has been established in accordance with Article 20 of the Maritime Traffic Safety Act. Vessels navigating in this area must follow the Navigation Rules stipulated by the Act. In particular, the Naka Suido ("Suido" means a channel) and the Nishi Suido within the Kurushima Strait adopt a globally unique navigation system known as "eastbound with the tide, westbound against it" (see (1) below). Under this system, the permitted direction of vessel traffic changes approximately four times daily, depending on the tidal current's direction.

(1) Navigation of Kurushima Kaikyo Traffic Route

Article 20, Paragraph (1) of the Maritime Traffic Safety Act prescribes a specific navigational method for Kurushima Kaikyo Traffic Route. In case of fair current (i.e., vessels sailing along the tidal current), vessels are required to navigate through the Naka Suido, and in case of head current (i.e., vessels sailing against the tidal current), vessels must navigate the Nishi Suido. For example, when the tidal current in Kurushima Kaikyo Traffic Route flows from north to south (from the west entrance to the east entrance), westbound vessels should navigate the Nishi Suido, whereas eastbound vessels should navigate the Naka Suido. (At the time of the accident, the tidal current in the Kurushima Strait was flowing southward.)

Furthermore, when navigating the Naka Suido, vessels are required to navigate as close as safely possible to O Shima and Oge Shima. When using the Nishi Suido, vessels should navigate close to the Shikoku coast.

(See Figure 2)

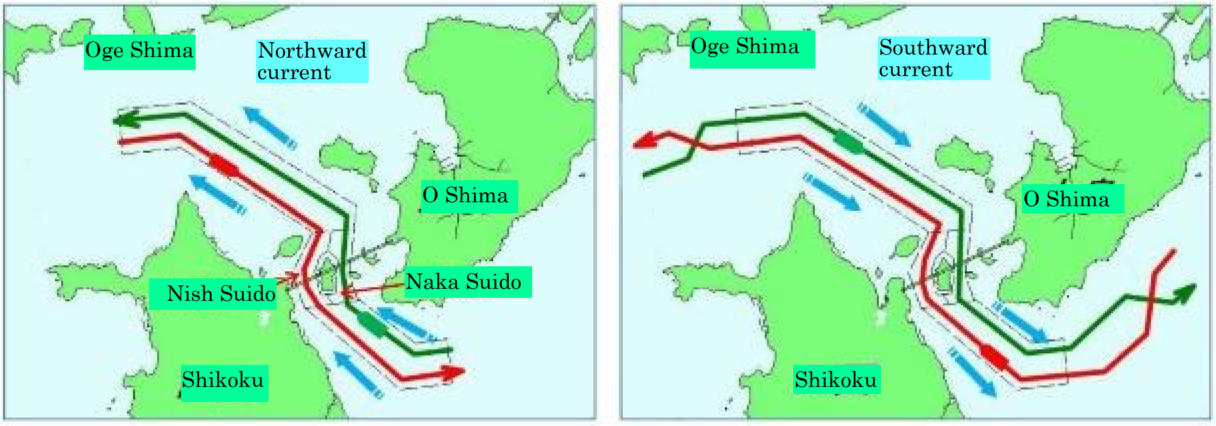


Figure 2 Overview of the Kurushima Kaikyo Traffic Route (quoted from Japan Transport Safety Board Digest, No.14)

(2) Obligation to Report

Article 20, Paragraph (4) of the Maritime Traffic Safety Act, along with Article 9, Paragraphs (3) and (4) of its Enforcement Regulations (Ministry of Transport Ordinance No.9 of 1973), stipulates that master of a vessel intending to navigate the route within the hour preceding or during a tidal current direction change must promptly report the vessel's name and other relevant details to the Commandant of the Japan Coast Guard (hereafter referred to as "JCG"). This report must be made after the vessel crosses the designated position reporting line and is submitted to the Kurushima Kaikyo Vessel Traffic Service Center, the 6th Regional Coast Guard Headquarters (hereafter referred to as "Kurushima MARTIS"). (See Figure 3)

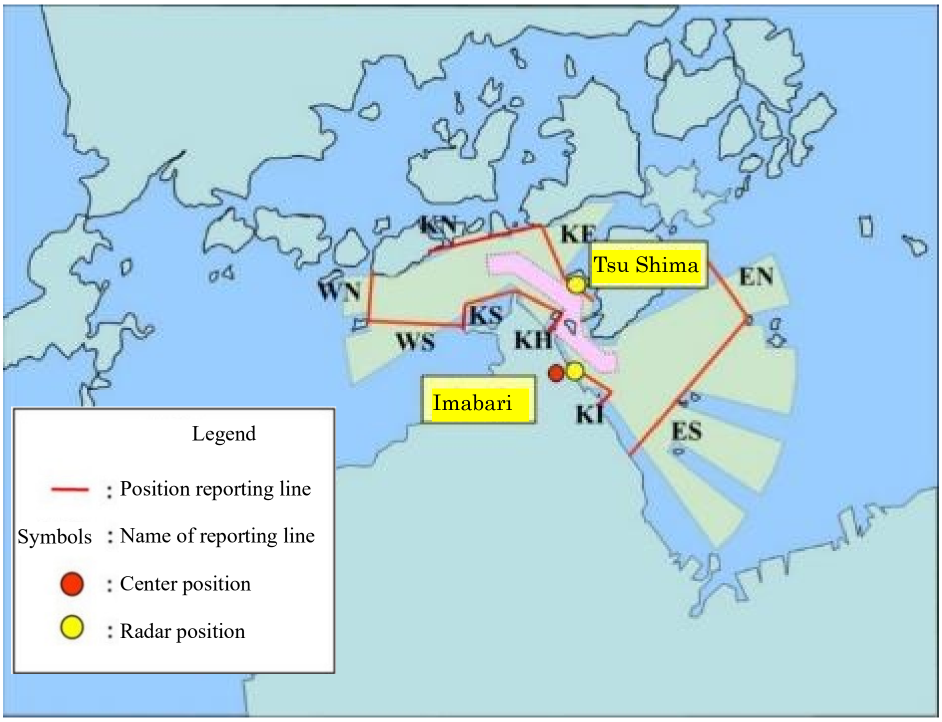


Figure 3 Position reporting line (quoted from Kurushima Kaikyo Vessel Traffic Service Center User Guide)

(3) Route Navigation Obligation

Under Article 3 of the Enforcement Regulations of the Maritime Traffic Safety Act, vessels measuring over 50 meters in length are required to follow the entire length of the Kurushima Kaikyo Traffic Route.

(4) Safety Guidance from the 6th Regional Coast Guard Headquarters

The 6th Regional Coast Guard Headquarters (hereafter referred to as the "6th Guard") provides navigation safety guidance to promote the safe passage of vessels in the Kurushima Kaikyo Traffic Route and surrounding sea areas. The Navigation Safety Guidance Collection (Revised 34th Edition, January 2018), which closely mirrors the content of the Sailing Directions for Seto Naikai (issued by the JCG in March 2018; hereafter referred to as the Sailing Directions for Seto Naikai), was published by the Navigation Safety Division of the Traffic Department, JCG. It outlines the following navigation safety recommendations issued by the 6th Guard for vessels operating in and around the Kurushima Kaikyo Traffic Route.

The 6th Regional Coast Guard Headquarters provides the following navigation safety guidance.

1. to 5. (Omitted)

6. Points to keep in mind when navigating the Kurushima Strait. (see Figures 7 and 8)

(1) Voyage planning should take the following into consideration:

(a) Whenever possible, schedule passage through the route during periods of minimal tidal current change.

(b) As much as possible, avoid navigating through the channels when strong tidal currents are expected.

(2) When entering the route during a southward current, vessels should follow the "starboard-to-starboard" rule within the route. To safely alter course according to the current direction, ensure the maneuver is made in a broad area of sea area outside the route entrance.

When departing from the route, be mindful of the surrounding conditions and operate the vessel with the utmost caution to maintain safety.

(3) to (5) (Omitted)

7. (Omitted)

8. Maintaining contact with the Kurushima Kaikyo Vessel Traffic Service Center

(1) Provision of information

Vessels equipped with VHF radiotelephones (Channel 16, 156.8 MHz) must maintain communication with the Kurushima Kaikyo Vessel Traffic Service Center while navigating within the route, major approach routes, and surrounding sea areas, as the center may provide important navigation safety information.

The Kurushima Kaikyo Vessel Traffic Service Center may initiate contact on Channel 13 if Channel 16 is congested, because vessels equipped with Channel 13 should monitor it in addition to Channel 16.

(2) (Omitted)

9. (Omitted)

10. Navigation of foreign vessels

Foreign vessels navigating the Seto Inland Sea must pay particular attention to and comply with the following:

(1) Fundamental practices, including maintaining a proper lookout, verifying the vessel's position, and monitoring VHF channels

(2) Navigational considerations related to the typical weather and sea conditions in the Seto Inland Sea

(3) The designated navigation method for the Kurushima Kaikyo Traffic Route ("Eastbound with the tide, westbound against it")

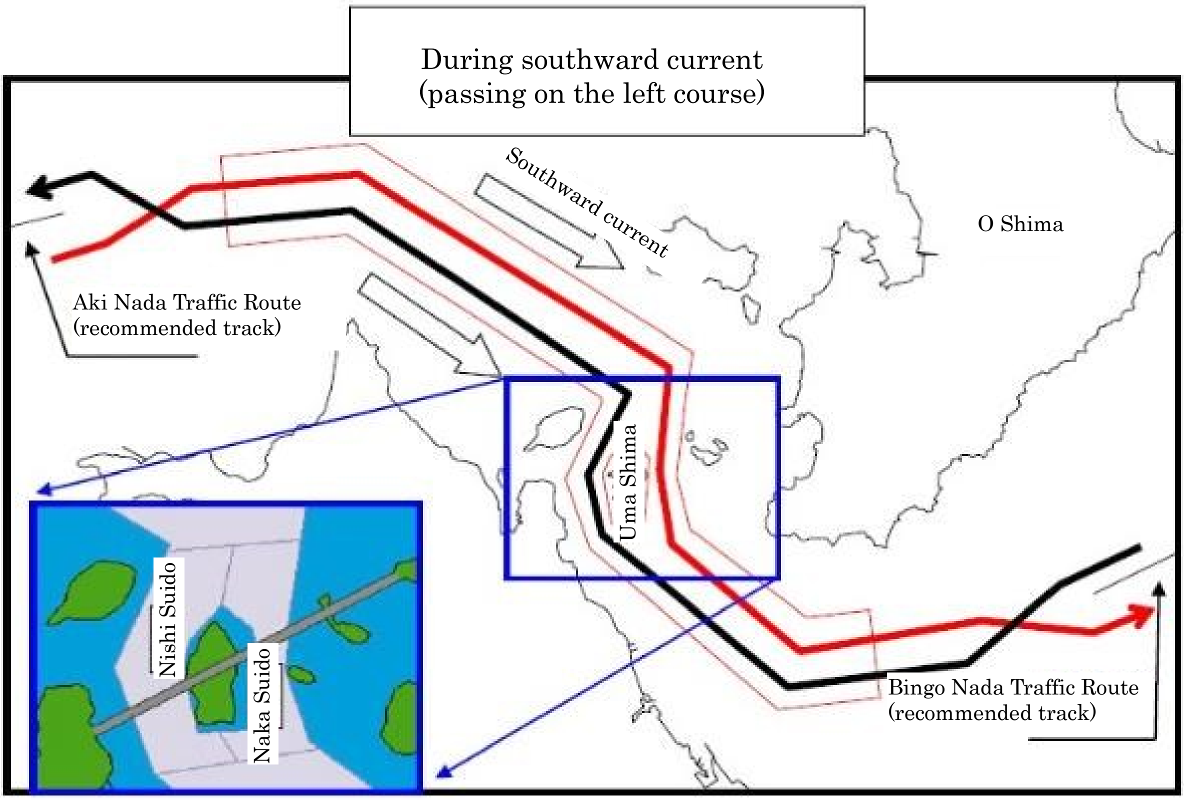
(4) Presence and operation of "KOMASE" stow net fishing boats in the Bisan Seto area

(5) Presence and operation of "SAWARA" drift net fishing boats in the sea areas surrounding the route

(In the Navigation Safety Guidance Collection (Revised 34th Edition, January 2018), this has been updated to read, "*(5) Presence and operation of "SAWARA" drift net fishing boats in the sea route and surrounding sea areas* ".)

Figure 7 (Omitted)

Figure 8



2.1.2 Sea Area Surrounding the Kurushima Kaikyo Traffic Route

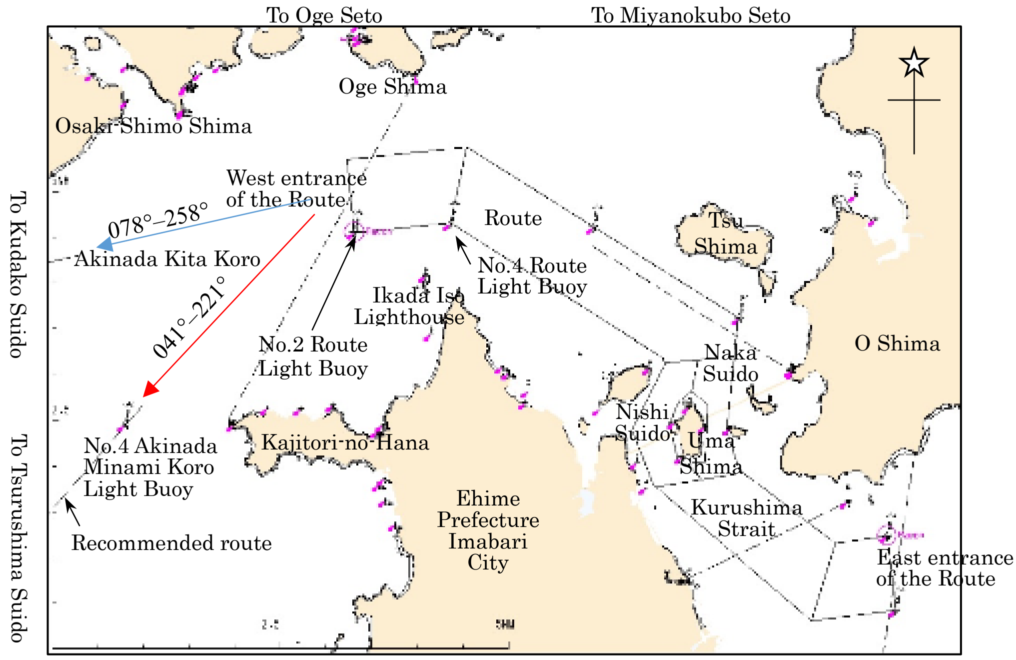
According to the Sailing Directions for Seto Naikai and Nautical Chart W141 (Aki Nada and Vicinity), the following information applies.

(1) The Sailing Directions for Seto Naikai provides the following guidance regarding the area around the entrance and exit of the East–West Route during a southward tidal current:

During a southerly current, vessels entering and exiting the East–West Route may cross paths near the entrance and exit points. And furthermore, close attention must be paid to the movements of other vessels. In particular, it is required enormously special caution near the west entrance due to vessels navigating into and out of Miyanokubo Seto, Oge Seto, and surrounding sea areas.

(2) The accident occurred west of the west entrance of the Kurushima Kaikyo Traffic Route. Between the west entrance of the route and Tsurushima Suido lies the Akinada Minami Koro (recommended route*1) with a course of 221° (true bearing, hereinafter the same). Along this route, four light buoys, numbered from No.1 Route Light Buoy to No.4 Route Light Buoy, mark the centerline of the route. The light buoy closest to the west entrance of the Kurushima Strait No.4 Route is Light Buoy. Additionally, between the west entrance of the Kurushima Kaikyo Traffic Route and the Kudako Suido, the Akinada Kita Koro (recommended route) follows a course of 258°, with a light buoy located at the midpoint. (see Figure 4)

*1 "Recommended route" does not refer to a route mandated by law or designated by the International Maritime Organization under the International Convention for the Safety of Life at Sea (SOLAS). Rather, it indicates a commonly used standard route that has been established through long-standing navigational practice.



* In the figure, areas labeled simply as "Route" indicate the Kurushima Kaikyo Traffic Route.

* No.4 Akinada Minami Koro Light Buoy was removed on July 1, 2024, following the designation of a new route. (see Section 5.2.3)

Figure 4 Situation in the waters near the Kurushima Strait (at the time of the accident)

2.2 Operation of Byakko, ULSAN PIONEER, and Surrounding Vessels

(1) Byakko

Byakko (hereinafter referred to as "Vessel A") is a roll-on/roll-off cargo ship*2 owned by the Japan Railway Construction, Transport and Technology Agency and Hokusei Kaiun Co., Ltd. (hereinafter referred to as "Company A_1") and operated by Prince Kaiun Co., Ltd. (hereinafter referred to as "Company A_2"). It was engaged in the transportation of vehicles between Yokosuka Port (Oppama area) in Kanagawa Prefecture, Kobe Ward in Hanshin Port, and Kanda Port in Fukuoka Prefecture. (see Photo 1)

Photo 1 Vessel A (before the accident)

(2) ULSAN PIONEER

At the time of the accident, ULSAN PIONEER (hereinafter referred to as "Vessel B"), a chemical tanker owned by HIDHC No.2 S.A. (Republic of the Marshall Islands), managed by

*2 "Roll-on/roll-off cargo ship" means a vessel that is designed to allow trailers and other vehicles to be driven onto and off the ship.

PTS CO., LTD. (Republic of Korea) (hereinafter referred to as "Company B"), operated by HEUNG-A SHIPPING CO., LTD. (Republic of Korea), was carrying 2,996 tons of acetic acid and was sailing from Nanjing Port, People's Republic of China to Osaka Ward, Hanshin Port. (See Photo 2)

Photo 2 Vessel B (before the accident)

(3) Surrounding vessels

At the time of the accident, a cargo ship (hereinafter referred to as "Vessel D"), en route from Kawasaki Port to Tokuyama-Kudamatsu Port, was sailing behind Vessel A, and a ferry (hereinafter referred to as "Vessel C"), navigating from Shin-Moji Port to Kobe Port, was sailing behind Vessel B.

2.3 Events Leading to the Accident

2.3.1 Navigation Tracks based on Automatic Identification System Records

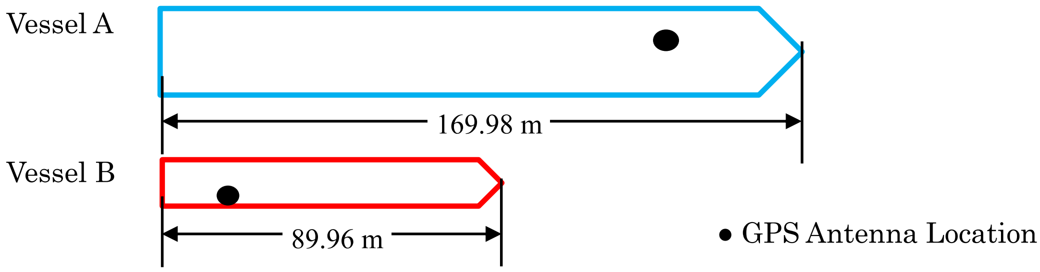
According to Automatic Identification System (AIS)*3 data obtained from a private data provider (hereinafter referred to as "AIS records"), the navigation tracks of Vessel A, Vessel B, Vessel D (sailing behind Vessel A), and Vessel C (sailing behind Vessel B) from around 23:30 on May 27, 2021, to around 00:15 on May 28, are shown in Appendix Table 1. (For Vessel C, AIS data is available from around 23:48 to around 23:54 on May 27, and for Vessel D, from around 23:37 to around 23:54 on the same date.)

The vessel positions shown in Appendix Table 1 represent the locations of the GPS antennas installed on each respective vessel. The locations of the GPS antennas on Vessel A and Vessel B were as follows.

	Distance from Bow	Distance from Stern	Distance from Port Side	Distance from Starboard Side
Vessel A	Approx. 37.2 m	Approx. 132.7 m	Approx. 5.6 m	Approx. 20.4 m
Vessel B	Approx. 72.1 m	Approx. 17.8 m	Approx. 11.9 m	Approx. 2.5 m

* Unit: "m" means "meter".

*3 "Automatic Identification System (AIS)" is a device that automatically transmits and receives information such as a vessel's identification code, type, name, position, course, speed, destination, and navigational status. This data is exchanged between vessels and shore-based navigational aids.



AIS records for Vessel A were no longer received after 00:10:08 on May 28.
(see Appendix Table 1: AIS Records for Each Vessel (excerpts))

The navigation tracks of Vessels A and B are shown in Figure 5.

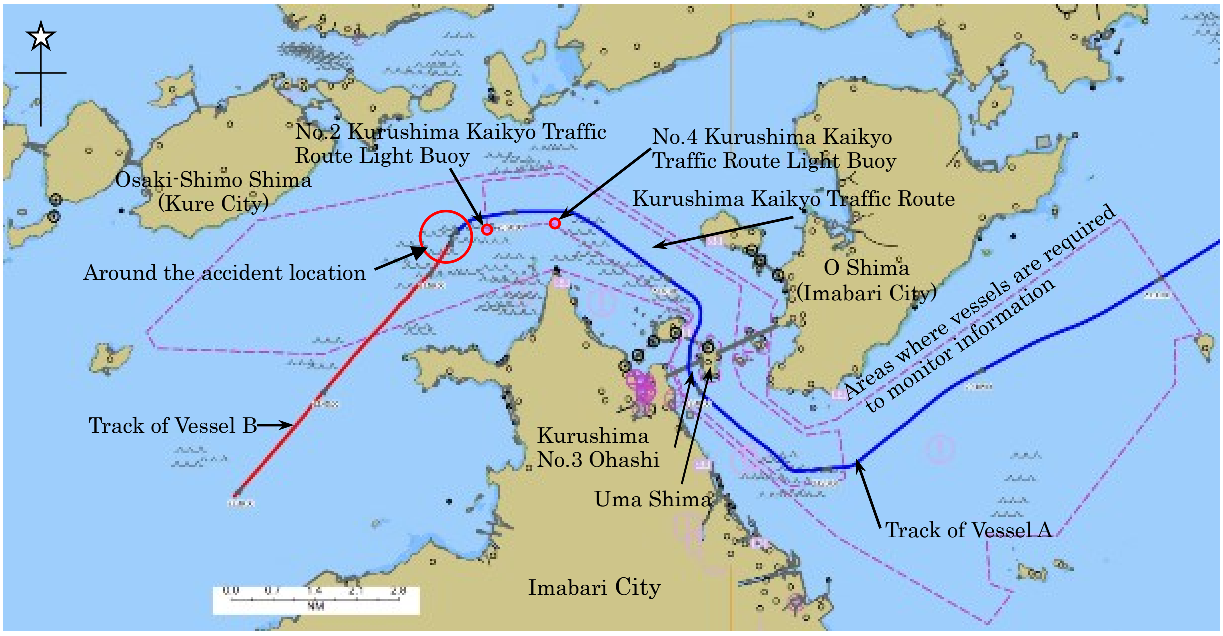


Figure 5 Navigation tracks of Vessel A and ULSAN PIONEER Vessel B based on AIS records

2.3.2 Information from the Voyage Data Recorder of Vessel B

The Voyage Data Recorder (VDR)*4 records from Vessel B included video footage from the two radars (No.1 and No.2) and the Electronic Chart Display and Information System (ECDIS)*5 installed on the navigation bridge (hereinafter referred to as "the bridge"), as well as audio recordings of conversations in the bridge. And the radar images (excerpts) are shown in Figures 7 to 14, ECDIS images (excerpts) are provided in Appendix Figure 1, radar data for Vessel A and Vessel D are summarized in Appendix Table 2, and audio excerpts are presented in Appendix Table 3. (See Figures 7 to 14, Appendix Figure 1: ECDIS image from Vessel B, Appendix Table 2: Information on each Vessel from Radar Images of Vessel B, Appendix Table 3: Audio Recordings of Vessel B (excerpts))

2.3.3 VHF Communication Records

*4 "Voyage Data Recorder (VDR)" is a device that records navigational data such as a vessel's position, course, speed, radar and ECDIS information, VHF radiotelephone communications, and audio from the bridge.

*5 "Electronic Chart Display and Information System (ECDIS)" refers to a device that can display a ship's own position on an official electronic chart (Electronic Navigational Chart or Raster Navigational Chart) that meets the standards of the International Hydrographic Organization (IHO), as well as displaying radar, scheduled passages and other information in combination, and also has the function of transmitting warnings when approaching shallows and other hazards.

According to the VHF communication records from Kurushima MARTIS, the primary communications between Kurushima MARTIS and Vessel A and Vessel B from 23:42 on May 27 to 01:33 on May 28 are presented in Appendix Table 4.

Channel 16 (CH 16) was used for calling and replying, whereas other channels were used for direct communication between stations.

(See Appendix Table 4: VHF Communication Records by Kurushima MARTIS (excerpts))

2.3.4 Events Leading to the Accident

(1) Operation of Vessel A

i) According to the report submitted by Company A_1 to the Kanto District Transport Bureau under Article 19 of the Seafarers' Act (Act No.100 of 1947) and the crew list for Vessel A submitted by Company A_1, Vessel A, manned with the master (hereinafter referred to as Master A) and 11 other crew members - all of Japanese nationality - on board, departed Hanshin Port (Kobe Ward) for Kanda Port at around 16:40 on May 27.

ii) According to the statements of the officer on duty of Vessel A (Second Navigation Officer, hereinafter referred to as "N. Officer A_1") and the ordinary seaman on duty (hereinafter referred to as "Ordinary Seaman A_1"), N. Officer A_1's questionnaire response, AIS records, VDR data, and VHF communication logs, Vessel A's operations leading up to the accident were as follows.

At around 23:19, Vessel A entered the Kurushima Kaikyo Traffic Route from its eastern entrance, heading toward Aki Nada. From around 23:30 to around 23:36, Vessel A navigated westward through the Nishi Suido Channel, as the current was flowing southward and westbound vessels typically used that channel.

Master A left the bridge while Vessel A passing the Kurushima No.3 Ohashi (bridge) and turning starboard after passing Nishi Suido Channel, by the time when it passed the No.4 Kurushima Kaikyo Traffic Route Light Buoy.

Just before reaching No.4 Kurushima Kaikyo Traffic Route Light Buoy, Vessel A adjusted at its course to approximately 270° to follow the course change of Vessel D, which was sailing ahead on its port side. At around 23:48, shortly after passing the Light Buoy, Vessel A overtook Vessel D on its starboard side and continued on the Traffic Route with at a course of approximately 259°.

N. Officer A_1 confirmed the presence of Vessel B and Vessel C on the radar at the time Vessel A overtook Vessel D.

At around 23:51:27, Vessel A exited the west entrance of the Kurushima Kaikyo Traffic Route, maintaining at a course of 260.7° and a speed (speed over the ground, hereinafter the same) of 18.2 kn.

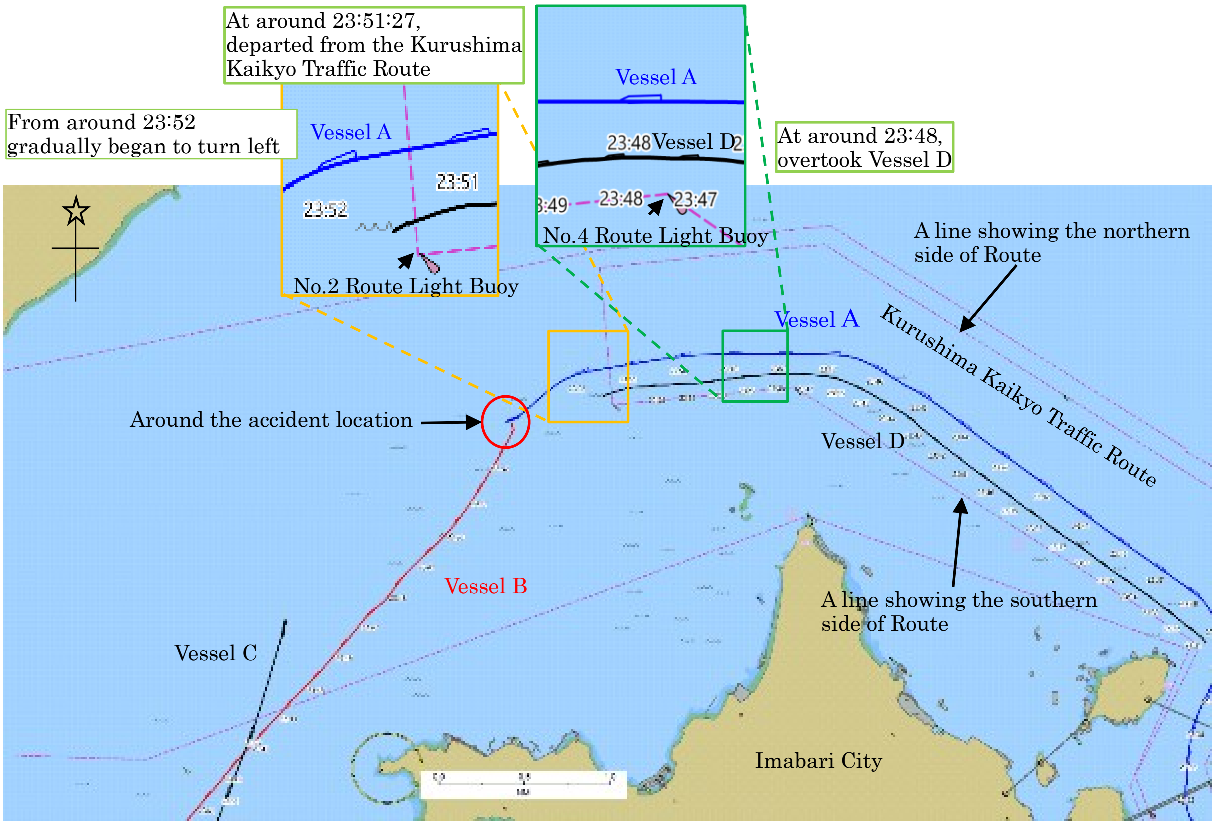
When Vessel A exited the west entrance of the Kurushima Kaikyo Traffic Route, N. Officer A_1 questioned the intended course of Vessel B, as it appeared to be navigating unusually. Typically, when the tidal current in the Kurushima Strait flows southward, vessels entering from the west entrance head north toward Osaki-Shimo Shima and approach the route from its northern side. Despite this, N. Officer A_1 did not perceive any immediate risk of collision with Vessel B. However, N. Officer A_1 did note that if Vessel A continued on its current course, it would likely pass close to Vessel C, which was approaching from behind Vessel B.

Since only two vessels - Vessel B and Vessel C - were present in the Akinada Minami

Koro, N. Officer A_1 intended to pass between them and proceed into the Koro. At around the time Vessel A exited the Kurushima Kaikyo Traffic Route, trial maneuvering*[6] was conducted using the radar. The results indicated that even if Vessel A altered course to port setting at 230°, it would still be able to pass Vessel B with a Closest Point of Approach (CPA)*[7] of approximately 0.2 (miles) M. Based on this assessment, Ordinary Seaman A_1 was instructed to turn port with the command, "Port easy" (Rudder angle at approximately 7° to port).

Vessel A began to turn port gradually at around 23:52.

(See Figure 6)



*In the figure, the term "Route" refers specifically to the Kurushima Kaikyo Traffic Route.

Figure 6 Navigation Track of Each Vessel based on AIS Records

During the turning, the front window frame of the bridge obstructed the view from the steering stand where Ordinary Seaman A_1 was stationed, and Vessel B appeared unexpectedly small, making it difficult for him to see it clearly. However, after setting at the course to 230° in response to N. Officer A_1's instructions - "Midship" (Center the rudder) and "Steady" (Maintain the current course) - Ordinary Seaman A_1 perceived that Vessel B was approaching head-on toward Vessel A.

N. Officer A_1 observed Vessel B when Vessel A was on a course of 230° and recognized a risk of collision. Since Vessel B's heading remained unchanged and the CPA was less than

*6 "Trial maneuvering" refers to a radar-based simulation function used for collision avoidance. Specifically, after setting the vessel's own speed, course, and delay time (i.e., the time between the current moment and when the vessel begins to change course or speed), the radar displays the predicted positions of both the own vessel and surrounding vessels at set intervals.

*7 "Closest Point of Approach (CPA)" refers to the minimum distance that will occur between two vessels. Typically, CPA and related values such as Time to CPA (TCPA) are calculated based on a reference position set either at the vessel's radar antenna or at the steering position.

one cable (0.1 M), he determined that a collision could not be avoided unless Vessel A altered course to starboard. Just as N. Officer A_1 was about to initiate the turning, Vessel B contacted them via VHF, asking, "What's your intention?" However, due to the close proximity of Vessel B, N. Officer A_1 was unable to respond, and then Vessel B replied, "Port to Port, Port to Port."

After replying "OK" to Vessel B, N. Officer A_1 instructed Ordinary Seaman A_1 to "Starboard (15° to starboard side)," and Ordinary Seaman A_1 executed to steer to starboard the helm.

Vessel A began to turn gradually to starboard side at around 23:53:27.

While turning, N. Officer A_1 looked out from the port wing and observed Vessel B colliding with Vessel A near the port midsection.

As Ordinary Seaman A_1 executed the steering to starboard with the helm, he saw Vessel B approaching Vessel A and believed a collision was imminent. Vessel B collided with Vessel A a few seconds later.

(2) Operation of Vessel B

According to statements from the master of Vessel B (hereinafter referred to as "Master B"), the officer on duty (Third Officer, hereinafter referred to as "N. Officer B_1"), and the officer scheduled for the next duty (Second Officer hereinafter referred to as "N. Officer B_2"), as well as the responses to the questionnaires from Master B and N. Officer B_1, the AIS data, the VDR data, and the VHF communication records, the operation of Vessel B prior to the accident was as follows.

Vessel B, manned with Master B (nationals of the Republic of Korea) and 12 other crew members (seven nationals of the Republic of Korea and five nationals of the Republic of the Union of Myanmar), departed from Nanjing Port in the People's Republic of China at around 07:10 (local time) on May 25, bound for Osaka Ward in Hanshin Port.

According to the route plan prepared by N. Officer B_2 prior to departure from Nanjing Port, Vessel B was scheduled to proceed through the Nishi Suido. While transiting the Kanmon Strait, N. Officer B_2 reconfirmed that Vessel B was expected to arrive at the Kurushima Strait at around 00:30 on May 28. As the tidal current in the Kurushima Strait was anticipated to be flowing northward at that time, the decision was made to maintain the original route plan through the Nishi Suido.

At around 23:40 on May 27, 2021, Vessel B, manned by N. Officer B_1 and the able seaman on duty (hereinafter referred to as "Able Seaman B"), was sailing northeast along the Akinada Minami Koro on a course of 041° at a speed of 14.3 kn, heading toward the southern side of the west entrance of the Kurushima Kaikyo Traffic Route.

At around 23:43, after Vessel B passed the WS Line (position reporting line) off the west coast of Kajitori-no-Hana, N. Officer B_1 reported the passage to Kurushima MARTIS. At that time, Kurushima MARTIS informed Vessel B that the current in the Kurushima Strait was flowing southward and instructed Vessel B to keep to the left side and proceed toward the Naka Suido. At around 23:46, Kurushima MARTIS again contacted Vessel B, reiterating the instruction to head toward the Naka Suido. At that time (at around 23:46:11), Vessel B was sailing on a course of 043° at a speed of 14.3 kn. There were no nearby vessels posing a risk due to their relative visible positions. (see Figure 7)

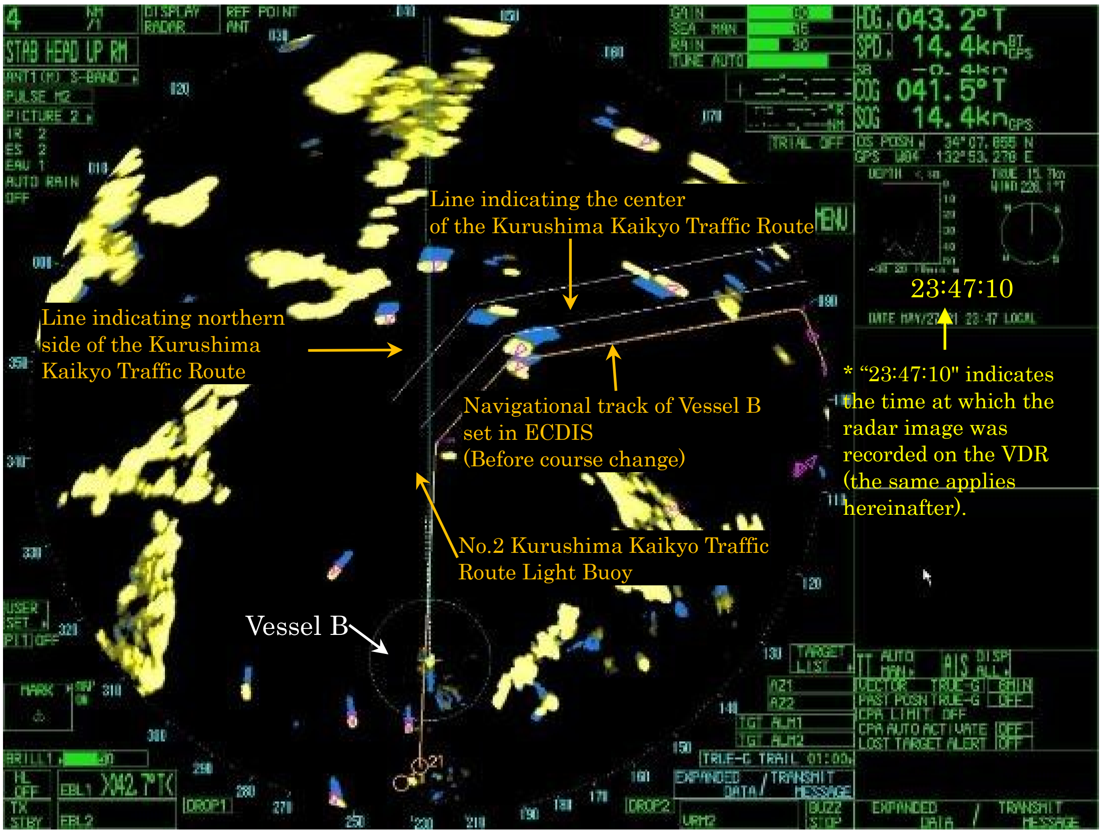


Figure 7 No.1 Radar image of Vessel B (recorded at around 23:47:10)

At around 23:48, N. Officer B_1 instructed Able Seaman B to set at a course of 040°, which was repeated by Able Seaman B. At that time, Master B came to the bridge, and N. Officer B_1 reported receiving a call from Kurushima MARTIS, advising them to head toward Naka Suido. Master B then instructed N. Officer B_1 to change the course in the ECDIS from a route that would have entered the west entrance of Kurushima Kaikyo Traffic Route from the southern side and proceeded toward Nishi Suido to one that would enter from the northern side and proceed toward Naka Suido. N. Officer B_1 began executing the course change at around 23:49.

At around 23:49:25, Master B instructed to set at a course of 035°, which Able Seaman B repeated.

At around 23:49:40, Vessel A was detected on No.1 Radar. Master B judged that there was little risk of collision if both Vessel B and Vessel A maintained their current courses and speeds, and consequently, decided to maintain the current course with the intention of passing aft. side of Vessel A. N. Officer B_1 also believed that Vessel A would cross ahead of Vessel B's fore side, as it was navigating at a higher speed. (see Figure 8)

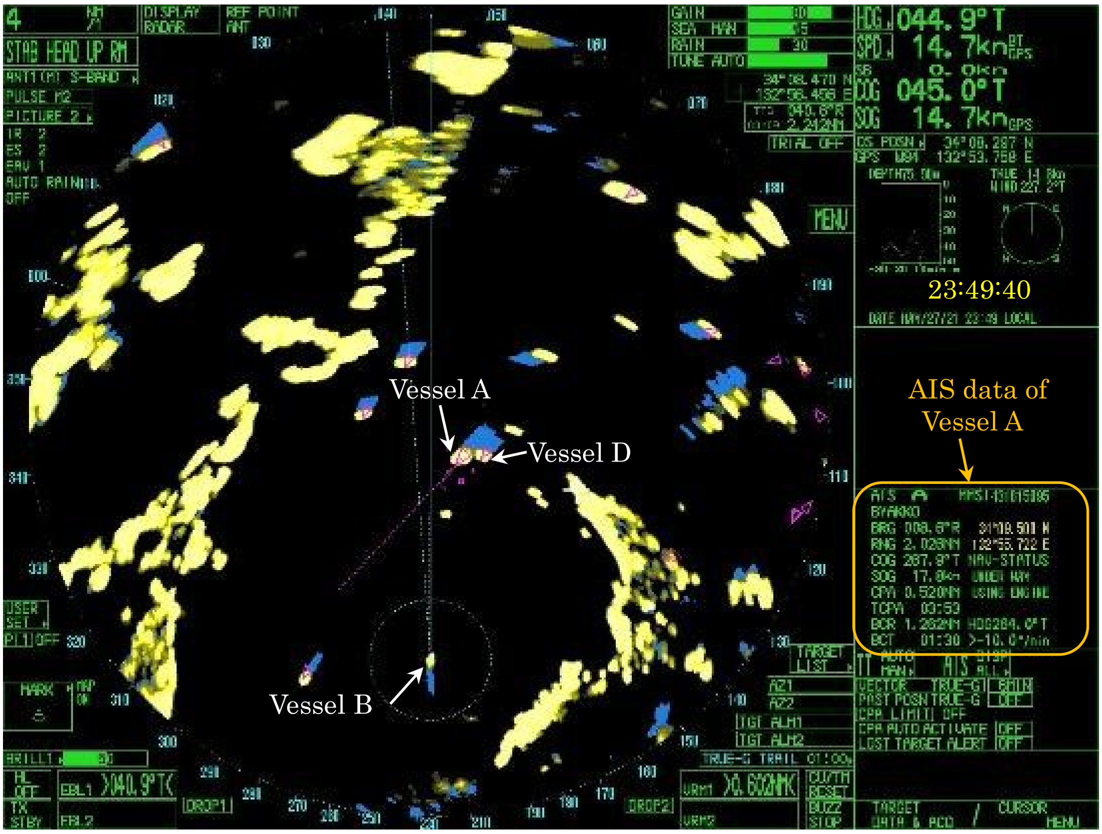


Figure 8　No.1 Radar image of Vessel B (recorded at around 23:49:40)

At around 23:50, Vessel B was navigating toward the northern side of the west entrance of the Kurushima Kaikyo Traffic Route. At around 23:50:38, Master B instructed to set at a course of 030°, which Able Seaman B repeated. (see Figure 9)

At around 23:51:18, Master B detected Vessel A on Radar No.2, followed by the detection of Vessel D at around 23:51:33. At that time (at around 23:51:33), the distance between Vessel B and Vessel A was approximately 1.1 M, with a CPA of approximately 0.3 M. (see Figure 10)

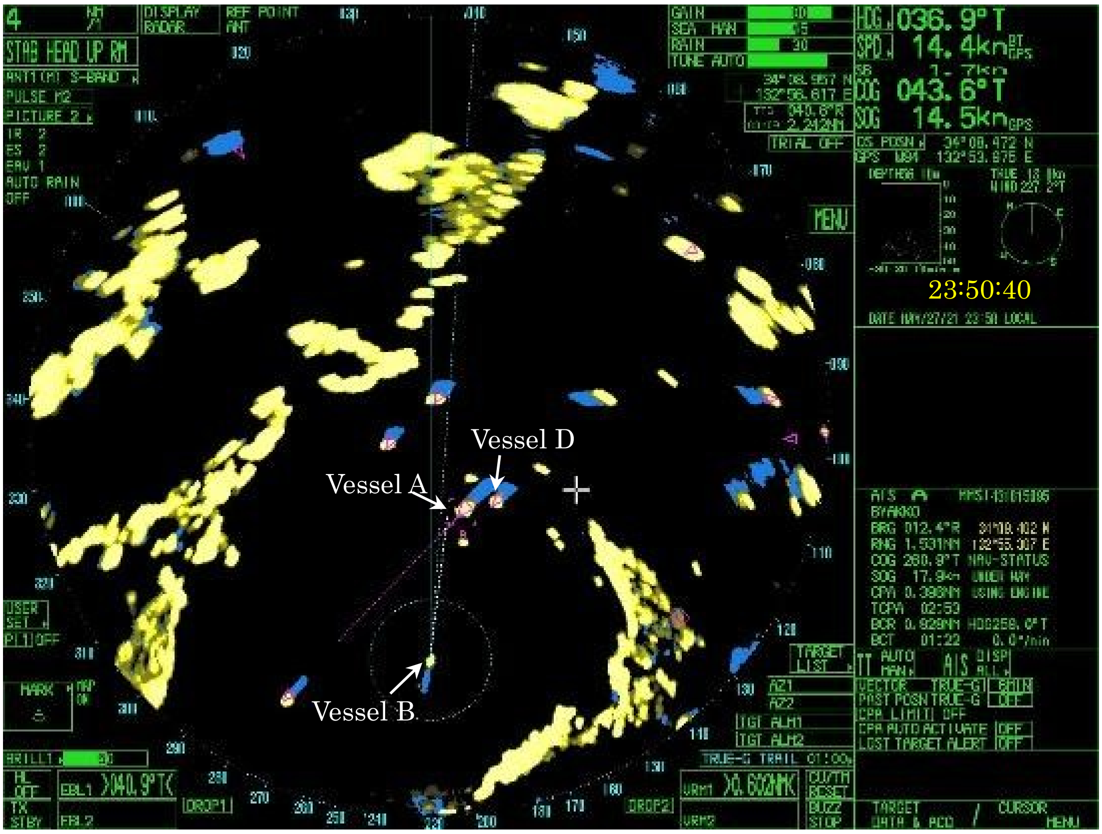


Figure 9　No.1 Radar image of Vessel B (recorded at around 23:50:40)

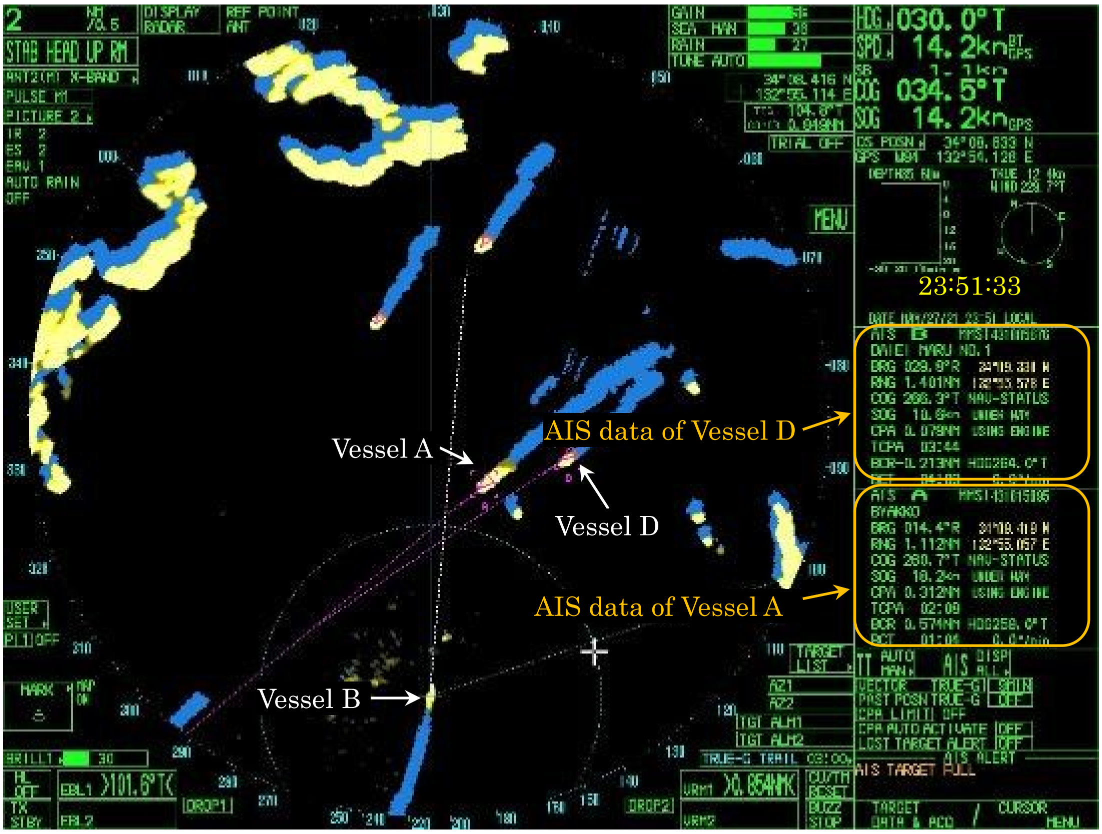


Figure 10　No.2 Radar image of Vessel B (recorded at around 23:51:33)

At around 23:52:33, the range setting of Radar No.2 was changed from 2 to 1.5 M. (see Figure 11)

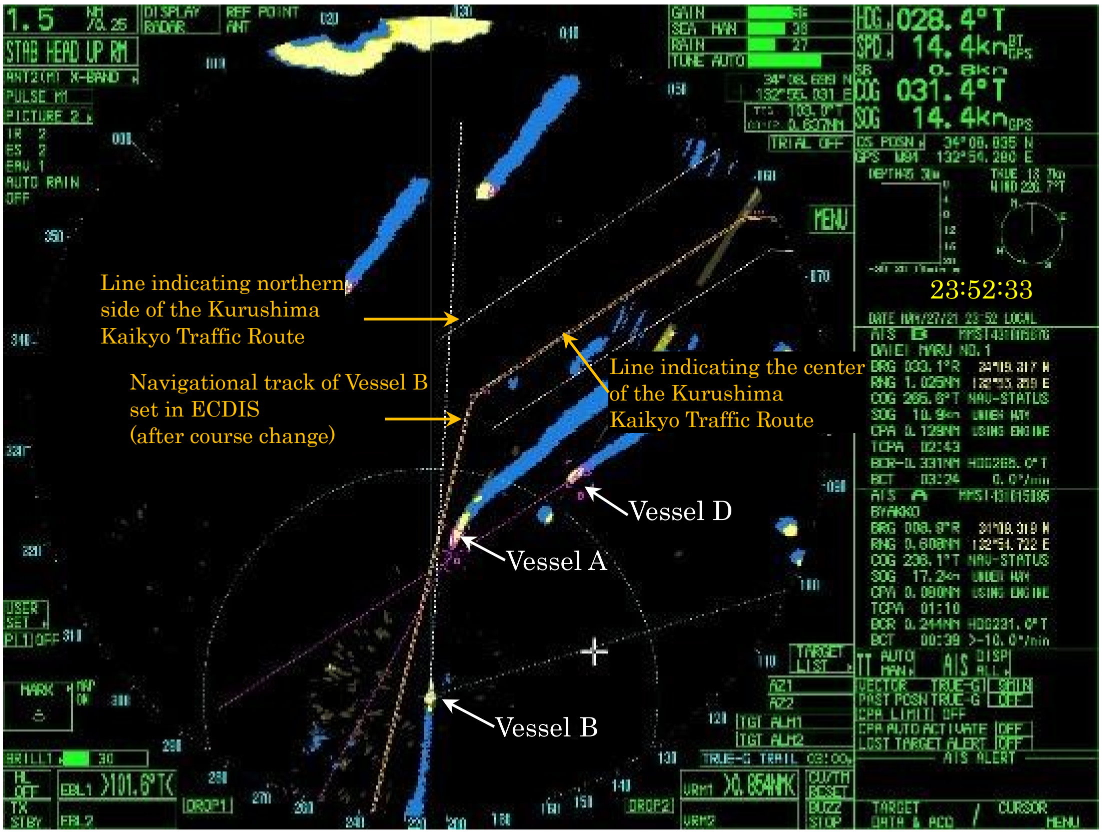


Figure 11　No.2 Radar image of Vessel B (recorded at around 23:52:33)

At around 23:52:42, Master B muttered to himself in Korean, "Why is that vessel heading toward us?" Then, at around 23:52:45, Master B gave an instruction to steer to set at a course of 020°, which Able Seaman B repeated. Shortly thereafter, at around 23:52:49, Master B remarked again in Korean, "Where is that thing heading?" (see Figure 12)

At around 23:52:50, N. Officer B_1 called Vessel A twice via VHF, stating, "Vessel A, Vessel A, this is Vessel B." After the second call, Vessel A responded, "Yes, this is Vessel A." N. Officer B_1 then asked, "What's your intention?" When there was no immediate reply, N. Officer B_1 continued at around 23:53:03 with, "Port to Port, Port to Port," to which Vessel A responded, "OK."

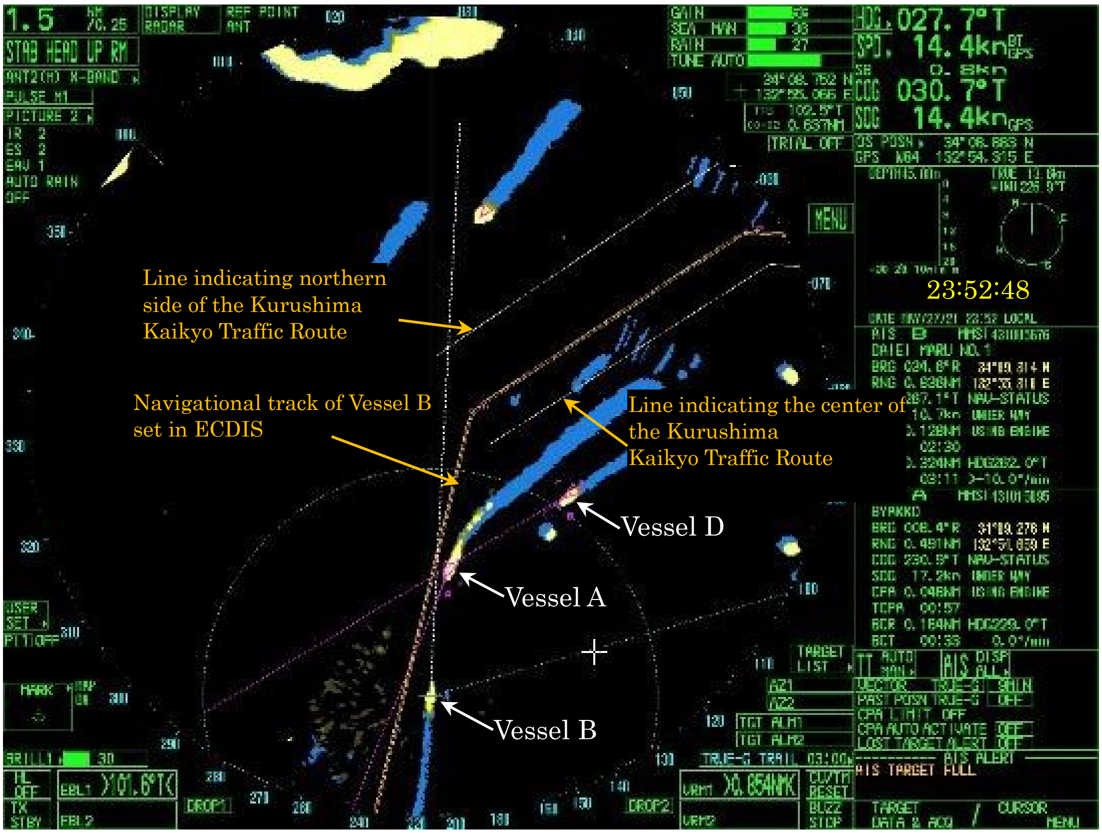


Figure 12 No.2 Radar image of Vessel B (recorded at around 23:52:48)

At around 23:53, Master B felt that a collision with Vessel A was imminent and became panicked. Immediately after N. Officer B_1 instructed Vessel A, "Port to Port, Port to Port" (at around 23:53:07), Master B shouted, "Hard port," which Able Seaman B repeated "Hard port (Steer to the left full the helm)". Thereafter, the phrases of "Port to Port" and "Hard port" were shouted multiple times in the bridge of Vessel B. (see Figure 13)

Shortly after 23:53:16, Master B repeatedly ordered, "Stop engine (Stop main engine)," which N. Officer B_1 echoed several times before responding, "Stop engine, sir."

At around 23:53:27, Vessel B began a sharp turn port. Master B repeatedly called out, "Full astern (Full speed backward)," which N. Officer B_1 echoed "Full astern". Shortly thereafter, Master B shouted, "Hard starboard (Steer to the right full the helm)," and just after, an impact sound was heard. (see Figure 14)

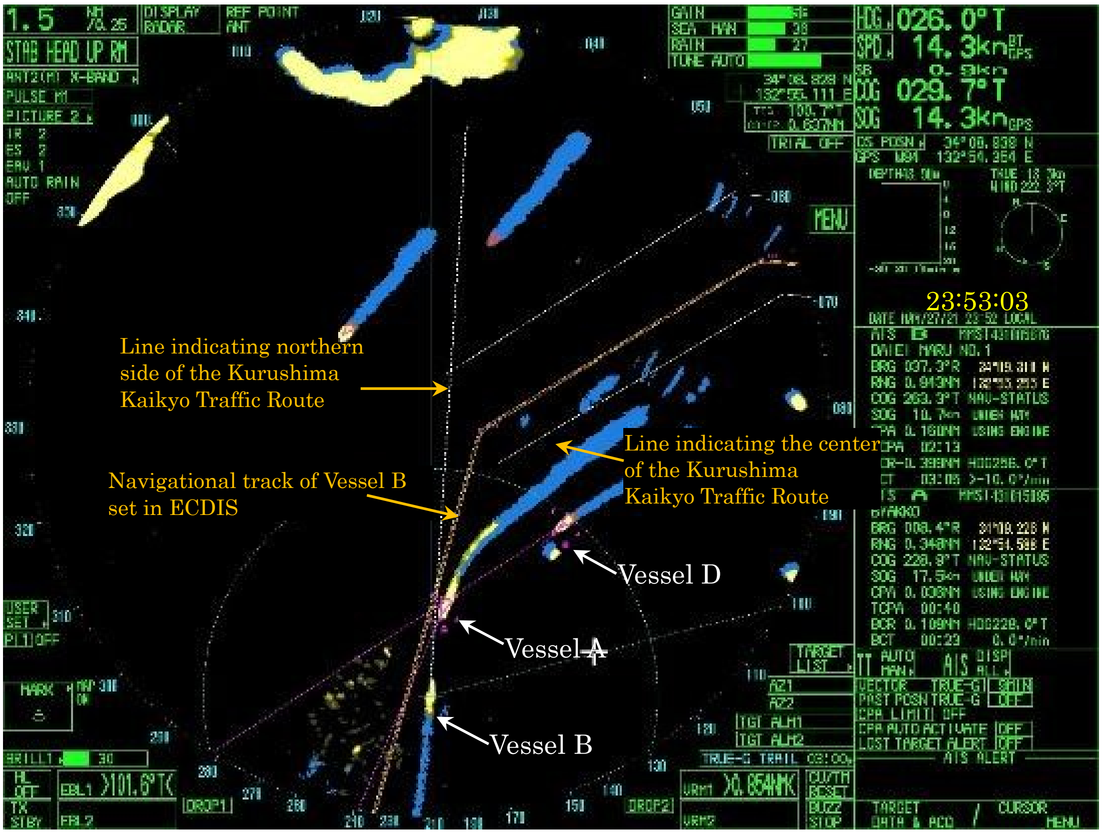


Figure 13　No.2 Radar image of Vessel B (recorded at around 23:53:03)

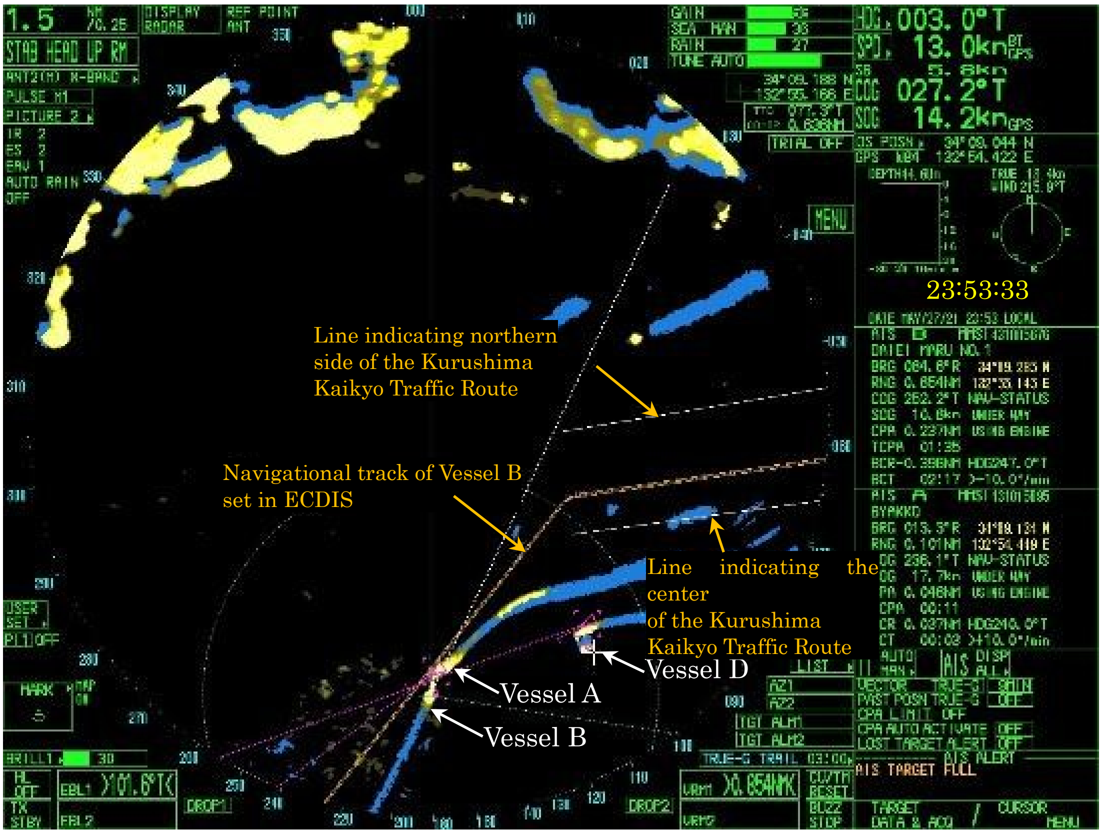


Figure 14　No.2 Radar image of Vessel B (recorded at around 23:53:33)

(3) Date, time, and location of the accident

The accident occurred at around 23:53:38 on May 27, 2021, at a position around 285° 1.4 M from Ikada Iso Lighthouse. (see Figure 15)

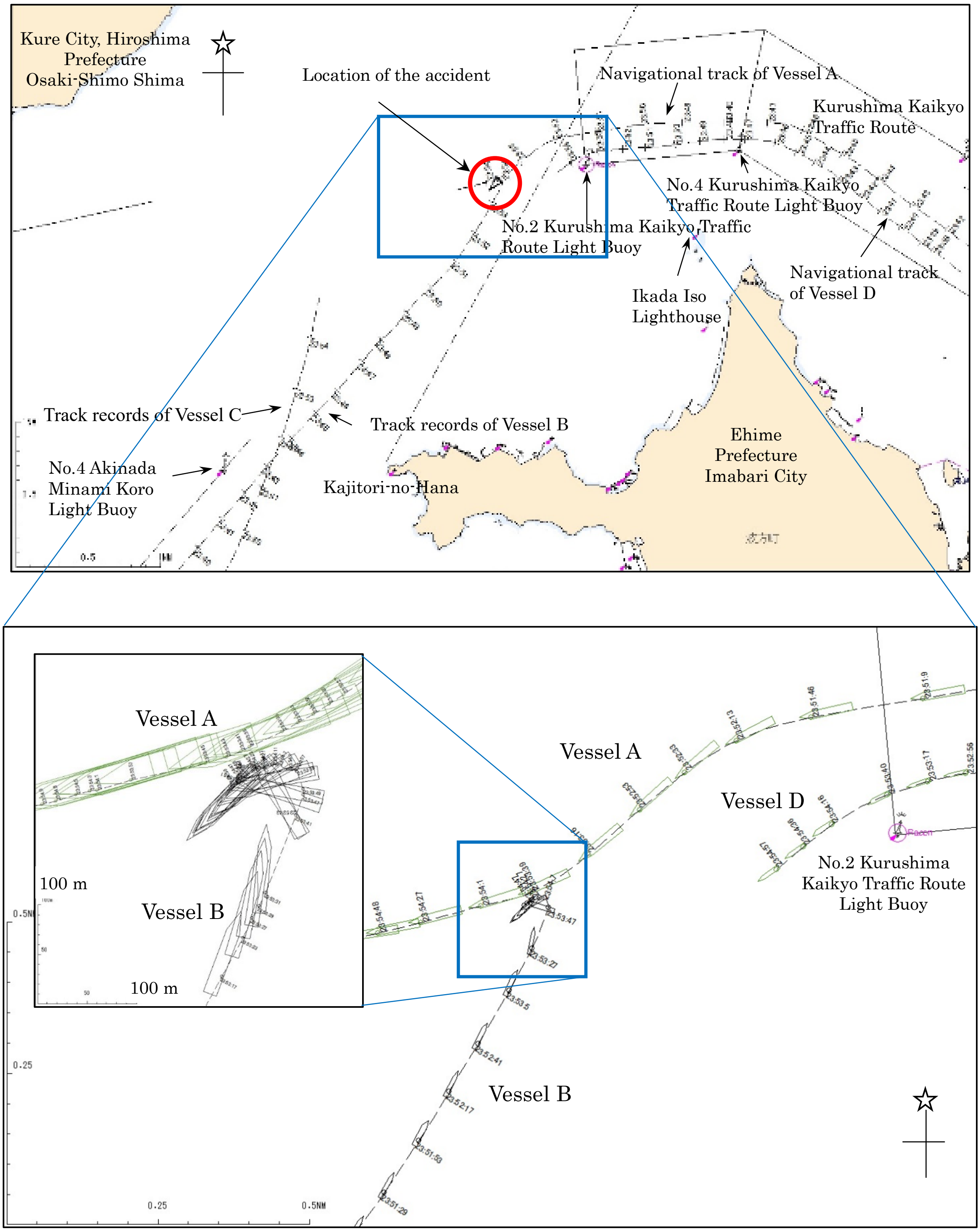


Figure 15 AIS tracks of Each Vessel

2.3.5 Other Information of Crew Member Statements Regarding Vessel Operation

(1) Statements of N. Officer A_1

i) After exiting the Kurushima Kaikyo Traffic Route, N. Officer A_1 and other crew members in the bridge observed only two vessels in the recommended route (Akinada Minami Koro). N. Officer A_1 decided to turn Vessel A to set at a course of 230° to pass between them and proceed toward the recommended route. At that time, N. Officer A_1 estimated that even on a 230° course, the CPA with Vessel B would be approximately two cables (0.2 M). N. Officer A_1 did not closely observe Vessel B's movements, but N. Officer A_1 believed it subsequently turned port.

ii) Around the time we turned to a course of 230° to port, Vessel B appeared to be slowly turning to port as well, though this was difficult to discern. Subsequently, a port-to-port passing agreement was made via VHF with Vessel B, and Vessel A turned to starboard accordingly. N. Officer A_1 assessed that a collision could be avoided if Vessel B also turned to starboard as agreed, so N. Officer A_1 did not take any action to reduce speed.

(2) Statements of N. Officer B_1

Around two minutes before the collision, N. Officer B_1 called Vessel A on VHF Channel 16. Although it appeared that Vessel B would be able to pass behind Vessel A, N. Officer B_1 initiated communication as Vessel A was drawing near. Vessel A responded, "This is Vessel A," so N. Officer B_1 asked, "What's your intention?" Vessel A replied, "Ahh," so N. Officer B_1 instinctively shouted, "Port to Port." This instruction was issued instinctively as the rapidly developing situation left no alternative course of action.

(3) Statements of N. Officer B_2

At around 23:53 on May 27, when N. Officer B_2 arrived at the bridge, N. Officer B_2 heard Master B shouting "Hard port" and "Full astern," and N. Officer B_2 perceived that there was a state of panic in the bridge.

2.4 Progress after the Occurrence of the Accident

(1) Statements of crew members of Vessel A

i) N. Officer A_1

Following the impact to the hull, N. Officer A_1 proceeded to the Master's room located at the rear of the bridge to alert Master A. Under Master A's instructions, N. Officer A_1 contacted Kurushima MARTIS and reported the accident.

After completing the report, a decision was made to abandon ship. They retrieved life jackets and launched the life raft on the starboard side. During this time, they observed that the lower part of Vessel A was submerged in seawater, so they climbed up the tilted side of Vessel A.

There were four of them on the starboard shell plating: N. Officer A_1, Third Navigation Officer (hereinafter referred to as "N. Officer A_3"), Ordinary Seaman A_1, and another Ordinary Seaman (hereinafter referred to as "Ordinary Seaman A_2"). While they were standing on the shell plating, water began to flood in, and they - N. Officer A_1 with Ordinary Seaman A_2, and N. Officer A_3 with Ordinary Seaman A_1 - were swept away, each pair holding on to one another with our arms around each other's shoulders. They swam desperately to avoid being pulled under as Vessel A foundered.

ii) Chief Navigation Officer (hereinafter referred to as "N. Officer A_2")

N. Officer A_2 was taking a rest in his room when he heard a loud bang followed by what sounded like Master A's scream. Believing that Vessel A had run aground, N. Officer A_2 jumped up and rushed to the bridge.

When N. Officer A_2 arrived, Master A and N. Officer A_1 were already there. N. Officer A_2 went out to the port wing with Master A and, based on what he observed, N. Officer A_2 felt that Vessel A had been struck. N. Officer A_2 saw the stern light of Vessel B off Vessel A's aft. side.

The hull was listing gradually, and Master A instructed that corrective action be taken. N. Officer A_2 checked the Ballast tank gauge displayed on the ballast control panel at the rear of the bridge - a panel equipped with gauges for the Ballast tanks and controls for operating ballast pumps and opening or closing ballast-related valves - and confirmed that there was no change. N. Officer A_2 attempted to correct the list by adjusting the water levels in the Heel tanks*[8], but the list appeared to worsen more and more.

At first, N. Officer A_2 thought that securing watertight integrity was more important than preparing life jackets. Master A had always instructed that, in the event of a collision, if the other vessel was on the port side, we should steer to port to stay close to the collided vessel and help stabilize the owned hull. In this accident as well, after the collision, Master A instructed to steer hard to port the helm and instructed N. Officer A_2 to do everything possible to stop Vessel A from listing. N. Officer A_2 thought conducted the ballast water control by the ballast control panel at the aft. side of the bridge (the panel was installed the ballast tanks' gauges and the function of starting and stopping the ballast pump, opening and closing the valves related ballast system, etc.) according to the procedures and the direction of Master A, but the list became progressively worse. There was no change in the Ballast tank gauges, and it appeared that the Ballast tanks were not damaged, however, Vessel A did not return to an even keel yet. N. Officer A_3 also confirmed that the bow was submerged. A loud cracking sound - like a lashing*[9] belt snapping - was heard, and the cargo suddenly shifted to port, which significantly increased the list. Master A then made the decision to abandon ship, announcing loudly that it was time to evacuate, and everyone moved to retrieve their life jackets. N. Officer A_2 believes Vessel A was listing more than 45° at that time.

Both N. Officer A_2 and Master A retrieved our life jackets and returned to the bridge. N. Officer A_2 believes Master A was positioned on the starboard side of the bridge after returning. Although they had discussed escaping from the starboard side, N. Officer A_2 slipped on the port side in front of the ballast control panel at the rear of the bridge and judged it would be impossible to climb up to the starboard side. Consequently, N. Officer A_2 decided to escape from the port side. At that time, three of them - N. Officer A_2, Chief Engineer (hereinafter referred to as "Chief Engineer A"), and Ordinary Seaman (hereinafter referred to as "Ordinary Seaman A_3") - were on the port side. N. Officer A_2 thought that the six recovered crew members, along with Master A, were on the starboard side. When the Hold Fan (the supply and exhaust mechanical ventilation fan for the vehicle loading area) and the handrails on the port side (located on the fourth deck) began to submerge, they double-checked the straps of their life jackets. When the water level reached the stairs

*[8] "Heel tank" refers to seawater tanks installed on both sides of a ship for the purpose of correcting the hull's lateral tilt.

*[9] "Lashing" refers to the securing of cargo (including vehicles, etc.) using chains, wires, ropes, belts, or similar equipment to prevent it from shifting due to sudden vessel motion during navigation.

leading from the bridge to No.4 Deck, and the Hold Fan was approximately half submerged, the three of them entered the water. They swam to safe area bearing the thought to move away from vessel A, taking care to avoid being caught in the suction as Vessel A foundered. When N. Officer A_2 looked back at Vessel A, it was still leaning but not yet fully submerged, and N. Officer A_2 could see the other crew members on the starboard side.

They were later recovered by a JCG patrol boat, while the crew members on the starboard side were recovered by a container ship.

iii) Chief Engineer A

Chief Engineer A was taking a rest in his room when he was awakened by a loud impact. Suspecting a collision, Chief Engineer A went to the bridge and found the situation chaotic. Since alarms for the main engine and the generators had been sounding, Chief Engineer A assumed that First Engineer (hereinafter referred to as "Engineer A_1") and Second Engineer (hereinafter referred to as "Engineer A_2") had gone to the engine room for the purpose of checking alarms and situations. Chief Engineer A discussed the situation of the collision with Master A, who was concerned about the condition of the main engine. Just as Chief Engineer A was about to head to the engine room, Vessel A suddenly began to lean. Chief Engineer A is not entirely certain, but he believes this occurred around 15 minutes after the collision, shortly after 00:00 on May 28.

Chief Engineer A descended to the vehicle deck from the starboard side to head to the engine room, but Vessel A was leaning so severely that he slipped and hit his body against the side of Vessel A. Around that time, Chief Engineer A noticed that seawater had already reached No.2 Deck and realized that it was no longer possible to access the engine room. Chief Engineer A returned to the bridge and attempted to contact the engine room, but when he got back to the accommodation area, he saw that the crew members were already putting on life jackets and preparing to abandon ship.

After receiving a life jacket from Ordinary Seaman A_3, the two of us went up to the bridge and placed a direct call to the engine room. Engineer A_2 answered, and when Chief Engineer A told him, "It's no good - abandon ship, get out," Engineer A_2 responded, " We understand."

It might have been possible to stop Engineer A_1 and Engineer A_2 from heading to the engine room. However, it took some time to fully grasp the situation after the collision, and since they did not initially anticipate Vessel A to founder from the collision alone, they were not particularly concerned at that moment.

iv) Ordinary Seaman A_1

After the collision, N. Officer A_1 seemed to be in a state of panic and went to call Master A. Once Master A arrived at the bridge, the other crew members also gathered there.

As Ordinary Seaman A_1 was grabbing the wheel handle at the steering stand, he was unable to change course by himself, so he simply waited for instructions. Master A arrived at the bridge, and together with N. Officer A_1, he observed the situation from the port wing. At that time, Vessel A was leaning rapidly to port. Master A then ordered the main engine to be stopped, and Ordinary Seaman A_1 operated the main engine in the accordance with the order.

The crew members gathered at the bridge, seemingly waiting for instructions from Master A on how to proceed. N. Officer A_3 observed that Vessel A was submerged up to the mooring equipment at the fore side of No.2 Deck. Following Master A's instructions, each crew member went to their quarters to retrieve a life jacket.

By that time, Vessel A's tilt had become so severe that it was difficult for them - Ordinary Seaman A_1, Ordinary Seaman A_2, Ordinary Seaman A_3, and the Chief Cook - to access the bridge while wearing life jackets. Both Ordinary Seaman A_2 and Ordinary Seaman A_1 grabbed the handrail and managed to escape. Realizing that Vessel A was likely going to founder, Ordinary Seaman A_1 spoke with Ordinary Seaman A_2 about lowering a life raft. After receiving permission from Master A, we began the process of lowering it. N. Officers A_1 and A_3 joined them, and the four of them worked together to launch the life raft. Unfortunately, it was dark, and visibility was poor, and the strong tide carried the life raft away after it was launched.

By this time, Vessel A had leaned fully onto its side, and they were standing on the starboard shell plating. Vessel A was foundering steadily from the bow, and they feared that heading toward the aft. side would result in being sucked into the foundering Vessel A. After discussing our options, they decided to move for the bow, aiming to enter the water as quickly as possible. The four of them made their way toward the bow, and as Vessel A continued to founder, waves began to crash toward us. They stood shoulder to shoulder against the current, bracing themselves as they left Vessel A.

Vessel A overturned on its port side while ramming the port bow., with only the starboard aft. side remaining afloat. After approximately two hours, Vessel A foundered. During this time, the current temporarily calmed while Vessel A remained floating and stationary, allowing them to get as far away from the wreck as possible. At that moment, N. Officer A_1 and Ordinary Seaman A_2, and N. Officer A_3 and Ordinary Seaman A_1 went in separate directions. Soon, we heard the voices of Boatswain (hereinafter referred to as "Boatswain A") and the Chief Cook, so they swam toward them. The four of them - N. Officer A_3, Ordinary Seaman A_1, Boatswain A, and Chief Cook - were reunited. After approximately an hour and a half to two hours, they were recovered by a container vessel that came to recover them.

Vessel A began to lean, and Ordinary Seaman A_1 heard the sound of the lashings breaking. Initially, Ordinary Seaman A_1 thought Vessel A had been struck directly from the side and was flooding. However, after discussing the situation with other crew_members post-accident, Ordinary Seaman A_1 did not believe that a vessel as large as Vessel A could founder, so at first, he felt it would be fine. However, as Vessel A continued to lean and the mooring equipment at the fore side became submerged, it became apparent that all the crew members were certain the ship would founder, prompting them to move toward abandoning ship.

(2) Statements of Crew Members of Vessel B

i) Statements and Response to the Questionnaire of Master B

Master B ordered all lights on the decks to be turned on and instructed Chief Navigation Officer (N. Officer B_3) to move to the bow with Boatswain of Vessel B to inspect for any damage. Master B also directed N. Officer B_2 and N. Officer B_1 to use searchlights to look for Vessel A and her crew members. After the search, Master B gathered all crew members at the MUSTER STATION and ordered N. Officers B_3 and B_2, along with one engineer, to conduct a search and rescue operation for the crew members of Vessel A.

N. Officer B_2 used Vessel B's searchlights to search for Vessel A. With permission from the JCG to assist in the search and rescue operations, N. Officer B_2 boarded a rescue boat along with N. Officer B_3 and the Chief Engineer. They participated in the search operations for the crew members of Vessel A who were outside Vessel A, but unfortunately, they were unable to recovery anyone.

Meanwhile, N. Officer B_1 communicated with Kurushima MARTIS regarding the collision, contacted Company B, prepared a draft accident report, and continued the search for Vessel A and its crew using Vessel B's searchlight.

ii) Statements of N. Officer B_1

It may not be entirely precise, but it seemed that after the collision, Vessel B moved alongside Vessel A, as if being dragged, for approximately 10 to 15 seconds. Since Vessel A was moving faster than Vessel B, it gave the impression that Vessel B was being pulled along before the two vessels eventually separated.

Immediately after the accident, they notified Kurushima MARTIS of the occurrence of the collision at the entrance to the Kurushima Kaikyo Traffic Route, followed by a call to Company B.

N. Officer B_2 contacted Kurushima MARTIS via VHF and received permission to conduct rescue operations. As a result, N. Officers B_3 and B_2, along with one engineer, boarded a rescue boat and participated in the rescue operations for approximately an hour and a half.

iii) Statements of N. Officer B_2

At the time of the accident, four people were in the bridge: Master B, N. Officer B_2, N. Officer B_1, and Able Seaman B. After the collision, N. Officer B_3 arrived at the bridge 1-2 minutes later, having felt the impact, and proceeded to check the bow. N. Officer B_1 then reported the accident to Kurushima MARTIS, whereas Master B contacted Company B.

After the collision, Vessel A and Vessel B moved together for a brief period. Approximately five to seven minutes later, none of Vessel A's lights were visible.

After the collision, N. Officer B_2, along with N. Officer B_3 and one engineer, launched a rescue boat to conduct rescue operations, but we were unable to recovery anyone.

2.5 Rescue Operation Process

(1) Response of the JCG

According to statements from the person in charge of JCG and public relations materials from the Imabari Coast Guard (hereafter referred to as "Imabari CG"), the response following the accident was as follows.

At around 23:56 on May 27, the 6th Guard became aware of the accident after receiving a report from Kurushima MARTIS. They immediately set up a response headquarters at the 6th Guard and dispatched patrol vessels and boats, etc. to begin search and rescue operations. Additionally, an on-site response headquarters was established at the Imabari CG Office. The Imabari CG also received cooperation from local fishing cooperatives and related organizations in the area to aid in the search and rescue operations.

At around 00:15 on May 28, a patrol boat arrived at the accident location and found Vessel A capsized on its port side with no lights. The crew members then spotted individuals wearing life jackets and lights floating near Vessel A and began rescue operations. A rubber boat from the patrol boat recovered a total of five people: two at around 00:37, two at around 00:45, and one at around 01:08. The five recovered crew members of Vessel A were transported to Imabari Port by the patrol boat and handed over to Imabari City's emergency rescue team at around 04:00.

The crew members of the patrol boat observed Vessel A was foundering with its bottom facing up at around 02:43.

Starting around 00:15, patrol vessels and boats arrived at the accident location one after another. A maximum of 10 patrol boats and 3 patrol vessels warned passing ships and conducted search and rescue operations. A JCG rotorcraft arrived above the accident location at around 03:13, and subsequent search and rescue operations were carried out using up to two rotorcraft and one fixed-wing aircraft.

At around 03:30, the 6th Guard sent a disaster dispatch request to the Kure Regional Headquarters of the Japan Maritime Self-Defense Force, which was accepted.

A survey vessel from the 6th Guard arrived at the accident location at around 06:40 and began searching for Vessel A using sonar, confirming an object believed to be Vessel A. Subsequently, a Special Rescue Team (hereafter referred to as "SRT"), National Strike Team, divers, and Mobile Rescue Technicians were dispatched. From around 11:33, SRT and divers conducted the first underwater search, visually confirming the vessel's name as Vessel A.

At around 08:44 on May 30, the special rescue team, which had been searching of the ship, discovered one person on the starboard aft. side of the steering gear room. The individual was later confirmed to be Engineer A_2, who was deceased.

By June 1, a total of eight underwater search activities and searches of Vessel A inside had been conducted.

By June 4, search operations involved a total of 43 patrol and survey vessels and boats, as well as nine aircraft. At sunset on the same day, the search operation was transitioned from a full-time operation to one conducted alongside regular patrols, and the local response headquarters was disbanded.

On August 20, the Imabari CG was notified by a salvage company that a diver from the company had conducted underwater search activities and had discovered a dead body in the workshop of the engine room of Vessel A. The dead body was retrieved by a patrol boat on August 21 and was later confirmed to be that of Engineer A_1.

On October 25, 2023, the Imabari CG was informed by a salvage company involved in the salvage operations of Vessel A that a dead body had been discovered in the bathroom lobby of Vessel A's accommodation area. The dead body was retrieved the same day, and subsequently DNA testing confirmed that the dead body was Master A.

(2) Response of a container vessel in the vicinity of the accident location

According to VHF communication records, the crew member rescue report of a container vessel that was sailing nearby after the accident, and the statements of the container vessel's master, the response of the container vessel was as follows.

While the container vessel was sailing through the Kurushima Kaikyo Traffic Route toward Mitajiri-Nakanoseki Port in Hofu City, Yamaguchi Prefecture, at around 00:00 on May 28, it learned of the accident through a VHF call from Kurushima MARTIS. The vessel departed the Kurushima Kaikyo Traffic Route near No.4 Light Buoy, and at around 00:10, the crew member spotted Vessel A leaning to the left and semi-submerged. At around 00:18, they proposed to conduct their rescue operations via VHF to Kurushima MARTIS, which then started the rescue operations.

The crew member of the container vessel discovered the crew member of Vessel A, threw a lifebuoy into the sea, and lowered a ladder overboard. They recovered four crew members of Vessel A and provided them with medical care, including bathing and changing clothes, aboard the container vessel. The recovered crew members were then transferred to a fire rescue boat of Imabari City.

(3) Response of the fire department in the vicinity of the accident location

According to statements from the JCG and the person in charge of fire department, as well as public relations materials from the Imabari CG, the response of the fire department in the vicinity of the accident location after the accident was as follows.

The Imabari City Fire Department received a report from the Imabari CG and became aware of the accident at 01:12. A fire rescue boat from the Imabari City North Fire Station (Hakata Island) arrived at the accident location at 02:18.

The fire rescue boat picked up the four crew members of Vessel A who had been recovered by the container vessel and arrived at Imabari Port at 03:05. At Imabari Port, the fire rescue team took over the four crew members of Vessel A and loaded them into the ambulance, which departed Imabari Port at 03:10 and arrived at a hospital in Imabari City at 03:17.

Another fire rescue team took over the five crew members of Vessel A, who had been recovered by a patrol boat, at Imabari Port. The crew members were separated into two ambulances, which then departed Imabari Port and arrived at a hospital in Imabari City by 04:20.

The fire rescue boat also participated in search and rescue operations on May 29 and 31, and a fire helicopter was involved in the search and rescue operation on May 29.

(4) Response of the Ministry of Defense

According to statements from the person in charge of JCG and public relations materials from the Ministry of Defense and the Imabari CG Office, the Ministry of Defense responded to the accident as follows.

At 03:30 on May 28, the Kure Regional Headquarters of the Japan Maritime Self-Defense Force received a disaster dispatch request from the 6th Guard. In response, one minesweeper was deployed for search and rescue operations on May 28. From May 29 to 31, two additional minesweepers, one minesweeper tender, and one submarine rescue vessel participated in the operations. Additionally, one aircraft was involved in the search and rescue efforts on May 30 and 31. The submarine rescue vessel provided support for the underwater search conducted by SRT.

(5) Response of local police in the vicinity of the accident location

According to statements from the person in charge of JCG and public relations materials from the Imabari CG Office, the response of local police in the vicinity of the accident location was as follows.

At the request of the Imabari CG, three patrol boats from the Ehime Prefectural Police - belonging to the Hakata Police Station, Matsuyama Nishi Police Station, and Yawatahama Police Station - participated in the search and rescue operations on May 28. One of these patrol boats continued participating in the operations until May 31.

(6) Response of fishery cooperatives in the vicinity of the accident location

According to statements from the person in charge of JCG and public relations materials from the Imabari CG Office, the response of fishery cooperatives in the vicinity of the accident location was as follows.

At the request of the Imabari CG, local fishery cooperatives participated in the search operations in the accident location. A total of 187 vessels belonging to the Obe, Imabari, Ohama, and Miyakubo Fishery Cooperatives took part in the search operations between May 28 and June 2.

2.6 Fatalities and Injuries to Personnel

(1) Vessel A

According to the autopsy reports for Engineer A_1 and Engineer A_2, the medical reports for N. Officer A_1, N. Officer A_2, N. Officer A_3, Chief Engineer A, and Ordinary Seaman A_1, as well as the missing crew member report submitted by Company A_1, and public relations materials from the Imabari CG, the fatalities and injuries sustained by the crew members of Vessel A are summarized in Table 1.

Table 1 Fatalities and injuries among crew members of Vessel A

Rank	Status of fatalities, injuries, and missing persons among Vessel A crew members
Master A	Death Master A was initially reported missing after the accident, but on October 25, 2023, his dead body was discovered in the bathroom lobby of the accommodation area on Vessel A. DNA testing confirmed the identity as that of Master A.
N. Officer A_1	Bruising on the fingers and abrasions on the backs of the feet
N. Officer A_2	Cervical sprain and bruising on left hand
N. Officer A_3	Bruising on knee and elbow joints
Chief Engineer A	Fracture of the distal left clavicle
Engineer A_1	Suspected drowning (death) Found in Vessel A (workshop in engine room) on August 20, 2021
Engineer A_2	Drowning (death) Found on May 30, 2021, in the wheelhouse of Vessel A
Ordinary Seaman A_1	Bruising on knee joints

(2) Vessel B

According to public relation materials from the Imabari CG, there were no fatalities or injuries among the crew member of Vessel B.

2.7 Damage to Vessels

(1) Vessel A

i) Damage

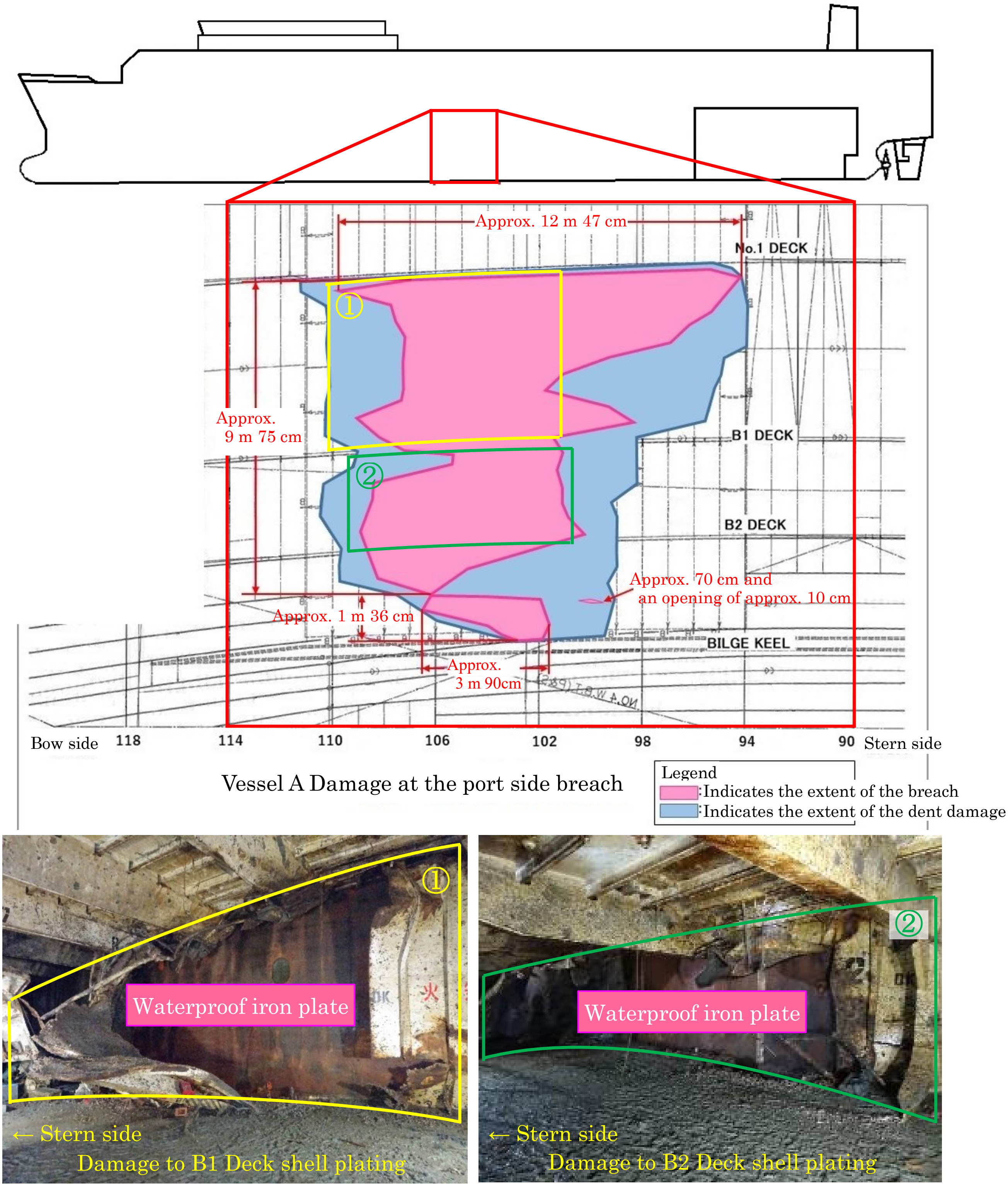
According to the statements of Vessel A's Crew Member, Vessel A sustained a breach in the center of its port side and subsequently foundered. According to public relations materials from the Imabari CG, Vessel A foundered approximately 4,500 meters north–northeast of the Kurushima Kajitori-no-Hana Lighthouse in Miyazaki, Namikata-cho, Imabari City.

After Vessel A was salvaged, an inspection of the hull damage was conducted in November 2023. This damage was around middle part on the port side, between frame numbers 94 and 110. The breach was found to be in the shape of an inverted triangle, approximately 9.8 meters high, with its base located approximately 12.5 meters below the first deck and its apex near the bilge keel. (see Figures 16 and Figures 17).

Additionally, it was confirmed that the clock installed in the bridge of Vessel A stopped at around 00:11:26.

ii) Spillage of fuel oil, etc.

According to Company A_1's response to the questionnaire, at the time of departure from Kobe Ward in Hanshin Port, Vessel A's port fuel oil tank contained approximately 152.4 kiloliters of fuel oil, while the starboard fuel oil tank contained approximately 190.4 kiloliters. Following the accident, operations were conducted to recover the remaining oil, and approximately 99% of the fuel was successfully recovered from both the port and starboard tanks. Residual oil was also recovered from other smaller-capacity tanks, preventing a large-scale oil spill.



Photograph shows the port side shell plating from the inside
(Waterproof plates are installed at the time of salvage construction)

Figure 16 Damage to the deck shell plating of Vessel A

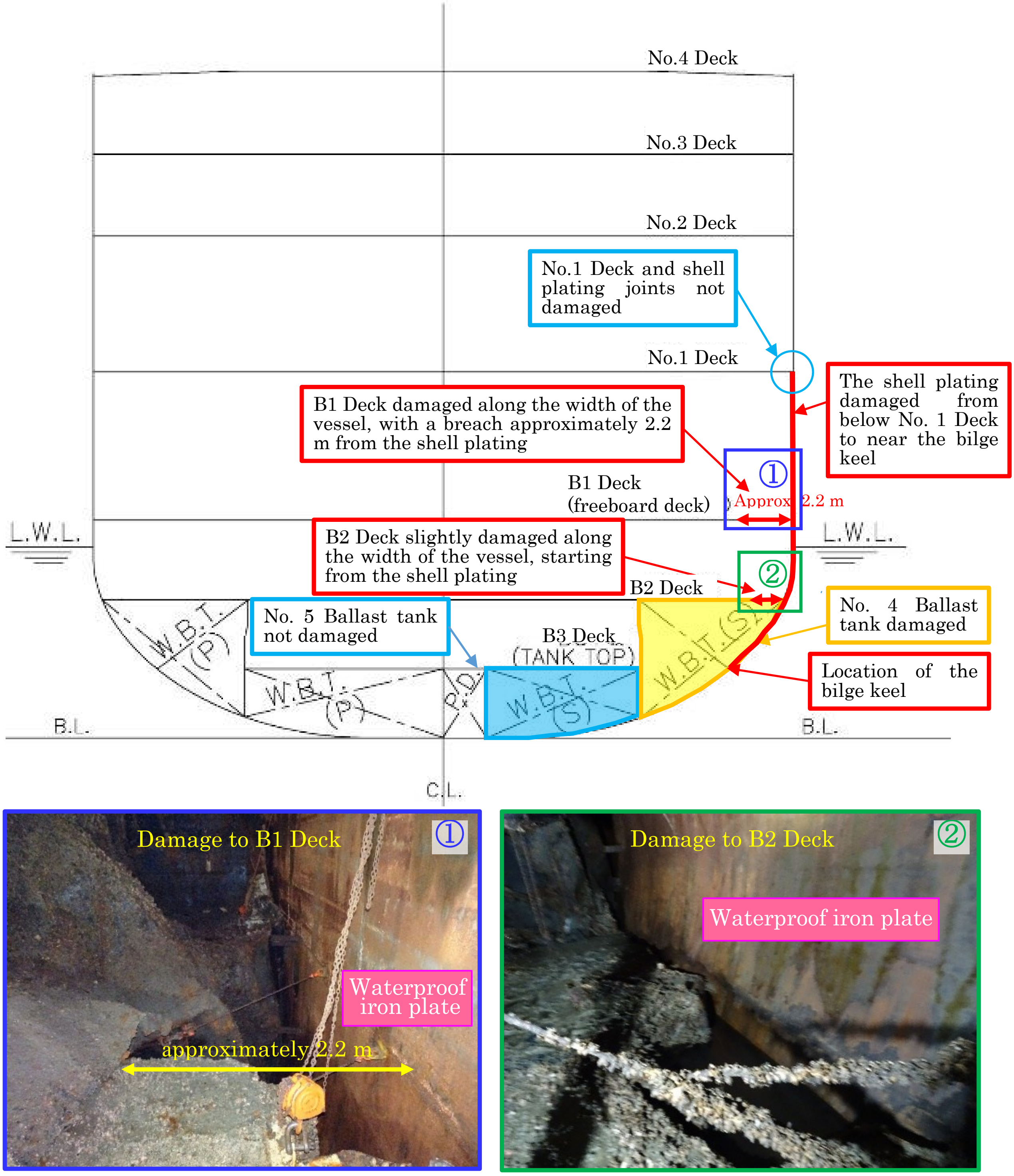


Figure 17 Damage to the deck of Vessel A

(2) Vessel B

Vessel B sustained crushing damage to the bow (including the collapse of the fore mast and the light) and bending damage to the bulbous bow. (see Photo 3)

Photo 3 Damage to Vessel B

2.8 Crew Member Information

(1) Age and certificate of competence

i) Master A: 66 years old

Third grade maritime officer license (Navigation)

Date of Issue: June 6, 1975

Date of Revalidation: April 3, 2018

Date of Expiry: August 24, 2023

ii) N. Officer A_1: 44 years old

Third grade maritime officer license (Navigation)

Date of Issue: September 28, 2009

Date of Revalidation: August 9, 2019

Date of Expiry: September 27, 2024

iii) Ordinary Seaman A_1: 19 years old

iv) Master B: 62 years old (Nationality: Republic of Korea)

Endorsement attesting to recognition of certificate under STCW*10 regulation I/10:

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

Management Level (Navigation), issued by the Republic of the Marshall Islands

Date of Issue: April 26, 2019

(Valid until April 25, 2024)

v) N. Officer B_1: 19 years old (Nationality: Republic of Korea)

Endorsement attesting to recognition of certificate under STCW regulation I/10: Management Level (Navigation), issued by the Republic of the Marshall Islands

Date of Issue: June 17, 2020

(Valid until March 11, 2025)

(2) Seagoing service experience

According to the statements of N. Officer A_1, Ordinary Seaman A_1, Master B, and N. Officer B_1, as well as the response to the questionnaire from Company A_1, the seagoing service experience of each individual is as follows.

i) Master A

After starting his career on a fishing vessel, Master A joined Company A_1 in February 1981. With approximately 46 years of seagoing service experience, Master A has served as a master at Company A_1 since November 1992. He was assigned to Vessel A as Master when Vessel A was completed and taken over in July 2020. After conducting seagoing service on other vessels, he was reassigned in Vessel A as Master on April 28, 2021.

Master A had extensive experience navigating through the Kurushima Strait.

According to his health certificate in his seafarer's handbook dated October 20, 2020, his state was "Fit for watchkeeping duties on-board." On the day of the accident, Master A was on duty in the bridge.

ii) N. Officer A_1

N. Officer A_1 started his career on a merchant vessel in April 1995 and joined Company A_1 in August 2019. With approximately 20 years of seagoing service experience, he conducted seagoing service as a navigation officer on board a sister vessel of Vessel A at Company A_1 from April to August 2020. N. Officer A_1 had been on board Vessel A since April 2021.

At the time of the accident, N. Officer A_1 was in good health.

iii) Ordinary Seaman A_1

Ordinary Seaman A_1 graduated from high school in March 2019 and joined Company A_1 in April 2019. Ordinary Seaman A_1 had been on board a sister vessel of Vessel A since around May 2019 and had been assigned to Vessel A since around April 2021, where he was involved in steering duties and other tasks.

Although Ordinary Seaman A_1 did not hold a maritime license, he was eligible for exemption from the written examination for a Fourth Grade Maritime Officer license (Navigation), due to completing a course at a high school training for Fourth Grade Maritime Officer (Navigation).

At the time of the accident, Ordinary Seaman A_1 was in good health.

iv) Master B

Master B has 41 years of experience as a crew member on ocean-going fishing vessels and merchant vessels, including 20 years as a master. He had been serving as the Master of Vessel B since around January 2021 and had multiple experiences passing through the Kurushima Strait.

At the time of the accident, Master B was in good health.

v) N. Officer B_1

N. Officer B_1 graduated from high school in 2019 and had 1 year and 6 months of seagoing service experience, including his trainee period. He had been on board Vessel B since June 2020. As of the time of the accident, N. Officer B_1 had passed through the Kurushima Strait from the west approximately 10 times, both during the day and at night.

At the time of the accident, N. Officer B_1 was in good health.

2.9 Vessels Information

2.9.1 Particulars of Vessels

(1) Vessel A

Vessel Number:	143784
Port of Registry:	Tokyo
Owner:	Japan Railway Construction, Transport and Technology Agency Company A_1
Management Company:	Company A_2
Classification Society:	Nippon Kaiji Kyokai (hereinafter referred to as "NK")
Gross Tonnage:	11,454 tons
L × B × D:	169.98 m × 26.00 m × 18.65 m
Hull Material:	Steel
Engine:	Diesel Engine × 1
Output:	14,160 kW
Propulsion:	5-blade fixed pitch propeller × 1
Date of Launch:	February 2020

(2) Vessel B

IMO Number:	9730969
Port of Registry:	Majuro, Republic of the Marshall Islands
Owner:	HIDHC NO. 2 S.A. (Republic of the Marshall Islands)
Management Company:	PTS CO., LTD. (Republic of Korea)
Operator:	HEUNG-A SHIPPING CO., LTD. (Republic of Korea)
Classification Society:	KOREAN REGISTER OF SHIPPING
Gross Tonnage:	2,696 tons
L × B × D:	89.96 m × 14.40 m × 7.50 m
Hull Material:	Steel
Engine:	Diesel Engine × 1
Output:	2,427 kW
Propulsion:	4-blade fixed pitch propeller × 1
Date of Launch:	January 2016

2.9.2 Hull Structure of Vessel A

(1) Hull Structure

According to the replies to questionnaires from Companies A_1 and A_2 and the general arrangement of Vessel A, the hull structure of Vessel A was as follows.

Vessel A had, from the top deck of the hull, the navigation bridge deck (bridge and crew accommodation), No.4 Deck (crew accommodation), No.3 Deck, No.2 Deck (upper deck), No.1 Deck, B1 Deck (freeboard deck), B2 Deck, B3 Deck (No.3 Deck to B3 Deck were vehicle loading

areas) and the engine room deck.
(See Figure 18, Photos 4 and Photos 5)

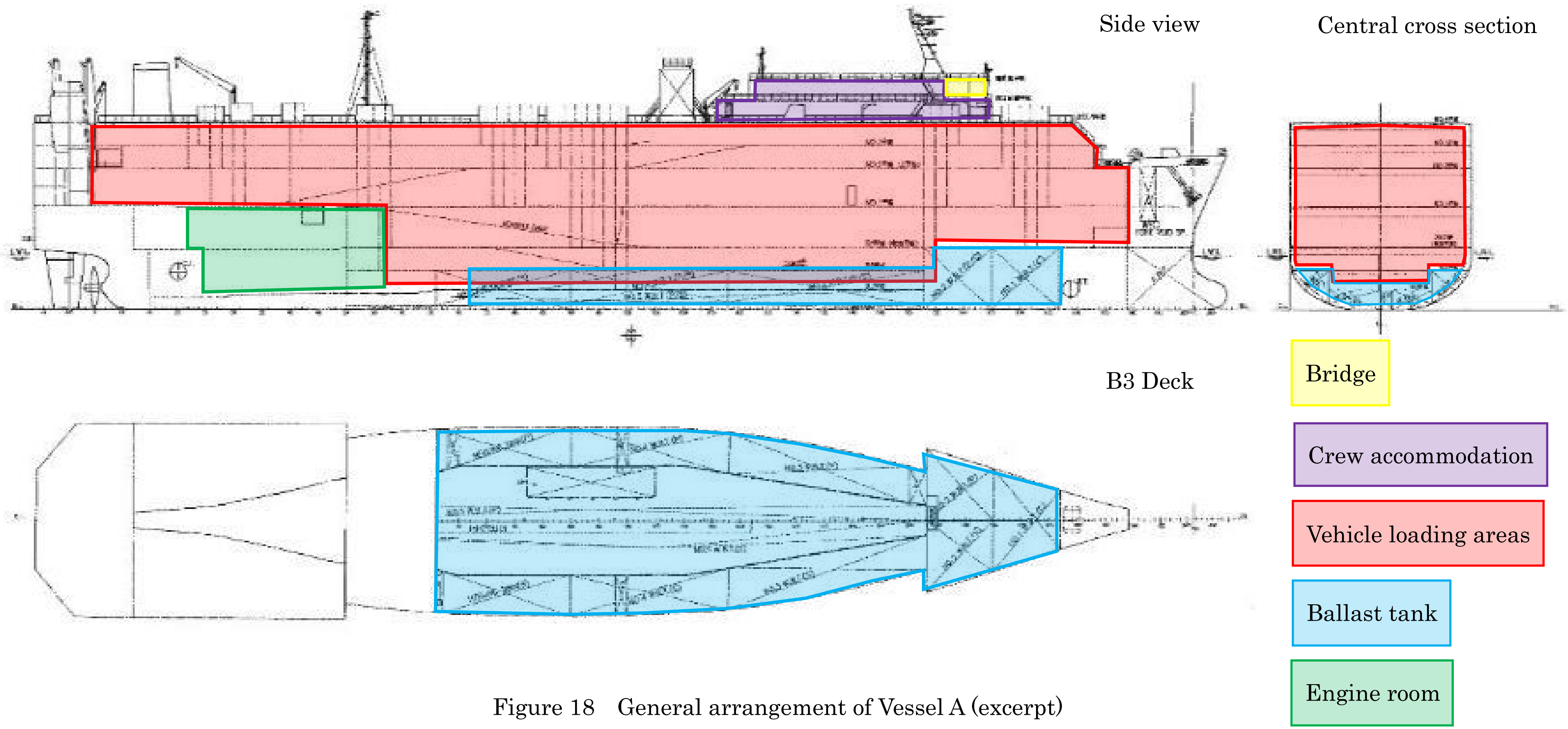


Figure 18 General arrangement of Vessel A (excerpt)

Photo 4　Condition of Vessel A's No.4 Deck (before this accident)

Photo 5　Condition of Vessel A's B2 Deck (before this accident)

In addition, in the double bottom structure, which extended from slightly aft of the fore side to slightly aft of the center of the hull, contained, from the bow, No.1 Ballast tank (center), No.2 to No.4 Ballast tanks (on both sides), No. 5 Ballast tank (center), and Heel tanks (on both sides).

There were no partition walls in the vehicle loading area, and the upper and lower vehicle decks were connected by a ramp, which was not watertight structure. In addition, the stopper clamps were installed on the floors of the vehicle decks to secure the cars with lashing belts (three types with tensile strengths of 2,000 kgf or more, 6,000 kgf or more, and 16,000 kgf or more).

(2)　Information on damage stability

Vessel A was constructed in accordance with the 2019 NK Steel Ship Rules.

Under Part C (Hull Structure and Outfitting) of these Rules, vessels with a gross tonnage of 500 tons or more and a freeboard length (Lf) of 80 meters or more are, in principle, required to comply with the Damage Stability Standards set forth in Chapter 4. These standards are intended to ensure that a vessel can avoid foundering or capsizing in the event of shell plating damage due to collision or grounding, and to maintain stability even when subject to a certain degree of external force.

However, mitigation measures are provided under the 2019 NK Steel Ship Rules Inspection Guidelines, Part CS (Hull Structure and Hull Outfitting of Small Steel Ships), Section Cs1.1 "Application and Equivalent Effectiveness," Subsection Cs1.1.1 "Application." These measures apply to limited coastal vessels and vessels operating in coastal or sheltered (flat water) areas - excluding those engaged in international voyages. Vessels that satisfy the following conditions are exempt from the requirement to comply with Damage Stability Standards.

・The vessel must be equipped with a flooding warning device that complies with the applicable requirements.

・The vessel must carry damage control information that satisfies the relevant standards. This documentation, which must be kept in the bridge, includes stability calculations for damaged conditions, methods for assessing risk based on those calculations, and layout diagrams of structures and equipment related to damage and flooding control, such as the arrangement of bilge pumps.

Vessel A was a vessel to which the aforementioned mitigation measure was applied.

It was equipped with a damage control information titled "Documents on stability in the event of damage for the master," and a copy was retained by Company A_1. This document was prepared to provide essential information for i) determining whether there was a risk of foundering, and ii) considering damage control measures in the event of flooding caused by a collision or similar accident. In particular, the information for assessing the risk of foundering included color-coded charts and graphs showing the results of calculations on the severity of damage (S-values), based on combinations of loading conditions (fully loaded, 60% loaded, lightly loaded) and trim conditions. Using this document, the master could readily assess the impact of the damage by selecting the diagram that most closely corresponded to the vessel's initial condition at the time of the accident, identifying the breached section, and referencing the associated "S-values" to evaluate the risk of foundering.

If the S-value is "0", it indicates that, according to the calculation rules, the ship will founder. For example, as shown in Figure 19, if an area outside the fore side section or engine room - such as the vehicle loading section - is damaged, the condition will be classified as "State 3 (S = 0)," meaning the ship will founder.

(See Figure 19)

According to the damage control document, calculations indicate that the ship is expected to founder if any of the following conditions are met:

- *Submersion of an external or internal opening, such as a hatch, watertight door, or ventilation duct, leading to continuous flooding into compartments beyond the initially flooded area;*
- *When the final equilibrium angle reaches 30° or more.*

Calculation condition (60% partial load draft): (P) side (port side) *damage*
Initial condition: dP (Partial draft (60% partial load draft)) *= 6.380 m,*
Trim (stern draft–bow draft) *= 1.700 m,*
G_0M ((initial) metacenter height) *= 1.20 m*
(Damage extent: Vertical = No.1 deck (up to)*, Horizontal = C.L.* (up to the center line of the hull))

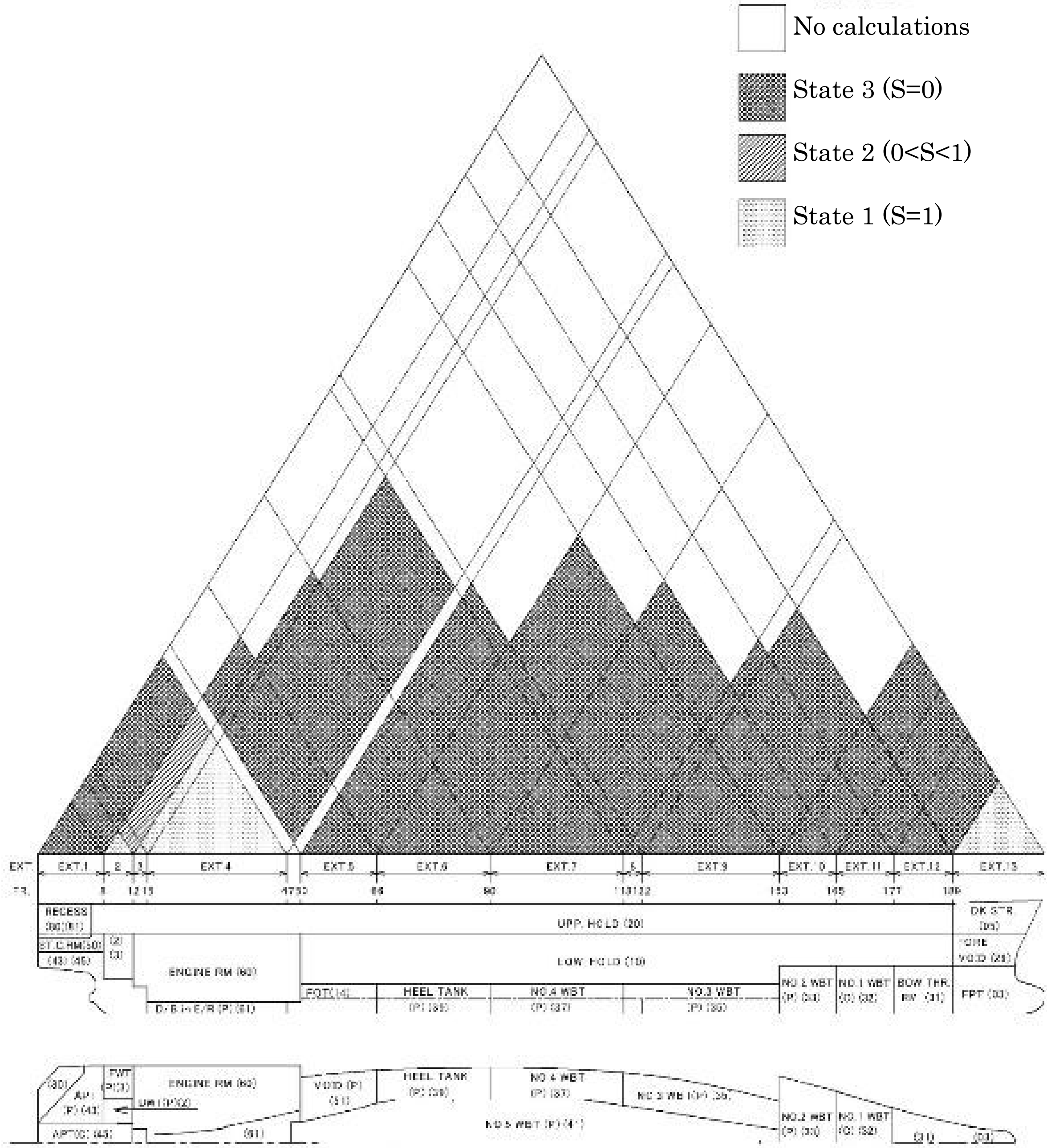


Figure 19 Chart showing calculated damage stability (example)

2.9.3 Vessel's Equipment

(1) Vessel A

According to Company A_1's response to the questionnaire and Vessel A's bridge arrangement, the functions and layout of the equipment installed on Vessel A's bridge were as follows.

The steering stand was located in the center of the bridge, with the main engine remote control device and other equipment on the starboard side. Two radars and an Electronic Chart Device were positioned on the port side.

The radars were equipped with a TT (Target Tracking: Automatic Collision Prevention Assistance Device) function, which allowed it to capture selected vessels and display their movements (CPA, TCPA*11, Bow Crossing Range [BCR]*12, Bow Crossing Time [BCT]*13, etc.) on the radar screen. It also had a trial maneuvering function in them.

At the time of the accident, the hull, engine, and equipment were not defects or malfunctions. (See Figure 20)

Interior view of the bridge (photographed from starboard to port side) before the accident

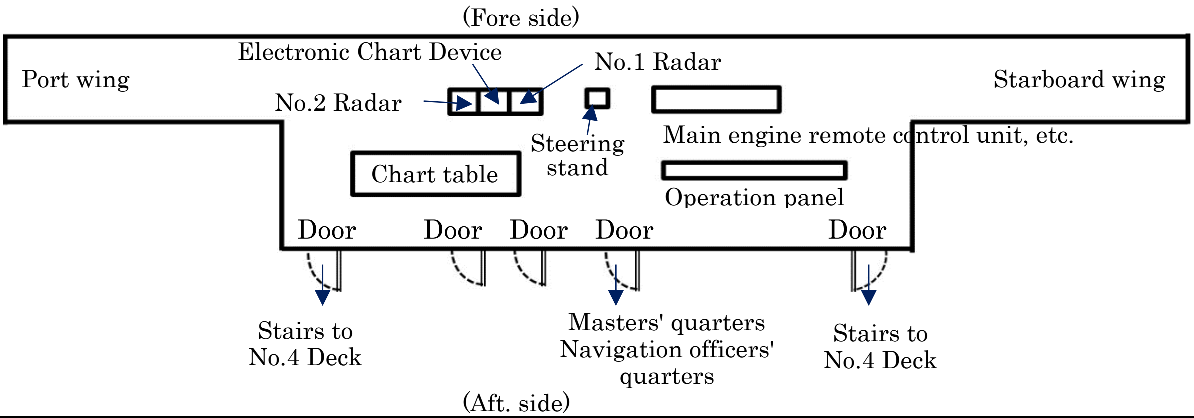


Figure 20 Schematic diagram of the equipment arrangement in the bridge of Vessel A

(2) Vessel B

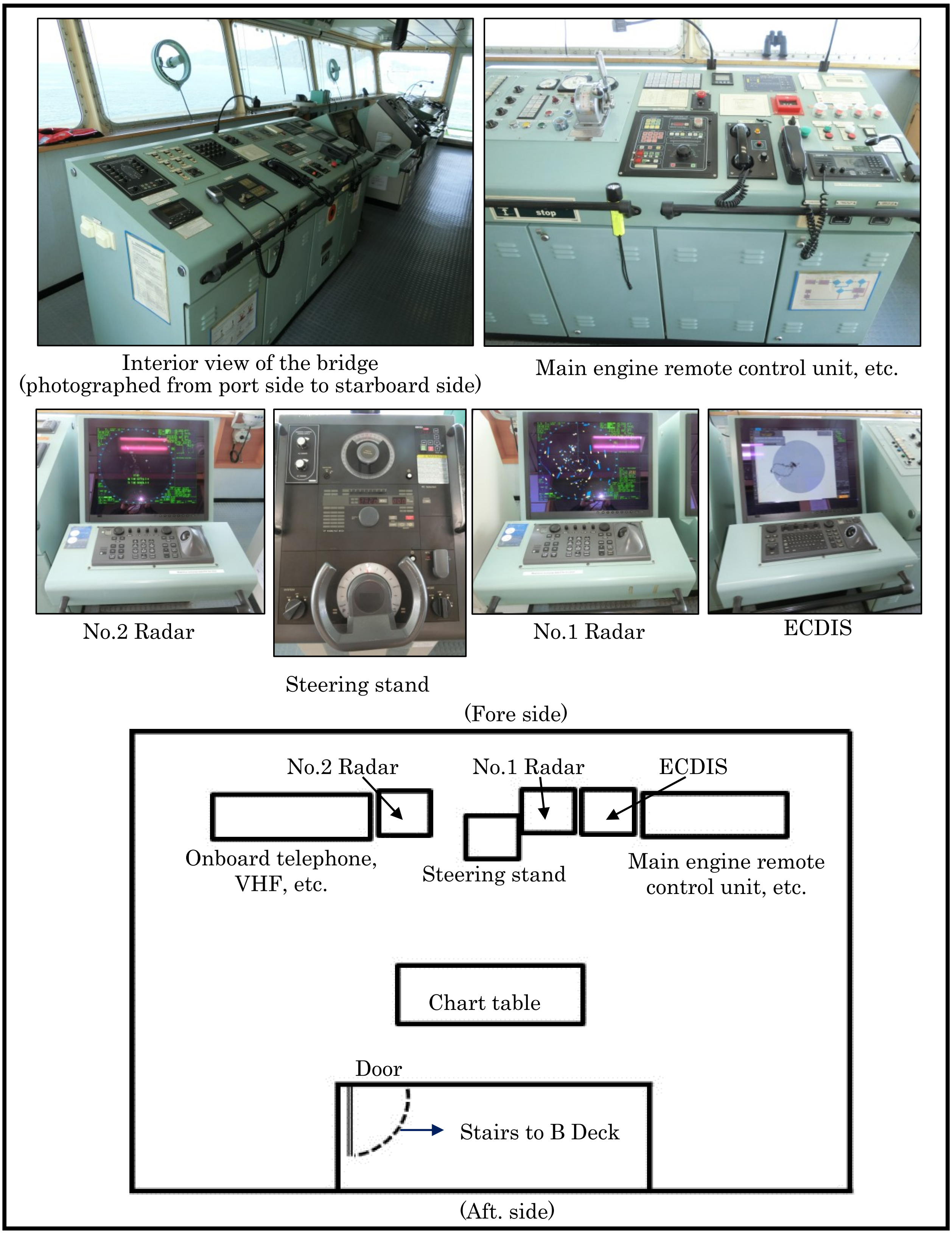
Vessel B was equipped with a steering stand located at the center of the bridge. On the starboard side, Vessel B had one radar, ECDIS, and the main engine remote control unit, while on the port side, it had another radar and VHF. The radar system was equipped with a TT function, which allowed it to track selected vessels and display their movement information, including CPA, TCPA, BCT, and BCR, on the radar screens.

*11 TCPA refers to the time until the closest approach of two vessels.

*12 BCR refers to the range at which the bow of a vessel will cross the path of another vessel.

*13 BCT refers to the time until the bow of a vessel crosses the path of another vessel.

According to the statement provided by N. Officer B_1, at the time of the accident, the hull, engine, and equipment were not defects or malfunctions.
(See Figure 21)



Interior view of the bridge (photographed from port side to starboard side)

Main engine remote control unit, etc.

No.2 Radar

Steering stand

No.1 Radar

ECDIS

Figure 21　Schematic diagram of the equipment arrangement in the bridge of Vessel B

2.9.4 Maneuverability Performance

(1) Vessel A

According to the sea trial report for Vessel A, the vessel's stopping and turning performance under an approximate 60% load condition (Fore draft: 6.01 m; Aft. draft: 6.43 m) was as follows.

i) Stopping distance and time (distance and time measured from the issuance of the full astern command to a complete stop)

Speed before full astern command	Distance	Time
23.73 kn	2,355 m	6 minutes 37 seconds

ii) Turning characteristics (steering angle 35°)

Turning direction	Speed	Maximum advance*[14]	Maximum transfer*[15]	Time
Port turning	23.73 kn	542.3 m	601.0 m	4 minutes 44 seconds
Starboard turning	23.73 kn	601.3 m	658.9 m	5 minutes 3 seconds

* "Time" refers to the duration required for the vessel to complete a 360° turning.

iii) Port turning test results (excerpt)

Turning angle	Elapsed time	Advance	Transfer
0°	0 second	0 m	0 m
5°	11.1 seconds	134.4 m	0.7 m

* "Elapsed time" refers to the duration between the issuance of a steering command and the moment the target turning angle is achieved.

iv) Starboard turn test results (excerpt)

Turning angle	Elapsed time	Advance	Transfer
0°	0 second	0 m	0 m
5°	14.1 seconds	171.5 m	–4.4 m
15°	21.0 seconds	252.7 m	–3.4 m

* "Elapsed time" refers to the time interval from the issuance of a steering command to the point when the specified turning angle is achieved.

(2) Vessel B

According to the sea trial report for Vessel B, its stopping and turning performance was as follows:

i) Stopping distance and time (distance and time measured from the issuance of the full astern command to a complete stop)

Speed before full astern command	Distance	Time
13.8 kn	676.2 m	2 minutes 33 seconds

(Displacement: 5,278 tons; Fore draft: 5.67 m; Aft. draft: 5.75 m)

ii) Turning characteristics (steering angle 35°)

Turning direction	Speed	Maximum advance	Maximum transfer	Time
Port turning	13.4 kn	241.5 m	201.8 m	3 minutes 16 seconds
Starboard turning	12.8 kn	290.3 m	221.0 m	3 minutes 30 seconds

(Fore draft: 5.65 m; Aft. draft: 5.73 m)

*[14] "Maximum advance" refers to the greatest longitudinal distance traveled by the ship's center of gravity from the point where the turning is initiated, measured along the trajectory (turning path) of the center of gravity during the turning maneuvering.

*[15] "Maximum transfer" refers to the greatest lateral distance moved by the ship's center of gravity from its initial position during a turning maneuvering within the designated turning area.

2.9.5 View from the Bridge

There were no structures obstructing the forward view at the fore side of either Vessel B or Vessel A's sister vessel. (see Photos 6 to Photos 9)

Photo 6 View of the fore side from the center of the bridge of Vessel A's sister vessel

Photo 7 View of the port fore side from the center of the bridge of Vessel A's sister vessel

Photo 8 View of the fore side from the port wing of Vessel A's sister vessel

Photo 9 View of the fore side from the center of the bridge of Vessel B (post-accident)

2.9.6 Loading Conditions

(1) Vessel A

According to Company A_1's questionnaire response, at the time of the accident, Vessel A was carrying 284 vehicles and 44 chassis. The draft measured approximately 5.50 meters at the fore side and 7.50 meters at the aft, side.

The loading conditions for each deck in the vehicle area are detailed in Table 2. The type (tensile strengths) and number of lashing belts used per vehicle varied according to the vehicle type. (see Table 2)

Table 2 Vehicle loading conditions

Deck	Loading conditions Type, number of vehicles, weight	Load weight	Lashings (per vehicle) Type of belt (tensile strengths) × number of belts used
No.3 Deck	Passenger car (1.5 t); 75 units	112.5 t	2,000 kgf or more × 4 pcs.
No.2 Deck	Passenger car (1.8 t); 102 units	183.6 t	2,000 kgf or more × 4 pcs.
No.1 Deck	Passenger car (1.5 t); 35 units Passenger car (1.8 t); 3 units Small truck (3 t); 8 units Large truck (10 t); 3 units Bus (3.6 t); 7 units Backhoe (17 t); 3 units Chassis (28 t); 26 units	916.1 t	2,000 kgf or more × 4 pcs. 2,000 kgf or more × 4 pcs. 6,000 kgf or more × 4 pcs. 6,000 kgf or more × 4 pcs. 6,000 kgf or more × 4 pcs. 16,000 kgf or more × 6 pcs. (Caterpillar section) 16,000 kgf or more × 2 pcs. (Arm section) 16,000 kgf or more × 4 pcs.
B1 Deck	Passenger car (1.8 t); 2 units Chassis (28 t); 18 units	507.6 t	2,000 kgf or more × 4 pcs. 16,000 kgf or more × 4 pcs.
B2 Deck	Passenger cars (1.5 t); 46 units	69.0 t	2,000 kgf or more × 4 pcs.
B3 Deck	None	—	—

(2) Vessel B

According to Company B's questionnaire response, at the time of the accident, Vessel B was carrying 2,996 tons of glacial acetic acid. The draft was approximately 4.70 meters at the fore side and 6.70 meters at the aft. side.

2.10 Weather and Sea Conditions

2.10.1 Meteorological Observations

(1) Observations from the Matsuyama Local Meteorological Observatory, located approximately 35 km south–southwest of the accident site, were as follows.

Date & Time	Weather	Visibility (km)
May 27 23:00	Cloudy	20.0
May 27 24:00	Cloudy	20.0

(2) Observations from the Imabari Regional Meteorological Observatory, located approximately 12.7 km southeast of the accident site, were as follows.

Date & Time	Air temperature	Wind direction	Average wind speed (m/s)	Precipitation (mm)
May 27 23:50	19.7°C	Southwest	3.1	0.0
May 27 24:00	19.7°C	West–southwest	3.4	0.0

(3) According to the National Astronomical Observatory of Japan, National Institutes of Natural Sciences (Inter-University Research Institute Corporation), the moonrise and set times in Matsuyama City, Ehime Prefecture at the time of the accident were as follows.

Moonrise: 20:19 on May 27

Highest point in the south: 00:16 on May 28

Altitude at the highest point: 34.0°

Moonset: 05:23 on May 28

Moon phase: 15.3 on May 27

(4) According to sea surface temperature data from the Osaka Regional Meteorological Observatory, the temperature in the Aki Nada and Iyo Nada on the day of the accident was approximately 17 °C.

2.10.2 Tide

(1) According to the Japan Meteorological Agency tide table, the tide in the Kurushima Route was near high tide at the time of the accident, with a tide level of approximately 379 cm at 23:56.

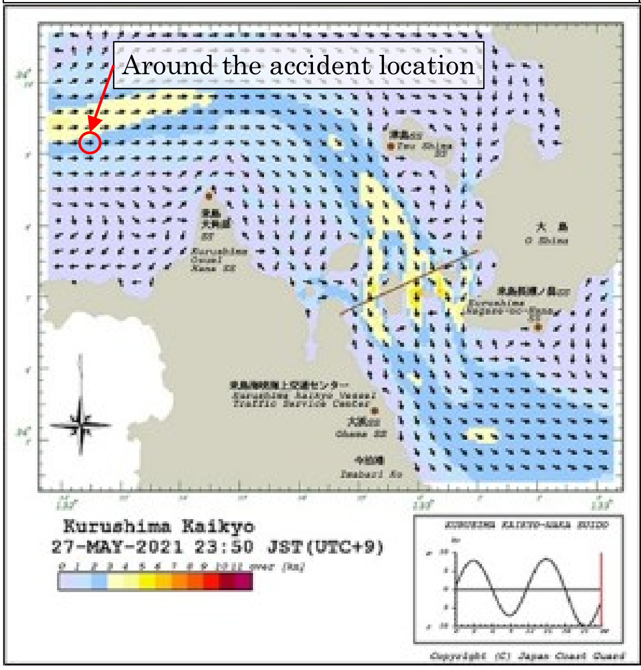
(2) According to the 2021 Tide Table published by the JCG, the current change times in the Kurushima Strait were as follows.

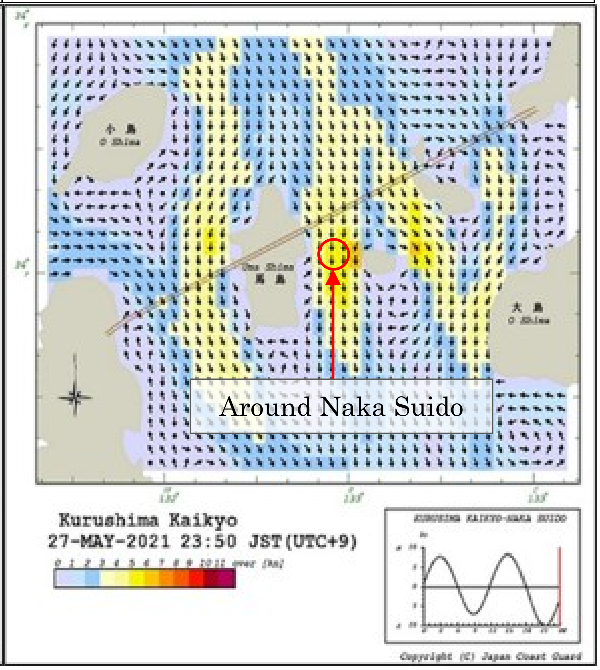
Naka Suido: May 28, 00:34 - current shift from south flow to north flow

Nishi Suido: May 28, 00:55 - current shift from south–southeast flow to north–northwest flow

(3) According to tidal information for the Kurushima Strait provided by the JCG, the conditions were as follows.

23:50 on May 27 Entire Kurushima Strait (east flow of approx. 2-3 kn in the accident location)	23:50 on May 27 Central part of the strait (south flow of approx. 3–7 kn near Naka Suido)





2.10.3 Observations by Crew Members

According to a report submitted by Company A_1 to the Kanto District Transport Bureau under Article 19 of the Seafarers' Act, the weather at the time of the accident was clear, with a north–northeast wind at force 2 and a wave height of 0.5 meters.

Master B stated that the current was very strong at the time of the accident.

N. Officer B_1 reported no weather, sea condition, or visibility factors that would have hindered watchkeeping duties.

2.11 Information on Watchkeeping and Maneuvering of Vessels

2.11.1 Information on VHF Communication

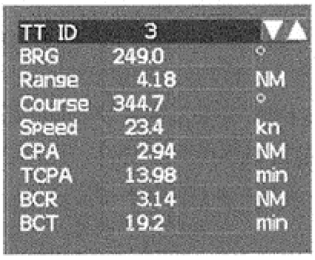
Regarding the use of VHF at the time of the accident, N. Officer A_1 stated that he did not know why Vessel B was not contacted. However, he explained that generally, he would initiate communication if he deemed it necessary, but if there were no issues, he would not make a call.

2.11.2 Information on CPA Values Indicated by TT

(1) Guidelines for CPA

The literature*[16] provides the following guidelines for CPA.

*[16] "Detailed Explanation of Nautical Instruments (Revised Edition)," Nobukazu Wakabayashi, Seizando-Shoten Publishing Co., Ltd., 2021.



TT ID	Target number
BRG	Bearing (bearing from own vessel)
Range	Range (range from own vessel)
Course	COG = Course Over Ground (true course of the target) Note: when the true course of the own vessel is entered into the radar
Speed	SOG = Speed Over Ground (speed over ground of the target) Note: when the speed over ground of the own vessel is entered into the radar
CPA	Closest Point of Approach (distance to CPA = DCPA)
TCPA	Time to CPA (time to CPA) xx min. xx sec. or yy.yy min.*
BCR	Bow Crossing Range (bow crossing distance)
BCT	Bow Crossing Time (bow crossing time) xx min. xx sec. or yy.yy min.*

* TCPA and BCT times can be displayed as xx:xx (minutes: seconds) or yy.yy (minutes and decimals).
Negative TCPA or BCT values, such as "-xx: xx" or "-yy.yy", mean that the closest point of approach or bow crossing range of the target has already passed (the closest point of approach or bow crossing range was xx minutes xx seconds ago or yy.yy minutes ago. The target is now moving away). Some devices do not display negative data.

(b) Numerical data display of TT
Figure 3-44 Example of TT display

(Omitted)

To assess the risk of collision using the TT system, numerical data - such as that shown in Figure 3-44(b) - is used alongside the vectors of object markers.

Small CPA (DCPA) → High risk of collision

Depending on the size and maneuverability of one's own vessel, for example,

0.2 NM or less: Take evasive action without delay if necessary

0.5 NM or less: Very dangerous

1.0 NM or less: Caution required

Small TCPA → Little or no time margin to take action

For object markers with small CPAs, it is effective to take evasive action while the TCPA is still large and there is sufficient time margin.

A small CPA (DCPA) value indicates a short closest point of approach, meaning the risk of collision is high if both vessels maintain their current courses. The example figures above serve only as rough guidelines for a typical small coastal cargo vessel and can vary depending on the maneuverability of the vessel, because it is important to understand the specific judgment criteria applicable to the vessel navigator is sailing. Larger CPA values may still be considered dangerous for larger vessels, and even greater caution is required for very large crude-oil carriers (VLCCs) and mega-container ships exceeding 300 meters in length.

(2) Risk of the vessel pilot becoming overconfident due to small CPA values indicated by the Automatic Radar Plotting Aids (ARPA)*[17] function

In the reference*[18], the CPA values are presented as follows.

John Hamilton "Third", *author of* A Rough Guide to Collision Avoidance, Navigation Accidents and Their Causes *(cited in this document), acknowledges that the use of ARPA for collision avoidance is effective but cautions against ship operators placing excessive trust in the small CPA values indicated by the ARPA function. In particular, the reference gives an example where a CPA of 0.5 M or less on the open ocean is considered a state with no immediate risk of collision - that is, it is not yet time to take evasive navigational measures, as the risk of collision is not imminent.*

(3) Influence of ship length on situational awareness

The reference*[19] points out that ship length is not considered when calculating CPA and TCPA, and offers the following inference.

Depending on the conditions of the two vessels and the position of the GPS antenna, when the reference point for calculating TCPA and DCPA is set at the center of the hull or the collision point, the difference between these reference points can become significant relative to L (the length of the ship). This discrepancy tends to increase as L becomes larger. Consequently, in certain navigational situations, ARPA information may overestimate the actual safety margin, potentially delaying the operator's recognition of imminent danger.

2.12 Information on Operation

(1) Vessel A

i) Regarding the Master's command on deck in narrow water channels, the Seafarers' Act stipulates the following.

(Command on deck)

Article 10: The Master (omitted) *must be on deck and in personal command of the vessel when passing through a narrow water channel or when any other danger to the vessel exists.*

ii) According to the Operational Standards established by Company A_2, based on the Safety Management Regulations (which must be reported to the Minister of Land, Infrastructure, Transport and Tourism pursuant to Article 11 of the Coastal Shipping Act (Act No.151 of 1952)), the following provisions apply to watchkeeping in narrow channels.

(Duty arrangement, etc.)

Article 6: Master shall determine the following arrangements and assignments in consultation with the shipowner, etc., and report them to the operation manager. The same procedure shall apply to any subsequent changes.

(1)–(4) (Omitted)

(5) Navigation arrangement in narrow water channels

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*[17] "Automatic Radar Plotting Aids (ARPA)" refers to a device that automatically processes changes in the positions of other ships detected by radar using computer algorithms. It displays information such as the other ship's course, speed, closest point of approach (CPA), time to closest point of approach (TCPA), predicted future position, and sounds an alarm - similar to the TT (Target Tracking) function - if a collision risk is detected due to proximity.

*[18] "On the Problem of Passing Safely in Cases Where New Collision Risk Applies" (Saeko Fujiwara (Morita), Masashi Fujimoto, Munetaka Konishi, Masateru Fuchi: Proceedings of the Japan Institute of Navigation, Vol. 137, Lecture at the 136th Lecture Meeting).

*[19] "Evaluation of Situational Awareness in Container Ship Collision Accidents" (Miyake Rina, Ito Hiroko, Yamamoto Seiko, Makino Masato: 2019, Proceedings of the Japan Institute of Navigation, Vol. 140)

iii) According to the statements of the person in charge of the Company A_2 and the response to the questionnaire, the Company A_2's understanding of navigation arrangements in narrow water channels was as follows.

Company A_2 has been operating similar vessels on the Kurushima Kaikyo Traffic Route with the same duties prior to assuming operational management of Vessel A. Our understanding is that when navigating narrow water channels, master is always present in the bridge and conducts navigational duty together with the officer on duty and ordinary seaman on duty. We seem that this practice is a standard behavior. During our visits on vessels, we have heard various accounts from masters, but none have reported being absent from the bridge while in narrow channels. Although some masters have mentioned feeling sleepy, since the vessels depart from Kobe Port and pass through the routes of Akashi, Bisan Seto, and Kurushima before arriving at Kanda Port at dawn, many have reported that despite sleepiness, they remain in the bridge throughout.

Before the Company A_2 assumed operational management, Company A_1 had chartered a similar roll-on-roll-off cargo ship to another operator on the Kurushima Kaikyo Traffic Route, because we never confirmed with Company A_1 whether the master was present in the bridge during navigation. Since it is generally expected that the master remains in the bridge, this was not a matter requiring discussion with the shipowner. The prevailing understanding was that master, navigation officer, and able seaman or ordinary seaman should all be on duty during navigation in narrow water channels.

iv) Ordinary Seaman A_1 made the following statements regarding the watchkeeping system in the bridge.

At the time of the accident, Master A left the bridge and transferred command of Vessel A to N. Officer A_1 near No.4 Kurushima Kaikyo Traffic Route Light Buoy. There is no fixed time for Master A to leave the bridge near the western entrance of the Kurushima Kaikyo Traffic Route; this decision is made based on factors such as the surrounding vessel traffic volume.

(2) Vessel B

According to the Master's Standing Orders for Navigation on Vessel B, the following provisions were established regarding the assignment of navigation officers and the basic watchkeeping system during navigation in the Seto Inland Sea.

2. Keeping a Good Watch

(Omitted)

4) In the following area where higher workload for navigation and collision avoidance is expected, two licensed officers (including Master) shall be placed on the bridge.

- (Omitted)
- *Inland Sea of Japan*
- (Omitted)
- (Omitted)

2.13 Analytical Investigation into the Factors of the Accident Occurrence by the National Maritime Research Institute, National Institute of Maritime, Port and Aviation Technology

2.13.1 Research of Assessment, etc. of Collision Risk between Vessels

To support the investigation into the cause of the accident, the National Maritime Research

Institute, National Institute of Maritime, Port and Aviation Technology (hereinafter referred to as "NMRI") was commissioned to assess cognitive support related to the behavior of both vessels prior to the collision, based on AIS data. NMRI also analyzed contributing factors by examining the navigational status of vessels in the surrounding waters.

The results of this analytical investigation are presented in Attachment 1.

The analysis employed four collision risk assessment indices: CJ (Collision Judgment), SJ (Subject Judgment), BC (Blocking Coefficient), and OZT (Obstacle Zone by Target). A brief overview of each index is provided below.

(1) CJ

CJ is an index that quantifies the risk of collision between two vessels in a one-to-one encounter. The risk level increases as the opposing vessel approaches.

Previous studies have indicated that a CJ value of 0.015 or higher signifies a clear risk of collision. In addition, analysis correlating CJ values with perceived danger suggest that a value of 0.007 or higher serves as a threshold for sensing potential collision risk, while a value of 0.013 or higher is associated with the perception that a collision is unavoidable.

(2) SJ

SJ is an index that evaluates the subjective perception of collision risk between two vessels, based on the perspective of an average vessel operator.

The SJ value ranges from −3 to +3, with the following interpretations:

Extremely dangerous	SJ = −3	Somewhat safe	SJ = +1
Dangerous	SJ = −2	Safe	SJ = +2
Somewhat dangerous	SJ = −1	Extremely safe	SJ = +3
No perceived risk	SJ = 0		

(3) BC

BC is an index that represents the extent to which the navigable space is obstructed by surrounding vessels, indicating the degree of blockage of the area available for avoidance maneuvers.

The value of BC ranges from 0 to 1. When BC is 1, it indicates that the area is completely blocked, leaving virtually no time margin and making collision avoidance through maneuvering impossible.

(4) OZT

OZT refers to a zone where a vessel's operating space is expected to be obstructed in the near future by other vessels. The evaluation zone - defined by specific direction and distance settings from the vessel - is used to determine whether an OZT poses a high collision risk. If an OZT falls at least partially within this evaluation zone, it is classified as an "OZTs with high collision risk." All other OZTs are categorized as "OZTs with low collision risk."

(See Attachment 1, Report on Analysis Contract for Collision Accident of Cargo Ship and Chemical Tanker.)

2.13.2 Analytical Investigation Regarding the Stability, Capsizing, and Foundering of Vessel A

To contribute to the investigation into the cause of the foundering of Vessel A in this accident, NMRI was commissioned to conduct an analytical investigation estimating the vessel's stability and the circumstances that led to its capsizing and foundering.

This analysis was based on damage status information provided by the Committee at the time of commissioning. In November 2023, the damage status of the salvaged Vessel A was confirmed, revealing some differences from the initially assumed damage status; however, it was confirmed that these differences would not affect the analysis results.

The findings of the analytical investigation are presented in Attachment 2.

(See Attachment 2: Report on Analytical Investigation of Sinking Accident (Sinking of Cargo Ship A))

2.14 Examples of Similar Accidents

Since October 2008, three collisions involving cargo ships or tankers (excluding small vessels under 20 gross tons) have occurred near the west entrance of the Kurushima Kaikyo Traffic Route. All accidents took place at night during the southward tidal current in the Kurushima Strait. (see Figure 22)

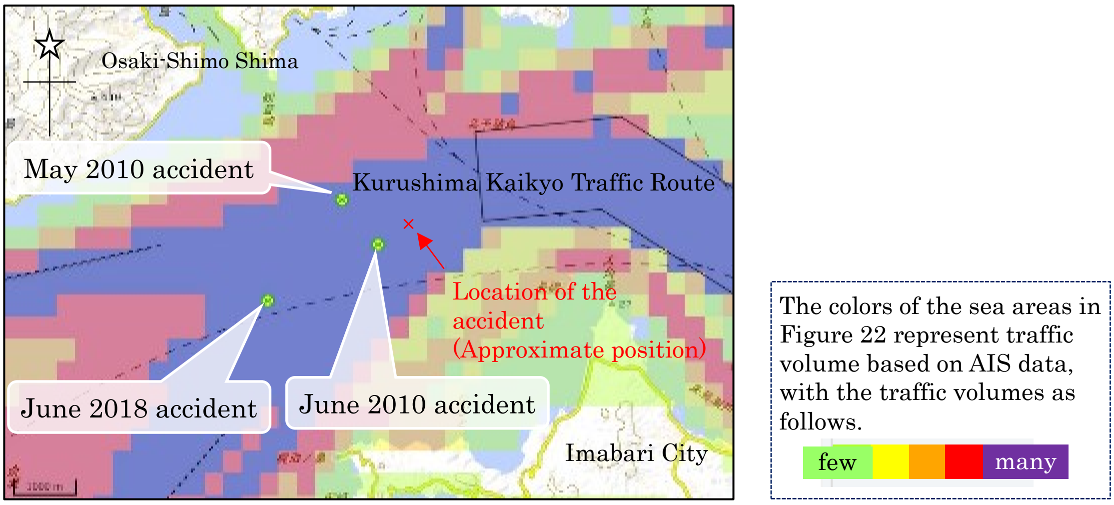


Figure 22 Locations of collisions involving cargo ships or tankers near the west entrance of the route (3 cases)

3 ANALYSIS

3.1 Situation of the Accident Occurrence

3.1.1 Course of Events leading to the Accident

The JTSB concludes that, based on Section 2.3, it is probable that the sequence of events leading to the accident involving Vessel A and Vessel B were as follows. (see Figures 23 and 24)

(1) Vessel A

i) At around 23:48 on May 27, 2021, Vessel A overtook Vessel D, which was sailing ahead on the port side, by overtaking from the starboard side near the time it passed No.4 Kurushima Kaikyo Traffic Route Light Buoy.

ii) Upon departing the Kurushima Kaikyo Traffic Route, N. Officer A_1 conducted trial maneuvering using the radar and determined that turning Vessel A 230° to port would allow passage clear of Vessel B with a CPA of approximately 0.2M. Consequently, he instructed Ordinary Seaman A_1 to "Port easy" to adjust the course to 230°.

iii) Vessel A departed the Kurushima Kaikyo Traffic Route at around 23:51:27, altered its course from approximately 260° to approximately 230° between 23:51:46 and 23:52:53, and continued to sail at an approximate speed of 17.3 kn.

iv) N. Officer A_1 spotted Vessel B when Vessel A was on a course of 230° and perceived a risk of collision.

v) Vessel A received a VHF call from Vessel B, and at around 23:53:03, in response to N. Officer B_1's "Port to Port" call, N. Officer A_1 replied "OK," then instructed Ordinary Seaman A_1 to steer "Starboard," which Ordinary Seaman A_1 promptly followed.

vi) Between 23:53:27 and 23:53:39, Vessel A turned starboard, changing its course from approximately 233° to approximately 241°, while maintaining a speed of approximately 17.8 to 17.6 kn.

vii) At around 23:53:38, Vessel A collided with Vessel B while turning starboard at approximately 17.6 kn.

(2) Vessel B

i) At around 23:43, Vessel B passed the WS Line off the west coast of Kajitori-no-Hana. N. Officer B_1 reported this to Kurushima MARTIS, which informed him that the currents in the Kurushima Strait were flowing south and advised him to head toward Naka Suido. At around 23:46, Kurushima MARTIS repeated the instruction to proceed toward Naka Suido.

ii) At around 23:48, Master B came onto the bridge of Vessel B and took over command from N. Officer B_1.

iii) N. Officer B_1 instructed a course of 040° at around 23:48. Master B then directed a course change to 035° at around 23:49:25 and further adjusted to 030° at around 23:50:38. Between 23:49 and 23:53, Vessel B altered course from approximately 038° to 030°, navigating north of the west entrance of the Kurushima Kaikyo Traffic Route, at speeds between approximately 14.7 and 14.2 kn.

iv) At around 23:49:40, Master B detected Vessel A using No.1 Radar. Master B judged that maintaining their current course and speed posed little risk of collision and intended to pass behind Vessel A. N. Officer B_1 also expected Vessel A to pass ahead of Vessel B since Vessel A was faster. N. Officer B_1 also thought that Vessel A would pass ahead of Vessel B since Vessel A was faster.

v) At around 23:52:42, Master B muttered to himself in Korean, "Why is that vessel heading toward us?" Shortly after, at around 23:52:45, Master B gave an instruction to change course to 020°.

vi) At around 23:52:49, Master B said in Korean, "Where is that heading?"

vii) At around 23:52:50, N. Officer B_1 called Vessel A via VHF to inquire about Vessel A's maneuvering intentions but received no response. At around 23:53:03, N. Officer B_1 instructed Vessel A to "Port to Port," and immediately afterward, Master B gave the order "Hard port."

viii) Between around 23:53:17 and 23:53:41, Vessel B turned to port, changing course from approximately 029° to approximately 022° (heading: 335° from 021°), while navigating at a speed between approximately 14.3 and 13.6 kn.

ix) At around 23:53:38, Vessel B collided with Vessel A while turning to port at around 13.6 kn.

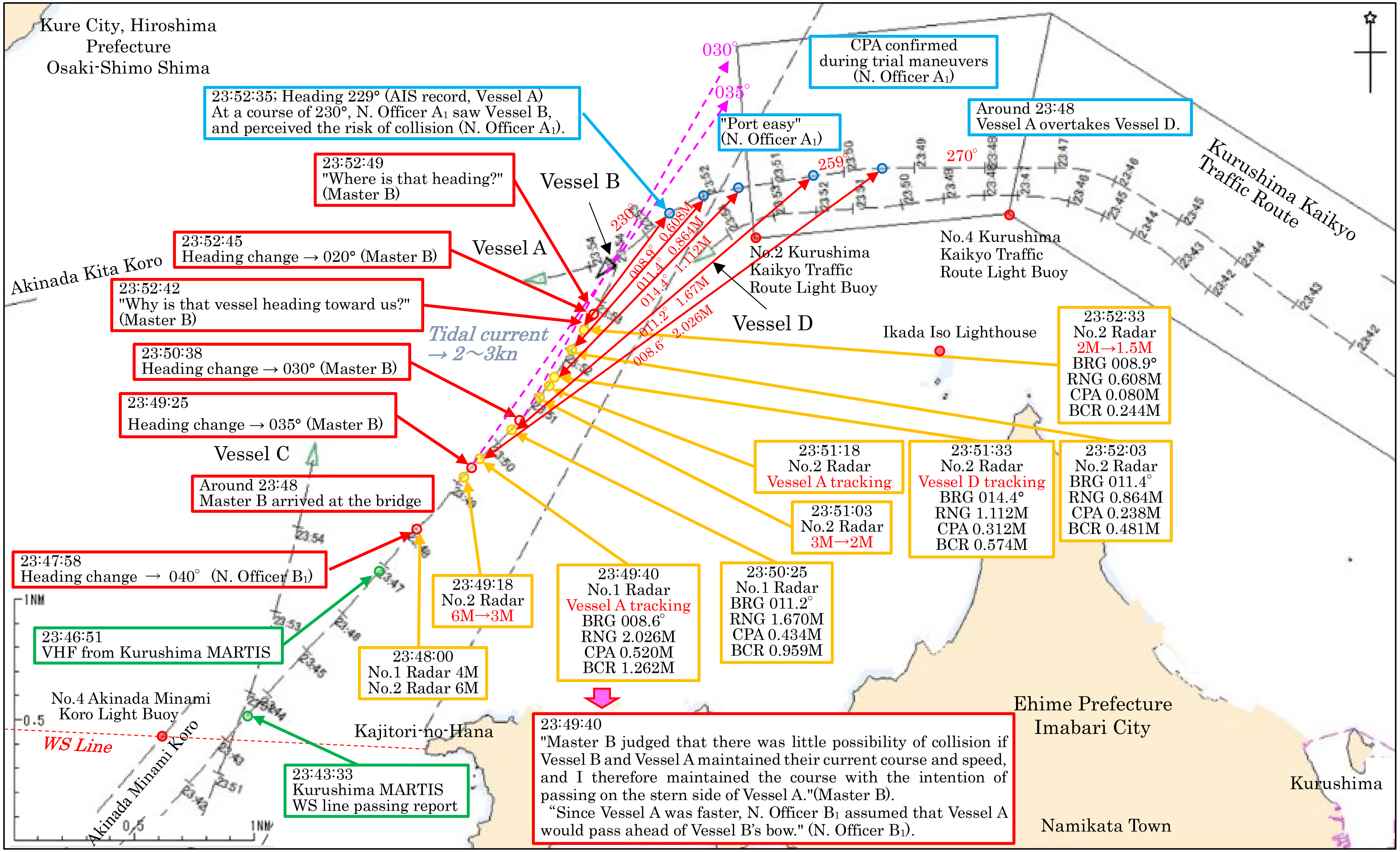


Figure 23 Course of events leading to the accident involving Vessel A and Vessel B (from around 23:43)

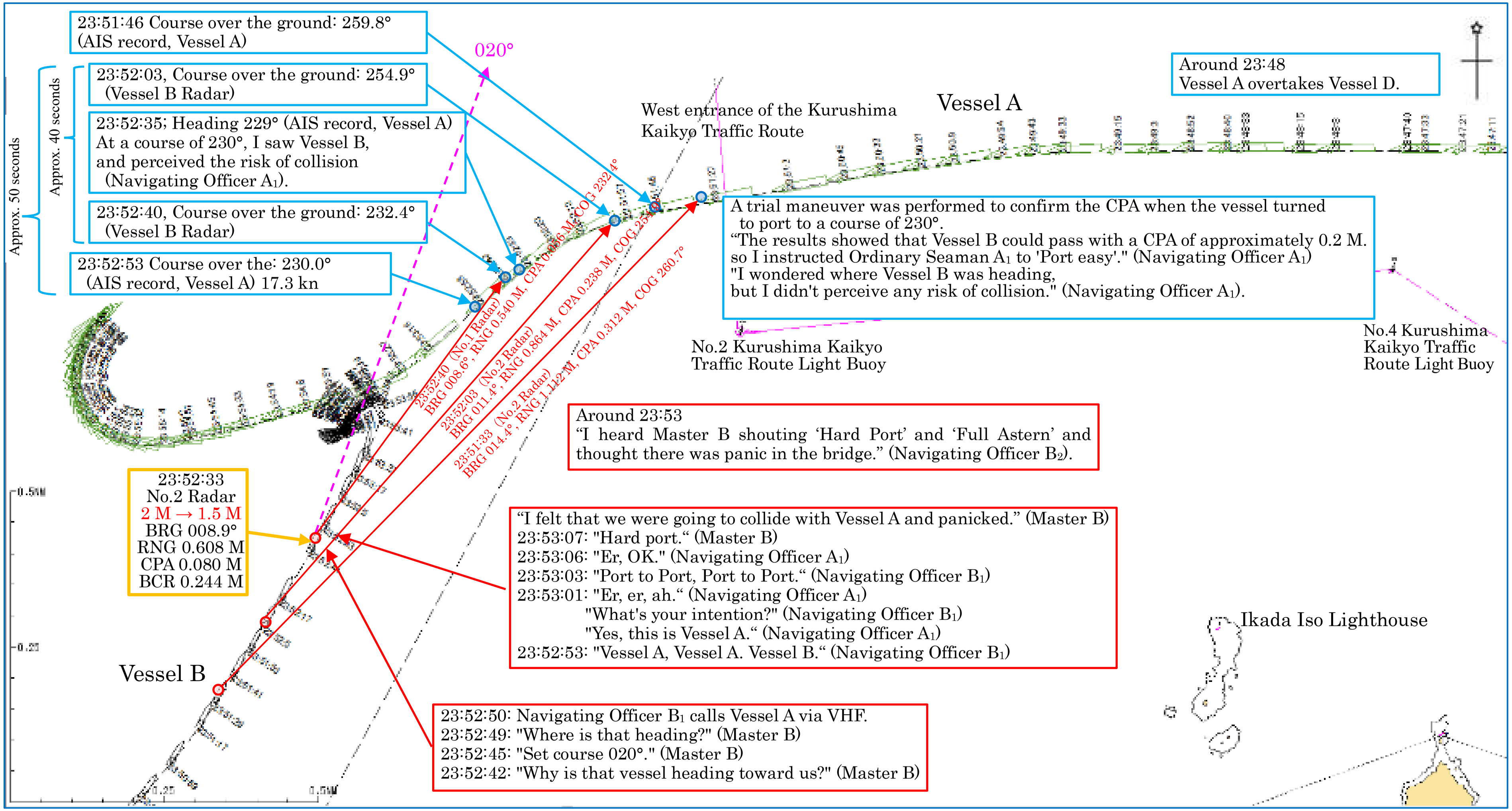


Figure 24　Course of events leading to the accident for Vessel A and Vessel B (from around 23:51)

3.1.2 Situation of Collision

The JTSB concludes that, based on Sections 2.7, 3.1.1, and Figure 25, it is probable that Vessel A was navigating at approximately 17.6 kn and Vessel B at approximately 13.6 kn when the center of the port side of Vessel A collided with the bow of Vessel B.

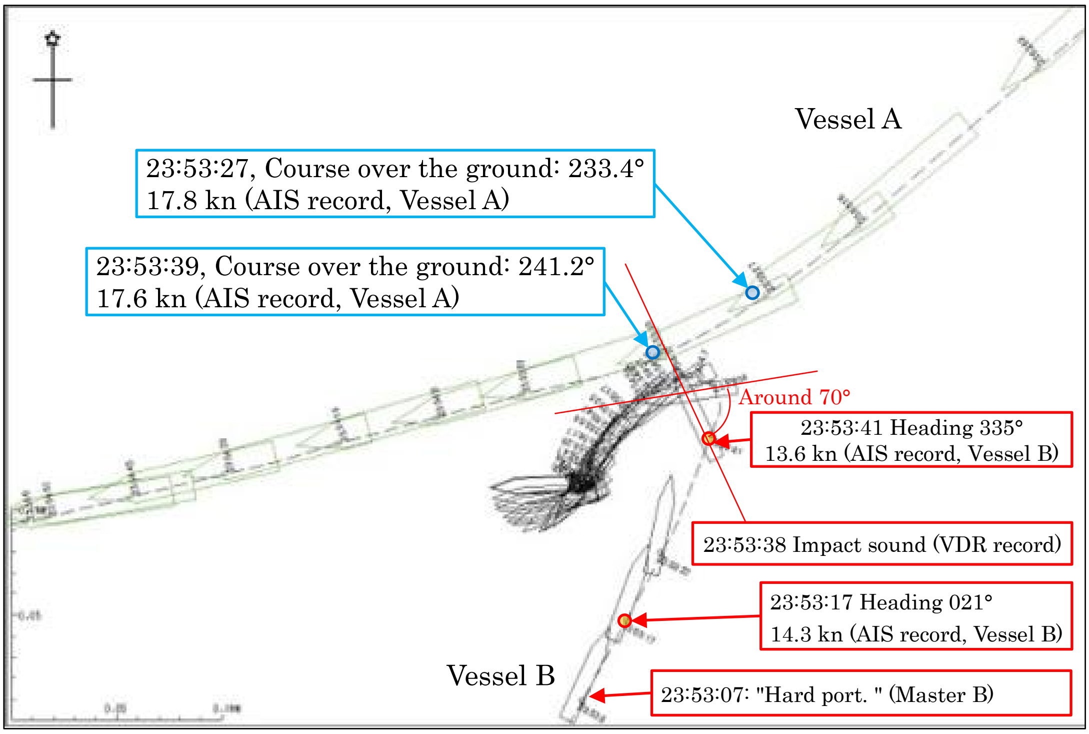


Figure 25 Collision situation of Vessel A and Vessel B

As described in Section 2.4, N. Officer B_1 stated, "It's not accurate, but it felt like Vessel B was being dragged along with Vessel A for approximately 10 to 15 seconds after the collision. Because Vessel A was faster than Vessel B, it felt like it was being dragged along, and then separated." However, according to the AIS record, Vessel B made a left turn of approximately 70° between 23:53:41 and 23:53:56, and it is possibly indicating that Vessel B moved as if being pushed by the faster Vessel A, rather than being dragged. (See Figure 25)

3.1.3 Date, Time, and Location of the Accident

The JTSB concludes that, based on Section 2.3.4, it is highly probable that the date and time of occurrence of the accident was at around 23:53:38 on May 27, 2021, when an impact sound was recorded in Vessel B's VDR record (see Attachment 3), and the location of the accident was approximately 285° and 1.4 M from Ikada Iso Lighthouse, according to the AIS records of Vessel A and Vessel B.

3.1.4 Situation after Collision

The JTSB concludes that, based on Sections 2.4, 2.5, and 2.13.2 (Attachment 2), it is probable that the situation after the collision was as follows.

(1) Vessel A

After the collision, N. Officer A_1 went to call Master A. Once Master A arrived at the bridge, the other crew members also gathered there.

Master A, N. Officer A_1, and others observed the collision from the port wing. The hull began to lean gradually, and Master A instructed N. Officer A_2 to correct the leaning. N. Officer A_2 attempted to correct it by adjusting the water level in the Heel tanks, but the leaning worsened.

Alarms for the main engine and other equipment sounded in the bridge, prompting Engineer A_1 and Engineer A_2 to head to the engine room.

N. Officer A_2 continued attempts to correct the leaning, but the hull did not return to an upright position. Due to sea water ingress through the breach and the lateral movement of loaded vehicles onboard caused by the breaking of lashing belts, by around 00:01 on May 28, when Master A decided to abandon the vessel, Vessel A was leaning approximately 37° to port, with the bow (No.2 Deck, the upper deck) submerged.

Concerned about the main engine's condition, Chief Engineer A initially proceeded to the engine room but returned to the bridge upon seeing the severe lean and ingress water reaching No.2 Deck.

After Master A decided to abandon the vessel, the crew members of Vessel A who had gathered at the bridge each went to retrieve their life jackets. Chief Engineer A received a life jacket from Ordinary Seaman A_3 while returning to the bridge, then proceeded back to the bridge, contacted the engine room, and instructed Engineer A_2 to abandon the vessel.

Three crew members - N. Officer A_2, Chief Engineer A, and Ordinary Seaman A_3 - evacuated from the port side, while six crew members - N. Officer A_1, N. Officer A_3, Boatswain A, Ordinary Seaman A_1, Ordinary Seaman A_2, and Chief Cook - evacuated from the starboard side.

As Vessel A continued to flood, it began to lean and eventually capsized to port side down. It then turned bottom side up and gradually foundered with its bow tilted downward until only the starboard aft. side remained visible above the water line. Vessel A fully foundered at around 02:43.

(2) Vessel B

After the collision with Vessel A, Master B turned on all lights on the decks, inspected the damage to the bow, and instructed the crew member to use searchlights to look for Vessel A and her crew member. At around 01:32, a rescue operation was requested via VHF to Kurushima MARTIS. A rescue boat of Vessel B conducted search and rescue operation for approximately an hour and a half but was unable to recovery anyone.

3.1.5 Situation of Rescue, etc. of Persons who Escaped into Sea Water from Vessel A

The JTSB concludes that, based on Section 2.5, the rescue situation of the crew member who escaped into the water from Vessel A is probably as follows.

Of the nine crew members who escaped, four - N. Officer A_3, Boatswain A, Ordinary Seaman A_1, and Chief Cook - were recovered while floating on the sea surface by a container ship that came to assist. The remaining five - N. Officer A_1, N. Officer A_2, Chief Engineer A, Ordinary Seaman A_2, and Ordinary Seaman A_3 - were recovered by a JCG patrol boat. The recovered crew members were transported by ambulances from Imabari Port to the hospital. Four crew members - N. Officer A_3, Boatswain A, Ordinary Seaman A_1, and Chief Cook - arrived at the hospital at 03:17, while the remaining five - N. Officer A_1, N. Officer A_2, Chief Engineer A, Ordinary Seaman A_2, and Ordinary Seaman A_3 - arrived by 04:20.

3.1.6 Status of Fatalities, Injuries, etc.

The JTSB concludes that, according to Sections 2.4, 2.5 and 2.6, the casualties and injuries were as follows.

(1) Master A

After giving the order to abandon the vessel, Master A and N. Officer A_2 went to their respective rooms to retrieve life jackets. N. Officer A_2 spotted Master A on the starboard side after returning to the bridge. However, Master A subsequently went missing and was later found in the bathroom lobby of the crew accommodation area of the salvaged Vessel A on October 25, 2023. DNA testing confirmed that the dead body was that of Master A. The actions of Master A after being spotted by N. Officer A_2 could not be determined, as there were no witnesses or objective information available.

(2) Engineer A_1

Engineer A_1 went to the engine room with Engineer A_2 to check the main engine and the generators after alarms sounded following the accident but subsequently went missing. He was discovered in the engine room of the foundered Vessel A on August 20, 2021, and the autopsy indicated drowning as the suspected cause of death.

It is unclear how long Engineer A_1 remained with Engineer A_2, as there were no witnesses or objective information. However, when Chief Engineer A headed for the engine room at around midnight on May 28, he had just descended to the vehicle deck and thought he could not reach the engine room because Vessel A was leaning to the left. Based on this, it is probable that Engineer A_1 drowned when it became difficult to escape overboard as Vessel A leaned to the left and seawater flowed into Vessel A.

(3) Engineer A_2

Engineer A_2 went to the engine room with Engineer A_1 to check the main engine and the generators after alarms sounded following the accident. After around 00:01, Chief Engineer A called the engine room from the bridge via direct call to instruct evacuation. Engineer A_2 agreed but subsequently went missing and was found in the steering gear room of the foundered Vessel A on May 30. The autopsy determined drowning as the cause of death.

What Engineer A_2 did after answering the phone in the engine room was unknown, as there were no witnesses or objective information available. However, as described in (2) above, it is likely that Engineer A_2, like Engineer A_1, died from drowning when Vessel A leaned to the port side and seawater flooded Vessel A, due to making escape overboard difficult.

(4) Chief Engineer A

It is highly probable that after the accident occurred, when Chief Engineer A headed to the engine room to check the condition of the main engine and other machinery, he slipped on the vehicle deck due to Vessel A leaning to port and struck his body against the sidewall, resulting in a fracture of the distal end of the left clavicle.

(5) N. Officer A_1, N. Officer A_2, N. Officer A_3 and Ordinary Seaman A_1

Based on the sprains and bruises sustained by N. Officers A_1, A_2, A_3, and Ordinary Seaman A_1, it is probable that these injuries were caused by falling or slipping during their escape from Vessel A or as a result of the hull's leaning.

3.1.7 Status of Damage to Vessels

The JTSB concludes that, from Section 2.7, the damage caused by the collision between Vessel A and Vessel B was as follows.

(1) Vessel A

Vessel A suffered a breach in the center of the port side, extending from frame number from

94 to 111. The breach was shaped like an inverted triangle, with a base of approximately 12.5 meters on the underside of No.1 Deck and a height of approximately 9.8 meters, with the apex located near the bilge keel.

(2) Vessel B

Vessel B suffered crushing damage to the bow, including the collapse of the forward mast light, and bending damage to the bulbous bow.

3.1.8 Situation of Operations

(1) Bridge Watchkeeping System

The JTSB concludes that, according to Sections 2.3 and 2.12, the bridge watchkeeping system was as follows.

i) Vessel A

Master A left the bridge after passing the Kurushima No.3 Ohashi and turning starboard, and after passing the No.4 Kurushima Kaikyo Traffic Route Light Buoy, and was probably not in command of Vessel A's maneuvering at the time of the accident.

The Seafarers' Act requires the master to be on deck in command when transiting narrow waterways. In addition, although Company A_2's Operational Standards stipulated procedures for determining duty assignments in narrow waterways, these procedures were not followed. Meanwhile, it is probable that the person in charge of Company A_2 understood that the master, officer on duty and crew member on duty would be assigned during narrow water channel transits, because they believed Master A was in the bridge.

ii) Vessel B

After passing the WS Line, Master B was contacted by N. Officer B_1 by phone and is recognized to have come up to the bridge at around 23:48.

According to the Master's Standing Order for Navigation of Vessel B, when sailing through the Seto Inland Sea, two officers qualified to keep duty in the bridge (including the master) were required to be stationed in the bridge.

(2) Route planning for Vessel B

The JTSB concludes that, from Section 2.3.4, it is certain that Vessel B was planning to navigate Nishi Suido from the south side of the west entrance of the Kurushima Kaikyo Traffic Route until around 23:49:23, when Master B instructed a change of plan to navigate to Naka Suido instead of Nishi Suido.

3.2 Causal Factors of the Accident

3.2.1 Situation of Crew Members

The JTSB concludes that the situation of crew members is as follows.

From Section 2.8, Master A, N. Officer A_1, Master B, and N. Officer B_1 each held legal and valid certificates of competence. Additionally, Ordinary Seaman A_1 possessed sufficient maritime knowledge and approximately two years of seagoing service experience, qualifying him for exemption from the written examination for the Fourth Grade Maritime Officer (Navigation) license. All of them were in good health at the time of the accident, and it is probable that there was nothing that would have hindered the operation of the vessel.

Master B had ample experience navigating the Kurushima Strait, whereas N. Officer B_1 had passed through the Kurushima Strait from the west approximately ten times, both during the day and at night.

3.2.2 Situation of Vessels

(1) Situation of the hull, engine and equipment

The JTSB concludes that, based on Section 2.9.3, it is probable that there were no defects or malfunctions in the hulls, engines, or equipment of Vessel A and Vessel B at the time of the accident.

(2) Situation of Visibility from Vessel A and Vessel B

The JTSB concludes that, from Section 2.9.5, since a sister vessel of Vessel A had no structures on the bow side that would have created a blind spot, it is highly probable that Vessel A similarly had no such structures on its bow side causing a blind spot. There were no structures obstructing the forward view from the bow of Vessel B.

3.2.3 Situation of Watchkeeping and Maneuvering

(1) Vessel A

The JTSB concludes that the situation of watchkeeping and maneuvering of Vessel A was as follows:

i) Based on Sections 2.3.4 and 2.11.1, it can be inferred that when N. Officer A_1 departed from the west entrance of the Kurushima Kaikyo Traffic Route, he questioned Vessel B's intended course, as Vessel B was proceeding unusually according to the radar. However, because he did not perceive any risk of collision, N. Officer A_1 did not initiate VHF communication to convey his own intentions or to confirm Vessel B's maneuvering plans, and continued navigating as planned.

ii) Based on the following information, it can be inferred that N. Officer A_1 departed from the west entrance of the Kurushima Kaikyo Traffic Route and executed a port turn toward the Akinada Minami Koro.

a. He believed that maintaining his current course from the west entrance of the Kurushima Kaikyo Traffic Route would bring him close to Vessel C, which was approaching from behind Vessel B. (2.3.4)

Vessel A encountered OZT with Vessel C at around 23:51 on May 27 (2.13.1 (Attachment 1 (3.2)).

b. Since only two vessels - Vessel B and Vessel C - were in the Akinada Minami Koro, N. Officer A_1 intended to pass between them and proceed along the Koro. In addition, when departing the Kurushima Kaikyo Traffic Route, N. Officer A_1 conducted trial maneuvers using radar and determined that the 230° port turn would allow Vessel A to pass Vessel B with a CPA of approximately 0.2 M. N. Officer A_1 then instructed Ordinary Seaman A_1 to "port easy" to change course to 230°.

iii) The exact timing of N. Officer A_1's trial maneuvering was unknown. However, considering the radar operation time, if the maneuvering occurred at around 23:50 before departing the Kurushima Kaikyo Traffic Route, Vessel B's course over ground at that time was at approximately 048°. However, at around 23:50, Master B ordered to set at a course of 035°, while Vessel B's actual course over ground was significantly to the right of this heading. Thereafter, Master B instructed to set a course of 030°, and Vessel B's course over ground gradually adjusted toward this heading. By around 23:51:29, the course over ground reached 035.2°. Since the trial maneuvering results were based on the assumption that the other vessel would maintain its current course and speed - and that the own vessel would likewise maintain its course and speed until initiating the turn - it is possible that the actual CPA value, considering the course intended by N. Officer A_1 and the course aimed for by Master B, was even smaller than the estimated CPA calculated from the data available at the time of the trial maneuvering.

iv) According to Section 3.1.1, Vessel A departed the Kurushima Kaikyo Traffic Route at around 23:51:27, changed course from approximately 260° to approximately 230° between 23:51:46 and 23:52:53, and continued sailing at a speed of approximately 17.3 kn. N. Officer A_1 sighted Vessel B once Vessel A had completed its course change. At that time, the distance between Vessel A and Vessel B was approximately 0.5 M.

v) N. Officer A_1 stated, "I did not see the detailed movements of Vessel B, but I think that Vessel B probably turned to port after that." (Section 2.3.5) When Vessel A departed the Kurushima Kaikyo Traffic Route (at around 23:51:30), Master B had instructed to set a course of 030°, while the actual course over ground was at approximately 035°. Subsequently, Vessel B's course gradually adjusted and converged toward the instructed to set the course of 030°. By around 23:52:42, at the time Master B was heard muttering to himself, Vessel B's course over the ground was at approximately 031°. Consequently, from Vessel A's perspective, Vessel B appeared to have altered its course approximately 5° to starboard. Furthermore, N. Officer A_1 stated that "Vessel B appeared to be continuing to turn to port gradually, but it was difficult to notice" (Section 2.3.5). On the other hand, human ability to visually detect rate of change in heading is generally considered to be approximately 1 to 2 degrees per minute when a reference point is available (see Attachment 1, 4.1(1)). Given that the rate of change in Vessel B's compass heading from around 23:51 to 23:53 exceeded 2 degrees per minute, it is probable that it could not be concluded that the port turn was difficult to notice.

vi) N. Officer A_1 stated, "An agreement was reached with Vessel B via VHF to pass Port to Port, so Vessel A turned to starboard." "I judged that there would be no collision if Vessel B also turned to starboard as agreed, so I did not take any measures to reduce speed." (Section 2.3.5) At that time, no vessels were present on Vessel A's starboard side that would have hindered its turning starboard. Furthermore, as shown in Attachment 1, 4.2 (3) and Figure 4.4, the BC value of Vessel A relative to Vessel B was nearly "0" from around 23:50 to around 23:53, indicating that the difficulty of maneuvering was extremely low. Consequently, it is possible that N. Officer A_1 did not feel the need to slow down.

vii) According to Appendix Table 2, at around 23:52:53 when Vessel A was heading for a course of 230°, Vessel A and Vessel B were approximately 0.4 M apart and had a CPA of 0.04 M. Based on this, it is possible that when N. Officer A_1 saw Vessel B when Vessel A was heading for a course of 230°, he sensed the risk of a collision and failed to respond to the VHF call from Vessel B.

viii) Based on the following, it is possible that at around 23:53 when Vessel B called by VHF, the two vessels appeared to the crew member onboard as if they were facing each other head-on.

a. Ordinary Seaman A_1, when Vessel A was turning to port, could not see Vessel B because the window frame in front of the bridge was obstructing the view from the steering stand where Ordinary Seaman A_1 was standing, and because Vessel B was surprisingly small. On the other hand, when the course was set to 230° in response to the orders of "Midship" and "Steady" from N. Officer A_1, Ordinary Seaman A_1 felt as if Vessel

B was coming toward Vessel A head-on (Section 2.3.4).

b. According to the AIS records of Vessel A and Vessel B and the VDR record of Vessel B, the relative positions of the two vessels at around 23:53 were as shown in Figure 26. The heading of Vessel A was 228° and the heading of Vessel B was 025°, with Vessel A seeing Vessel B's bow approximately 13° to the port bow and Vessel B seeing Vessel A's bow approximately 8° to the starboard bow. (See Figure 26)

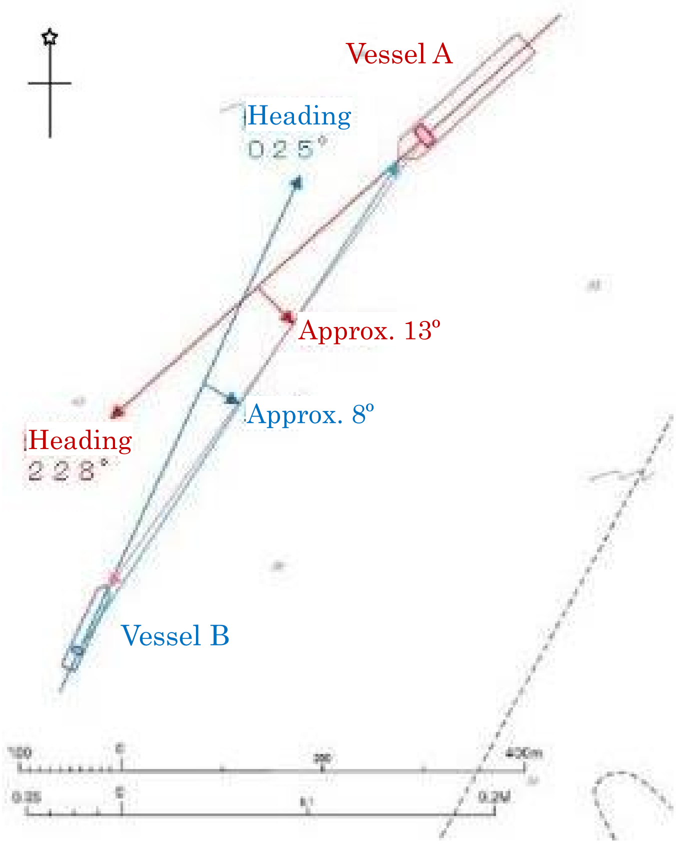


Figure 26 The relative position of Vessel A and Vessel B just before the collision (at around 23:53)

(2) Vessel B

The JTSB concludes that the situation of watchkeeping and maneuvering of Vessel B was as follows:

i) From Sections 2.3.4 and 3.1.1, Vessel B received two communications from Kurushima MARTIS at around 23:43 and at around 23:46 to head toward Naka Suido. At around 23:48, after Master B came up to the bridge, the planned route that had been set in the ECDIS based on the assumption of navigating Nishi Suido was changed to a route to navigate Naka Suido.

ii) From Sections 2.3.4 and 3.1.1, it can be concluded that at around 23:48, Master B came up to the bridge of Vessel B and received a report of the contents of the communication with Kurushima MARTIS from N. Officer B_1. Thereafter, at around 23:49:25, Master B instructed a course of 035°. Therefore, during this time, command of Vessel B was probably taken over from Officer B_1 to Master B.

iii) From Section 3.1.1, at around 23:49:40, Master B detected Vessel A on No.1 Radar, and determined that there was little possibility of a collision if Vessel B and Vessel A maintained their current course and speed, and maintained the current course with the aim of passing on the aft. side Vessel A. N. Officer B_1 also thought that Vessel A would pass Vessel B's bow first because Vessel A was faster.

This suggests that Master B likely assumed that Vessel A would maintain its current course and speed, and did not consider ascertaining Vessel A's maneuvering intentions through VHF communications. Furthermore, N. Officer B_1 stated that when asked why he called Vessel A via VHF approximately 50 seconds before the collision (his statement was " approximately two minutes before"), he stated, "I thought Vessel B would be able to pass by the aft. side of Vessel A, but Vessel A was approaching so I contacted it." This suggests that N. Officer B_1 may have initially assumed that Vessel A would maintain its current course and speed, and did not consider using VHF communications to ascertain Vessel A's maneuvering intentions.

As shown in Attachment 1, Figure 4.3, the BCR indicated that until around 23:50, Vessel A and Vessel B were more than 1.0 M apart, with Vessel B passing on the aft. side of Vessel A and Vessel A passing on the bow side of Vessel B. Also, as shown in Attachment 1, Section 3.3, Vessel B encountered an OZT with Vessel A at around 23:47, and between around 23:49 and around 23:50, the OZT with Vessel A existed on the port side of Vessel B's course, but until around 23:52:10, it was an "OZT with low risk of collision."

iv) Based on the following, it is probable that Master B noticed Vessel A turning to port sometime between 23:52 and 23:52:40.

a. Vessel A began to gradually turn to port at around 23:52 (Section 2.3.4).

b. The course over the ground of Vessel A shown by Vessel B's No.1 Radar changed to 257.2° at 23:51:55, and the course over the ground of Vessel A shown by Vessel B's No.2 Radar changed to 254.9° at 23:52:03. (Appendix Table 2)

c. At around 23:52:33, the range of Vessel B's No.2 Radar was changed from 2 M to 1.5 M. (2.3.4, 3.1.1 (Figure 23, Figure 24))

d. At around 23:52:42, Master B muttered to himself, "Why is that vessel heading toward us?" (in Korean), and then at around 23:52:45, Master B instructed to set a course of 020°. (Sections 2.3.4 and 3.1.1 (Figure 23, Figure 24))

v) At around 23:52:45, Master B instructed a course of 020°, but based on the following, it is possible that Master B instructed a course of 020° assuming that Vessel A and Vessel B would pass each other starboard-to-starboard.

a. If Vessel B was to head for a course of 020° based on its position at the time when it was instructed to do so (at around 23:52:45), it would be heading north of the west entrance of the Kurushima Kaikyo Traffic Route. (Section 3.1.1 (Figure 24))

b. Vessel A's course over the ground was changing to the left until around 23:52:53 (bow heading remained almost constant from around 23:52:35), and it is possible that he thought that Vessel A would continue to turn further to port after that.

It was not clear whether Master B's consideration of the possibility of passing Vessel A starboard-to-starboard at this time influenced his issuing the "Hard port" order just before the collision.

vi) At around 23:53, when Vessel A approached almost directly in front of Vessel B, based on the following, it is probable that the bridge of Vessel B, which was ahead of Vessel A, was in a state of confusion, and it is possible that Master B was not in a state to calmly communicate with those in the bridge and make decisions on how to avoid a collision.

a. At around 23:53, Vessel A's speed was approximately 17 kn and Vessel B's speed was approximately 14 kn, and it is probable that the two vessels were approaching each other at a relative speed of more than 30 kn.

b. At around 23:53, it is possible that the two vessels appeared to crew members to be facing each other head-on (Section 3.2.3(1) (9)).

c. At around 23:52:49, immediately after changing course to 020°, Master B said, "Where is that heading?" (in Korean) (Section 2.3.4, 3.1.1 (Figure 23, Figure 24)).

d. At around 23:53, Master B felt that his vessel was going to collide with Vessel A and panicked (Sections 2.3.4 and 3.1.1 (Figure 24)).

e. Immediately after N. Officer B_1 told N. Officer A_1, "Port to Port, Port to Port," Master B shouted, "Hard port." Then, in the bridge of Vessel B, "Port to Port" and "Hard port" were shouted multiple times. In addition, Master B repeatedly called out, "Stop engine," "Full Astern," and then shouted, "Hard Starboard," and then an impact sound was heard (Section 2.3.4, 3.1.1, Attachment 3).

f. At around 23:53 when N. Officer B_2 came up to the bridge, Master B's maneuvering commands sounded like shouts in the bridge, and it seemed like a state of panic (Section 2.3.5).

vii) As described in Sections 2.3, 3.1.1, and 3.1.2, N. Officer B_1 who was surprised by the unexpected approach of Vessel A, told Vessel A to go "Port to Port" at around 23:53:03. In response, N. Officer A_1 turned to starboard, but Master B immediately gave the order to go "Hard port" at around 23:53:07. Vessel B turned to port in a manner contrary to the navigation method that N. Officer B_1 had instructed Vessel A to use, and Vessel A and Vessel B collided. It was not possible to determine why Master B ordered "Hard port." Additionally, N. Officer B_1 stated that he instinctively said, "Port to Port", and it is probable that he was shaken by the unexpected movement of Vessel A and said it spontaneously without obtaining approval from Master B.

A simulation was conducted to determine how the relative positions of Vessel A and Vessel B would have changed if Master B had not ordered "Hard port" and Vessel B had continued on the course of 020° instructed by Master B at around 23:52:45. The results are shown in Figure 27. (Regarding Vessel A, N. Officer A_1 stated, "I thought that I would not be able to avoid Vessel B unless I turned to starboard, so I planned to turn to starboard," before being called by Vessel B on VHF. Since it is assumed that Vessel A would have turned to starboard regardless, this course was used as Vessel A's track at the time of the accident. For Vessel B, the simulated track was based on the turning angular velocity and drift angle observed when Master B changed course from 035° to 030°, treated as a similar maneuvering. The simulation calculated Vessel B's track assuming it advanced from 23:53:05 (heading 025°) until reaching a heading of 020°, then maintained that heading until around 23:53:45.)

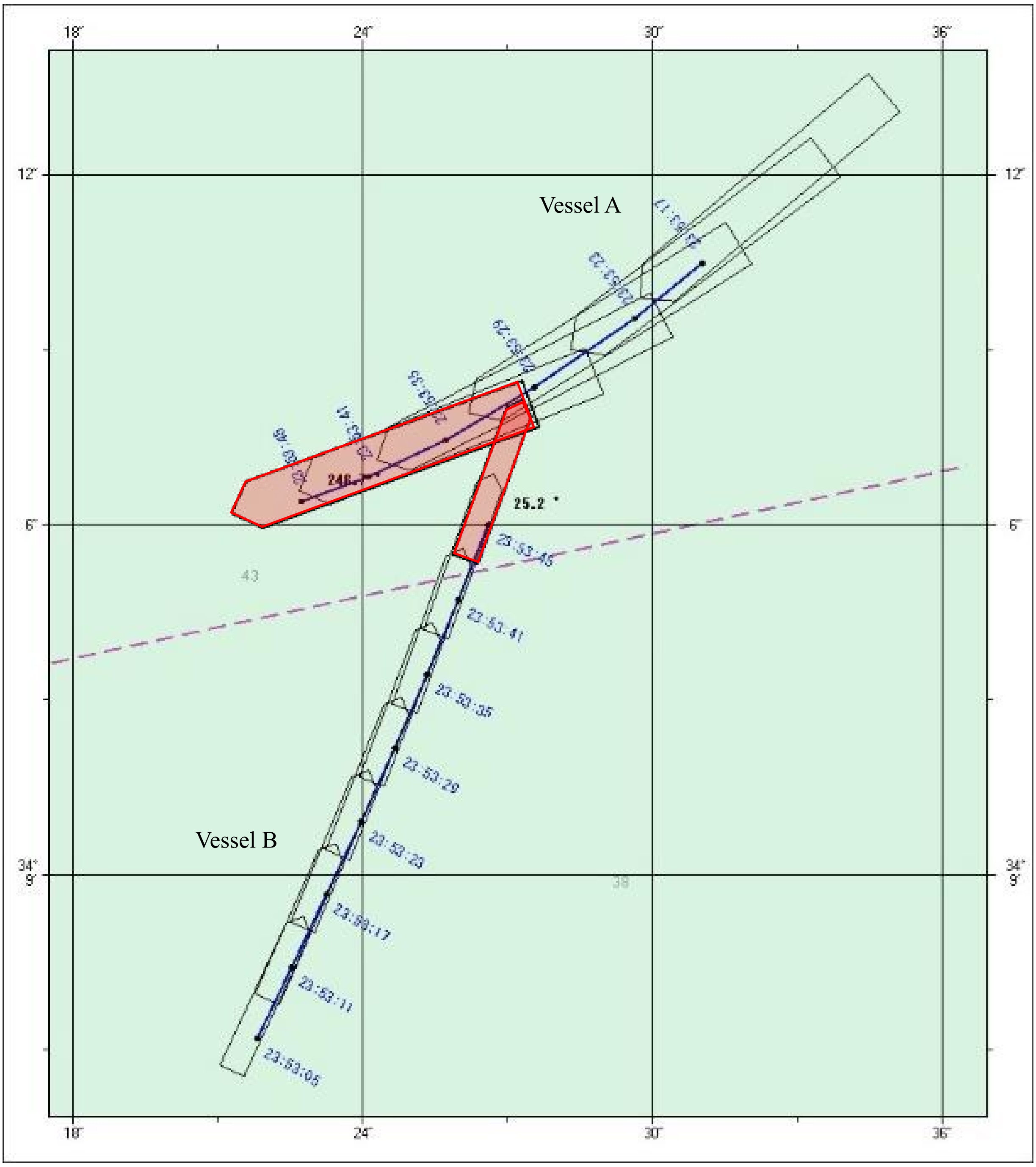


Figure 27 (Assumption) Course trajectories of both vessels if Vessel B had maintained its course without turning to port just before the collision.

3.2.4 Analysis of the Watchkeeping and Maneuvering Utilizing Collision Risk Assessment

The crew member's perception of danger of collision and the collision risk assessment in Attachment 1 were compared and verified in chronological order for Vessel A and Vessel B, as shown in Table 3.

Table 3 Comparative Verification of Crew member's Perception of Danger of Collision and Collision Risk Assessment

Time	Vessel A	Vessel B
At around 23:49:40		Vessel B: Vessel A was detected by No.1 Radar (Section 2.3.4). Master B: Judged that there was little possibility of collision if Vessel B and Vessel A maintained their current course and speed, and maintained current course with the intention of passing on the aft. side of Vessel A (Section 2.3.4). N. Officer B_1: Since Vessel A was faster, N. Officer B_1 assumed that Vessel A would pass Vessel B's fore side first (Section 2.3.4). CPA: approximately 0.5 M (Attachment 1 (Figure 4.3)) *OZT: Up until around 23:52:10, Vessel B encountered an OZT on the port side of its bow that posed a low risk of collision (with Vessel A)* (Attachment 1 (Section 4.3 ii)). CJ: Negative (rising trend) (Attachment 1 (Figure 4.5)) SJ: Approx. +2 (Attachment 1 (Figure 4.5)) BC: Approx. 0.1 (*the value had been rising continuously since around 23:46 before Vessel A changed course at No.4 Light Buoy, and it is possible that the difficulty of maneuvering was increasing.*) (Attachment 1 (Section 4.2 iii), Figure 4.5))

At around 23:51:27 (when Vessel A departed from the west entrance of the Kurushima Kaikyo Traffic Route)	N. Officer A_1: When Vessel B departed from the west entrance of the Kurushima Kaikyo Traffic Route, it was proceeding on an unusual course, which made me wonder where Vessel B was heading, but N. Officer A_1 did not feel there was any risk of collision at that point. N. Officer A_1 also thought that if we continued on the same course that we had taken from the west entrance of the Route, we would come close to Vessel C, which was approaching from behind Vessel B. N. Officer A_1: Since there were only two vessels, Vessel B and Vessel C, in the Akinada Minami Koro, N. Officer A_1 intended to pass between these two vessels and head for the Koro. Also, when departing the Kurushima Kaikyo Traffic Route, N. Officer A_1 performed trial maneuvers using radar and found that even if Vessel A turned 230° to port it would be possible to pass Vessel B while maintaining a distance of approximately 0.2 M in CPA, so N. Officer A_1 instructed Ordinary Seaman A_1 to "Port easy" to change course to 230°. (Section 2.3.4) OZT: *It was found that Vessel A encountered an OZT by Vessels B and C at the exit of the Kurushima Kaikyo Traffic Route. Although the OZT of Vessel C was farther from Vessel A than that of Vessel B, and there was sufficient distance between Vessel A and the OZT of Vessel B to allow navigation, it cannot be concluded that the OZT of Vessel C had no influence on Vessel A's navigation* (Attachment 1 (Section 3.2)). CJ: Approx. 0.005 (Attachment 1 (Figure 4.4)) SJ: Approx. -1.3 (Attachment 1 (Figure 4.4)) BC: Almost 0 (Attachment 1 (Figure 4.4))	

At around 23:52:42	Ordinary Seaman A_1: When turning to port, there was a piece of ship's frame at the position of the steering stand where Ordinary Seaman A_1 was standing, and Vessel B was surprisingly small, making it difficult for Ordinary Seaman A_1 to see, but when N. Officer A_1 gave the orders "Midship" and "Steady," and they headed for a course of 230°, Ordinary Seaman A_1 felt that Vessel B was close, or rather, directly ahead (Section 2.3.4)	Master B: Muttered to himself, "Why is that vessel heading toward us?" Then, at around 52:45, he ordered a course of 020°, which Able Seaman B repeated (Section 2.3.4)
At around 23:52:49-50		Master B: Said "Where is that heading?"(Section 2.3.4). N. Officer B_1: Called Vessel A via VHF. Although Vessel B was expected to pass on the aft. side of Vessel A, N. Officer B_1 started to communicate with Vessel A as it was approaching (Section 2.3.5) OZT: *Due to Vessel A's course change of approximately 30° upon exiting the Kurushima Kaikyo Traffic route and Vessel B's gradual course adjustment, between around 23:52:10 and around 23:53:30, the two vessels encountered an OZT almost directly ahead of Vessel B, creating a high risk of collision* (Attachment 1 (Section 4.3 ii))). CJ: Rose sharply, exceeding approx. 0.015 *(the value rose sharply to the positive side after 23:51 for Vessel A, so it is possible that the risk of collision was increasing)* (Attachment 1 (Section 4.2 i), Figure 4.5)). SJ: Approx. −2.5 *(at around 23:53, the value was below −2, so it is possible that the risk of collision was extremely high)* (Attachment 1 (Section 4.2 ii), Figure 4.5)) BC: Rose sharply above approx. 0.3 (Attachment 1 (Figure 4.5))
At around 23:52:53	N. Officer A_1: When Vessel A headed for a course of 230°, N. Officer A_1 saw Vessel B and perceived the risk of a collision. Since Vessel B's heading had not changed, and the CPA with Vessel B was less than one cable (0.1 M), N. Officer A_1 thought Vessel A would have to turn to starboard to avoid Vessel B. Just as N. Officer A_1 was about to turn to starboard, and then received a call from Vessel B on VHF, asking, "What's your intention?" However, they were too close and N. Officer A_1 had no way to respond. (Section 2.3.4)	

At around 23:53	N. Officer A_1: An agreement was reached via VHF with Vessel B to pass Port to Port, so Vessel A turned to starboard. Vessel B also judged that there would be no collision if it turned to starboard as agreed, so it did not take measures to reduce its speed (Section 2.3.5). OZT: *Due to Vessel A's course change at the exit of the Kurushima Kaikyo Traffic route, it encountered an OZT with a high risk of collision almost directly ahead until around 23:53:30* (Attachment 1 (Section 4.3 i))). CJ: Rose sharply beyond 0.01 *(the rapid increase from around 23:52 onwards suggests that it is possible that the risk of collision was increasing)* (Attachment 1 (Section 4.2 i), Figure 4.4)) SJ: Approx. −2 (*negative after around 23:50 and below −2 just before 23:53, suggesting that the risk of collision may have been extremely high.* (Attachment 1 (Section 4.2 ii), Figure 4.4)) BC: Almost zero until around 23:53 (*It is possible that the difficulty of maneuvering was extremely low.*)	Master B: Master B felt that Vessel B was going to collide with Vessel A, and panicked (Section 2.3.4). N. Officer B_2: When N. Officer B_2 came up to the bridge, and then heard Master B shouting "Hard Port" and "Full Astern." N. Officer B_2 thought there was a state of panic in the bridge (Section 2.3.5). OZT: Vessel B encountered an OZT almost directly in front of it, which posed a high risk of collision. (Attachment 1 (Section 4.3 ii), Figure 4.6)). CJ: Rose sharply above 0.02 (Attachment 1 (Figure 4.5)) SJ: Approx. -2.5 (Attachment 1 (Figure 4.5)) BC: Rose sharply above 0.3 (*the value rose sharply just before 23:53, and reached a maximum of approximately 0.90 just before the collision, which suggests that the situation was almost unavoidable by any maneuvering of the vessels.*) (Attachment 1 (Section 4.2 iii), Figure 4.5))

The JTSB concludes that as shown in Table 3, the risk indicated by the CJ and SJ values and the results of the collision risk assessment by OZT are generally consistent with the risk of collision perceived by the crew member.

(1) Vessel A

Regarding OZT, Vessel A encountered an OZT with Vessel C at around 23:51 when it departed the Kurushima Kaikyo Traffic Route. N. Officer A_1 stated that he was concerned about Vessel C, stating, " If Vessel A continued on the same course as when we departed from the west entrance of the (Kurushima Strait) route, N. Officer A_1 thought we would also come close to Vessel C, which was coming from behind Vessel B." This is consistent with the danger indicated in the OZT with Vessel C (Attachment 1 (Figure 3.2(e))). On the other hand, Vessel A had encountered an OZT with Vessel B since at around 23:47 (Attachment 1 (Figure 3.2(c))), and at around the time Vessel A departed the Kurushima Kaikyo Traffic Route, a group of OZTs by Vessel B were present ahead of Vessel A's port side as seen from Vessel A (Attachment 1 (Figure 3.2(e))). However, N. Officer A_1 turned to port toward the group of OZTs (Attachment 1 (Figure 3.2(e))), because N. Officer A_1 took actions contrary to the danger indicated by the OZTs.

The BC value for Vessel B was almost "0" until just before the collision, and the degree of maneuvering difficulty with respect to Vessel B remained low (Attachment 1 (Figure 4.4)). This may be due to the fact that there was a wide area of water to the starboard side of Vessel A that extended along the course (a course that is not blocked by Vessel B or C) on which Vessel A's avoidance maneuvers would not be affected by Vessel B or C.

(2) Vessel B

Regarding the OZT, Vessel B encountered an OZT with Vessel A starting at around 23:47 (Attachment 1, Figure 3.3(c)). However, until Vessel A turned to port, the group of OZTs caused by Vessel A, as observed from Vessel B, remained on the port side of Vessel B's course (Attachment 1, Figure 3.3(d)). This aligns with the understanding of Master B and N. Officer B_1 that if both Vessel A and Vessel B maintained their course and speed, Vessel B would pass astern of Vessel A, consistent with the hazard indicated by the OZT.

Regarding the BC value for Vessel A, the CPA dropped below 0.25 due to Vessel A's turning port (Attachment 1, Figure 4.3), and then began to rise rapidly from around 23:52 (Attachment 1, Figure 4.5). From around 23:53 onward, it was assessed that the maneuvering difficulty for Vessel B had increased such that avoiding a collision by any maneuvering became almost impossible. This is more likely that be due to the fact that after around 23:53, the heading course of Vessel B was blocked by Vessel A due to the exclusive area that had been formed around Vessel A (Attachment 1 (Figure 3.3 (f))). These values are probably largely consistent with the risk of collision perceived by the crew members.

3.2.5 Analysis of the Accident Occurrence

The JTSB concludes that according to Sections 2.3.4, 2.11.2, 3.1.1, 3.1.8, 3.2.3, and 3.2.4, the causes of this accident were as follows.

(1) Vessel A

i) Vessel A departed the Kurushima Kaikyo Traffic Route at around 23:51:27, and changed course from approximately 260° to approximately 230° between 23:51:46 and 23:52:53.

ii) It is probable that when N. Officer A_1 departed the Kurushima Kaikyo Traffic Route, he conducted a trial maneuvering using the radar and determined that turning to port to a course of 230° would allow Vessel A to pass Vessel B while maintaining a CPA of approximately 0.2 M on the port side. Additionally, he considered that if he continued on the same course as when departing from the west entrance of the Kurushima Kaikyo Traffic Route, he would come close to Vessel C, which was approaching from behind Vessel B. Therefore, it is probable that N. Officer A_1 turned to port toward the Akinada Minami Koro and continued navigating along that course.

iii) It is probable that N. Officer A_1, based on the results of the trial maneuver, thought that he would be able to secure a distance of approximately 0.2 M CPA and pass Vessel B port to port, therefore, he turned to port and continued navigating. However, it is possible that the CPA value based on the actual situation was even smaller than the CPA calculated based on the data at the time N. Officer A_1 performed the trial maneuvering, and according to the reference, although it depends on the size and maneuverability of the vessel, a CPA value of 0.2 M is a very dangerous distance, and is a situation in which avoidance measures should be taken without delay if necessary. It is probable that N. Officer A_1 did not fully understand the significance of the danger posed by a small CPA value indicated by the radar function.

iv) It is probable that when Vessel A was departing from the west entrance of the Kurushima Kaikyo Traffic Route, N. Officer A_1 wondered where Vessel B was heading because it was proceeding on an unusual course, but as he did not sense any risk of collision, he continued navigating without communicating his intentions to Vessel B in advance by VHF.

However, it is probable that the following suggests that he should have communicated the maneuvering intentions of Vessel A to Vessel B via VHF before issuing the command to turn port.

a. As described in iii), the CPA of 0.2 M with Vessel B assumed by N. Officer A_1 is a dangerous distance.

b. Although N. Officer A_1 did not feel there was a risk of collision with Vessel B, it is possible that when Vessel A and Vessel B approached within approximately 1 M, if Vessel A had turned left, the two vessels would have approached each other closer and the risk of collision would have increased.

v) As indicated by the collision risk index BC value, the difficulty of maneuvering Vessel A relative to Vessel B was low, and subsequently it is probable that avoidance measures could have been taken, such as abandoning the turning to port before approaching Vessel B or turning to starboard early.

vi) As described in Section 2.1, when navigating through the Kurushima Strait when the tidal currents are flowing southward, it is necessary to be aware of the surrounding conditions and make efforts to operate safely. The Seafarers' Act requires the Master to take command of the vessel when passing through a narrow waterway, and the person in charge of Company A_2 were aware that in narrow waterways the Master always performs navigational duty in the bridge together with the navigation officer on duty and ordinary seaman on duty. However, Master A left the bridge within the Traffic Route after passing the Kurushima No.3 Ohashi and turning starboard, and at around the time of passing the No.4 Light Buoy in the Traffic Route, because he was not in charge of conning Vessel A at the time of the accident. It is probable that considering that the situation at the time of the accident was near the west entrance of the Kurushima Kaikyo Traffic Route with a southerly current, and that because Master A was not in the bridge, Vessel A was not in a position to properly maintain a lookout, judgment of the surrounding conditions, or communicate with Vessel B via radio.

(2) Vessel B

i) It is probable that when Master B confirmed Vessel A on radar at around 23:49:40, he assumed that Vessel A would maintain its current course and speed, and that Vessel B, while changing course to port, intended to pass by the stern of Vessel A and head for the north side of the west entrance of the Kurushima Kaikyo Traffic Route.

ii) Because Master B and N. Officer B_1 assumed that Vessel A would maintain its current course and speed, it is possible that they did not consider ascertaining Vessel A's maneuvering intentions through VHF communications.

iii) It is probable that Master B noticed Vessel A turning to port sometime between around 23:52 and 23:52:40, but it is probable that the time from when Master B noticed Vessel A turning to port until Vessel A's course changed to approximately 230° and approached directly in front of Vessel B was no longer than approximately 50 seconds. In this short period of time, the relationship between Vessel A and Vessel B changed significantly, and at around 23:53 when Vessel A approached almost directly in front of Vessel B, it is probable that the crew members on bridge of Vessel B, which was unexpectedly ahead of Vessel A, fell into a state of confusion. Although it was not possible to determine why Master B ordered "Hard port" immediately before the collision, it is possible that Master B was not in a position to calmly communicate with those in the bridge and make the decision to take actions to avoid the collision.

iv) At around 23:53:03, N. Officer B_1 told Vessel A to go "Port to Port," and N. Officer A_1 agreed, causing Vessel A to turn starboard. However, immediately thereafter, at around 23:53:07, Master B gave the order to go "Hard port," and Vessel B continued to turn port in a manner different from the navigation method that N. Officer B_1 had instructed Vessel A to follow, and Vessel A and Vessel B collided.

v) If Vessel B had proceeded as assumed in Section 3.2.3 (2) vii), as shown in Figure 27, it is possible that it would have avoided colliding with the center of Vessel A's hull, but would have collided with Vessel A's stern. Consequently, it is possible that the collision itself could not have been avoided even if Vessel B had not turned to port due to Master B's order to "Hard port."

vi) Further hypothesizing from the situation in Figure 27, if Vessel B had not only not turned to port, but had also turned to starboard to go "Port to Port" at around the time N. Officer B_1 told Vessel A "port to port," or at around the time the master ordered "Hard port," it is possible that the collision could have been avoided.

However, as stated in Section 3.2.3 (2) vi), it is possible that the bridge of Vessel B was in a state of confusion at around 23:53, and Master B was not in a position to calmly communicate with those in the bridge and make decisions on how to avoid a collision.

vii) As described in Section 2.1, when entering the Kurushima Strait when the tidal current is flowing south, special navigation procedures are required, and furthermore sufficient safety checks must be made. Considering that the only navigation officer on duty the bridge was the inexperienced N. Officer B_1, it is probable that Master B was late in coming up to the bridge. Considering that Vessel B was navigating near the west entrance of the Kurushima Kaikyo Traffic Route with the southward current flow, it is probable that the delay in Master B coming up to the bridge and taking command of Vessel B affected his lookout and judgment of the surrounding conditions.

viii) When passing through the Kanmon Strait, Vessel B reconfirmed that it was scheduled to pass through the Kurushima Kaikyo Traffic Route at around 00:30 on May 28, when the current was flowing north, and maintained its plan to navigate Nishi Suido from the south of the west entrance of the route until around 2 M before the west entrance of the route. Later, Vessel B was contacted by Kurushima MARTIS and instructed to navigate through Naka Suido, and they were making the necessary changes to their route plans from Nishi Suido Channel to navigate through the Naka Suido. It is probable that the fact that Vessel B did not adjust its speed and changed its course after approaching the route has led to the situation where it approached Vessel A near the west entrance of the route. When passing through the route, it is probable that Vessel B should have always been aware of the scheduled time of entry into the route, taking into account its own position, speed, etc., confirmed the time of current change in the Kurushima Strait, and constantly aware of whether it would enter the route when the tide was forward or reverse, and adjusted its course, speed, etc.

3.2.6 Analysis of Damage Stability of Vessel A

The JTSB concludes that possibility for effective damage control of Vessel A at the time of the accident was as follows.

As described in Section 2.9.2 (2), Vessel A was constructed with mitigating measures but without the requirements for damage stability.

From 2.9.6 (1), the draft of Vessel A was approximately 5.50 meters at the fore side and 7.50 meters at the aft. side at the time of this accident. From Section 2.7 (1), Vessel A suffered a breach in the center of the port side (an inverted triangular breach measuring approximately 9.8 meters in height, from frame number from 94 to 110, with its base approximately 12.5 meters below Deck. No.1 and its apex near the bilge keel). Based on the above, a case was selected with a chart whose calculation conditions (load condition, draft and trim) from the damage control data were close to the situation at the time of the accident,

Calculation conditions (60% partial load draft): (P) side damage
Initial conditions: dP = 6.38 m, Trim = 1.7 m, G_0M = 1.20 m
(Damage area: Vertical direction = No.1 Deck, Width direction = C.L.)

The breach was applied to the chart, revealing that although it fell within the range of one compartment flooding in "EXT.7," the chart's color indicated that even with one compartment flooded in "EXT. State 3 (S = 0)," Vessel A was in a condition that could be judged to be foundering. (see Figure 28)

From 3.1.4, it is also probable that at around 00:01 on May 28, when Master A decided to abandon the vessel, Vessel A had leaned at approximately 37° to port due to flooding of the Ballast tanks and the lateral movement of the loaded vehicles onboard caused by the broken lashing belts. The damage control document states that if the final equilibrium angle reaches 30 degrees or more, it can be concluded that Vessel A would founder; hence, it was clear that Vessel A was in a condition indicating imminent foundering.

Consequently, it is probable that, given the circumstances of this accident, there was no possibility for effective damage control, and an immediate decision to abandon the vessel was necessary.

Calculation condition (60% partial load draft): (P) side damage

Initial condition: dP = 6.380 m, Trim = 1.700 m, G_0M = 1.20 m

(Damage extent: vertical = No.1 deck, horizontal = C.L.)

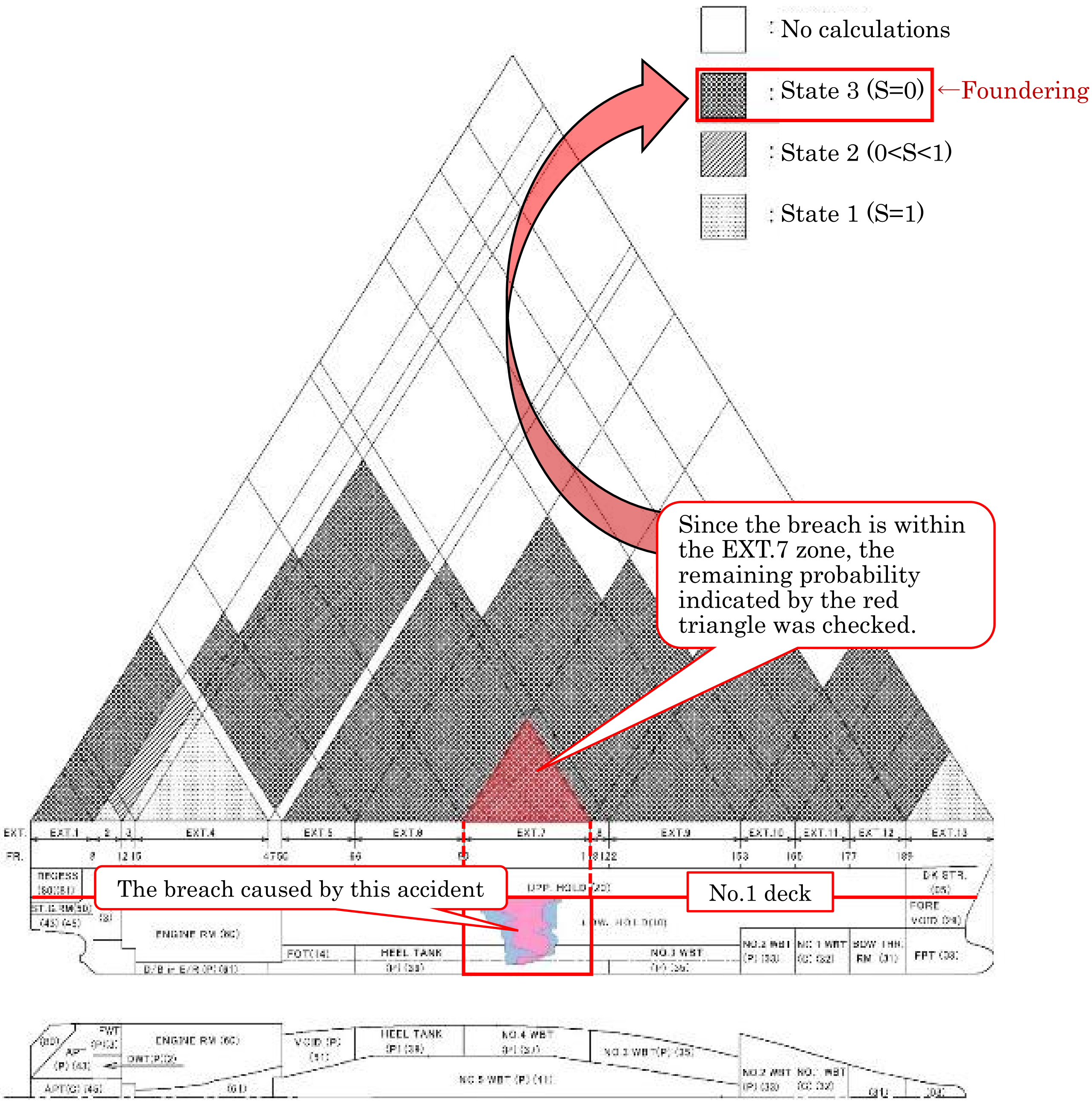


Figure 28 Calculated state of damage stability (close to the state at the time of the accident)

3.3 Analysis of Measures to Alleviate Damage

This accident occurred when Vessel A, which was constructed without applying the Damage Stability Standards due to mitigation measures, suffered a breach amidships on the port side during a collision. Within a short period, Vessel A flooded, capsized, and foundered. For the following reasons, the JTSB concludes that it is probable that the crew member of Vessel A did not fully understand the vessel's damage stability performance.

(1) Immediately after the collision, N. Officer A_2 headed to the bridge and was instructed by Master A to adjust the leaning, and attempted to do so using the Heel tank. (Section 2.4 (1) ii))

(2) N. Officer A_2 stated that he thought waterproofing was more necessary than providing life jackets first. (Section 2.4 (1) ii))

(3) Chief Engineer A stated that, although he might have been able to prevent Engineer A_1 and Engineer A_2 from proceeding toward the engine room, it would have taken time for Chief Engineer A to fully grasp the situation after the collision. Chief Engineer A also mentioned that Chief Engineer A did not believe Vessel A would founder from just the collision alone, so Chief Engineer A was not overly concerned at that time. (Section 2.4 (1) iii))

(4) Ordinary Seaman A_1 thought that Vessel A was leaning, that Ordinary Seaman A_1 had heard the sound of the lashings breaking, and that it had been hit directly from the side and was taking in water, but after talking with other crew members after the accident, Ordinary Seaman A_1 did not think that a vessel as large as Vessel A could founder, so at first he felt that there was no problem. However, when Vessel A gradually started to lean and the mooring equipment at the bow became flooded, Ordinary Seaman A_1 stated that he felt certain that the vessel would founder and that all the crew members moved to abandon ship. (Section 2.4 (1) iv))

Consequently, if the crew members of Vessel A had been fully aware of the vessel's damage stability, and had understood that an early decision to abandon ship might be necessary depending on the location of the damage, it is possible that a different outcome could have been achieved. Specifically, had Master A and N. Officer A_1 immediately assessed the situation from the port wing following the collision, recognized that damage control was unfeasible and that there was a risk of foundering, and promptly decided to abandon ship, Engineer A_1 and Engineer A_2 were possibly not heading to the engine room - or could have evacuated at an earlier stage - and might have been able to leave Vessel A along with the other crew members, thereby potentially reducing personal injury.

4 CONCLUSIONS

4.1 Probable Causes of the Collision

The JTSB concludes that the probable causes of the collision are as follows.

This accident occurred at night during the period when navigation in the Kurushima Kaikyo Traffic Route is designated for the southerly current. Vessel A was heading southwest from the west entrance of the route, while Vessel B was heading northeast from the Akinada Minami Koro toward the west entrance of the Kurushima Kaikyo Traffic Route. As the two vessels approached each other on crossing courses, Vessel A judged that there was no risk of collision with Vessel B if it altered course to the Akinada Minami Koro after departing from the Kurushima Kaikyo Traffic Route. Shortly after departing, when the vessels were approximately 1 M apart, Vessel A changed course

30° to port to set a heading of 230° without communicating its maneuvering intentions to Vessel B by radio. Consequently, Vessel A came close to Vessel B, which was heading north near the west entrance, intending to pass the stern side of Vessel A. Confusion arose on Vessel B's bridge due to the sudden and unexpected course change by Vessel A. N. Officer B_1, without Master B's approval, communicated with Vessel A via VHF, expressing a desire to pass "Port to Port" (a passing method in which each vessel passes on the other's port side). Although Vessel A agreed and turned starboard, it is probable that Vessel B, following Master B's order to "Hard port," did not maintain the agreed "Port to Port" passing arrangement. Therefore, it is probable that this divergence in maneuvers ultimately resulted in the collision between Vessel A and Vessel B.

It is probable that Vessel A did not communicate its intention to maneuver to Vessel B when it altered course 30° to port toward the Akinada Minami Koro because N. Officer A_1, having conducted a trial maneuver using the radar function prior to the course change, judged that a Port-to-Port passage would be possible with a CPA of approximately 0.2 M, and therefore did not perceive a risk of collision. It is likely that the passing distance between Vessel A and Vessel B assumed by N. Officer A_1 was insufficient, and that he did not fully comprehend the implications of the small CPA value indicated by the results of the trial maneuver.

It was not possible to determine Master B's intention when he issued the command "Hard port", however, it was likely that, at the time Vessel A set a course of 230°, the distance between the two vessels was only approximately 0.5 M, and Vessel A's outline was rapidly approaching Vessel B at a relative speed of over 30 kn. Under such circumstances, it is possible that Master B was unable to maneuver based on calm and rational judgment.

Contributing factors to the accident are as follows.

It is probable that it is involved in the occurrence of the accident, although Vessel A was navigating near the west entrance of the Kurushima Kaikyo Traffic Route, Master A was not present in the bridge. As a result, Vessel A was not in a position to properly maintain a lookout, judgment of the surrounding conditions, or communicate with Vessel B via radio.

In addition, it is probable that it is involved in the occurrence of the accident, although Vessel B had initially planned to transit the Kurushima Kaikyo Traffic Route during a north-flowing current, it did not adjust its speed accordingly and instead altered its course only after approaching the route while the current was flowing south. This led to a situation in which it came into close proximity with Vessel A near the west entrance of the route. Furthermore, it is probable that it is involved in the occurrence of the accident, although N. Officer B_1 did not necessarily have sufficient seagoing service experience, there was a delay in Master B's arrival in the bridge to assume command. This delay adversely affected Vessel B's lookout and judgment of the surrounding conditions.

4.2 Factors Contributing to Damage Increase

It is likely that the number of personal injuries to the crew members of Vessel A could have been reduced that, the crew members of Vessel A possessed a better understanding of Vessel A's damage stability, and recognized the necessity of making an early decision to abandon ship depending on the location of the damage sustained in the collision.

5 SAFETY ACTIONS

5.1 Measures to Prevent Recurrence and Mitigate Damage Considered Necessary

5.1.1 Accident Prevention Measures

As stated in Section 4.1, it is probable that this accident occurred because Vessel A changed course without communicating its maneuvering intentions to Vessel B as the two vessels approached each other, resulting in a rapid reduction in the distance between them. In addition, Vessel B more likely did not take evasive action in accordance with the agreement made with Vessel A, which ultimately led to the collision. Regarding Vessel B's method of avoidance, given that the situation at the time of the accident had already developed into a condition prone to collision, it is considered difficult to take direct and effective measures against the errors in judgment made after the situation had deteriorated. Consequently, in order to prevent the recurrence of similar accidents, it is essential to examine the sequence of events that led to this situation and systematically eliminate the factors that increased the risk of an accident.

Examining the process leading up to this accident from this perspective, the following measures are considered necessary to prevent the recurrence of similar accidents.

(1) Persons who are on duty of bridge watchkeeping should closely monitor the movements of surrounding vessels, and upon noticing an approaching vessel or having any uncertainty regarding another vessel's movements, they should avoid making assumptions. Instead, the persons proactively initiate VHF communication at an early stage to confirm each other's maneuvering intentions in proactive and appropriate attitude.

(2) Persons who are on duty of bridge watchkeeping should maintain a comprehensive visual lookout alongside effective use of navigational instruments. The persons should fully understand the significance of data provided by these instruments - such as the CPA value - and develop the competence to make informed maneuvering decisions based on that information. Especially when using the CPA value, the persons should ensure they take into account the length of their vessel so as not to underestimate the actual passing distance.

(3) A master should comply with the obligation to maneuver in narrow waterways as stipulated in the Seafarers' Act, and the obligation to navigate along designated routes as required by the Ship Operation Standards. Only after confirming that safety conditions have been met - such as the resolution of vessel congestion - should the master hand over maneuvering authority to the navigation officer on duty.

(4) Master and navigation officers on duty should strictly adhere to the watchkeeping systems stipulated in the Safety Management Regulations, the Safety Management Manual, the Master's Standing Orders for Navigation, and other relevant guidelines.

(5) When navigating narrow channels and waterways or other areas prone to congestion, the master and the navigation officer on duty should make thorough preparations in advance concerning special navigation procedures, planned courses, and the specific characteristics of the sea areas, and should strive to operate the vessel accordingly and safely. In particular, vessels planning to navigate routes with established special navigation rules, such as the Kurushima Kaikyo Traffic Route, should continuously monitor their position, speed, and estimated time of entry, and be prepared to enter the route accordingly. When navigating the Kurushima Kaikyo Traffic Route, always confirm the timing of current changes and remain aware of whether your vessel will enter the strait during flood or ebb tide, adjusting your course, speed, and other parameters accordingly.

5.1.2 Damage Reduction Measures

In this accident, Vessel A - constructed without applying Damage Stability Standards due to mitigation measures - became flooded, capsized, and foundered within a short period following the collision. Although the reason why Master A was unable to abandon ship could not be determined, it is likely that the two engineers, having proceeded to the engine room, were unable to escape, which resulted in their loss of life.

From the crew members' statements, it appears that many did not believe a vessel as large as Vessel A could founder from a mere collision. However, if the crew members had accurately understood Vessel A's damage recovery capabilities and recognized the need to decide on abandoning ship early - based on the location of the collision damage - it is possible that the two engineers would not have proceeded to the engine room, or would have evacuated it sooner, enabling them to abandon the vessel without delay. Therefore, to minimize damage from similar accidents, ship owners, management companies, and masters should thoroughly understand the vessel's stability performance when damaged, ensure this knowledge is effectively communicated to all crew members, and regularly conduct abandonment drills that consider the vessel's damaged stability.

5.2 Accident Prevention Measures Taken after the Accident

5.2.1 Measures Taken by Company A_1 and Company A_2

Company A_1 continuously has conducted collision avoidance training twice a month for the crew members of each ship it manages. The training covers topics such as maneuvering to avoid obstacles, operating engine telegraphs, using navigation instruments and communication devices, and employing sound signals (whistles).

Company A_2 conducts monthly vessel visits by the operations team, organizes joint drills (including scenarios such as seawater ingress caused by contact with another vessel and subsequent ship abandonment), provides education for both shore-based and onboard personnel, and manages the submission and analysis of near-miss reports in accordance with its Safety Management Regulations.

5.2.2 Measures Taken by Ship Management Company of Vessel B

Company B, a ship management company, has provided safety education and training for crew members of its managed vessels focusing on collision prevention and speed management in congested waters. Additionally, it has implemented the following measures to prevent recurrence of similar accidents (excerpts).

(1) Installation of ECDIS/Radar monitor screens in the master's quarters of the managed vessels
(2) Implementation of internal/external navigation practice audits
(3) Implementation of VDR remote monitoring
(4) Inspection of navigation plans on land (ECDIS installed in the office)
(5) Regular onboard training (SHS (Ship-Handling Simulator) / BRTM (Bridge Resource Team Management)*[20] / ECDIS)

*[20]_Refers to a method by which bridge team members, under the master's leadership, effectively utilize and manage all available resources - including crew member, equipment, and information - to ensure the safe and organized operation of the ship.

(6) Onboard training by external experts (COLREG (International Regulation for Preventing Collision at Sea, 1972) / Narrow Waterway Route Planning / BBS (Behavior Based Safety)

5.2.3 Measures Taken by the 6th Guard

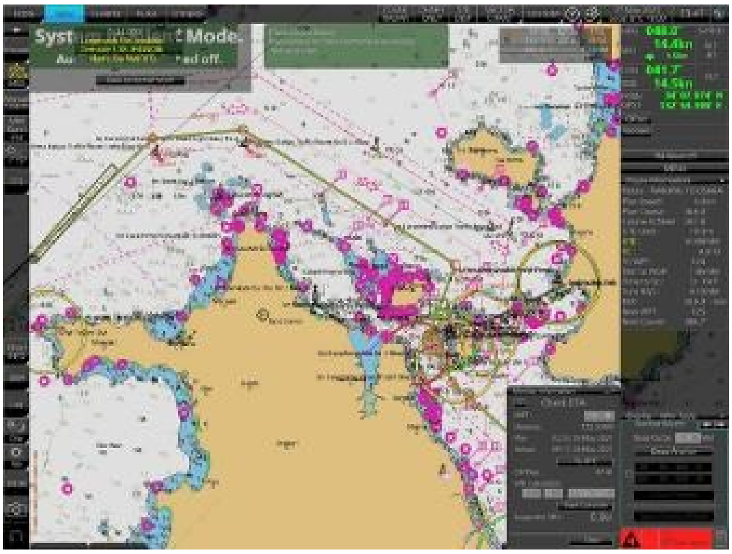
In response to collisions with fatalities and missing persons in the western sea areas of the Kurushima Kaikyo Traffic Route in recent years, the 6th Guard convened the "Committee on Navigation Safety Measures for the Western Sea Areas of the Kurushima Kaikyo Traffic Route." The committee, composed of scholars, experts, maritime relevant and fishery personnels, and relevant government agencies, worked to seek through implementation of measures to prevent the recurrence of similar accidents. They summarized and evaluated opinions on safety measures for the area and secured agreement from local users.

According to the compiled safety measures, designating specific routes for entry and departure at the west entrance of the Kurushima Kaikyo Traffic Route can eliminate overlaps between the intersection points of vessels entering and leaving the route and the course-changing points of vessels departing the route. The measures came into effect on July 1, 2024, as route designations established under the Maritime Traffic Safety Act.

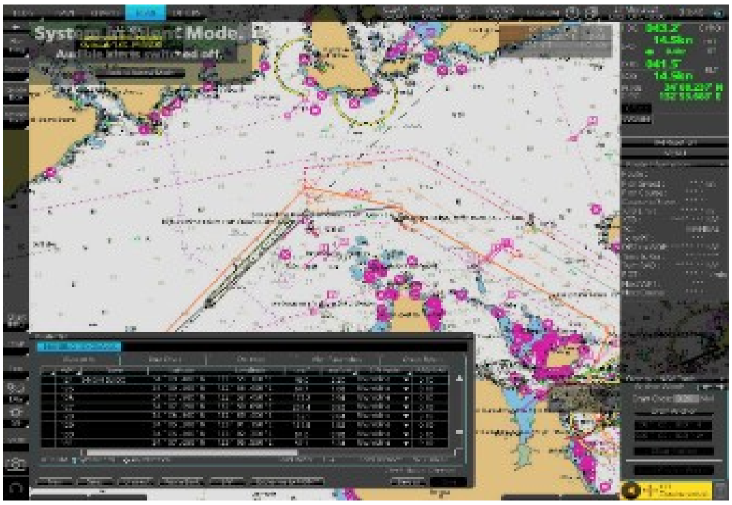
(See Attachment 3, the 6th Regional Coast Guard Information Leaflet)

Appendix Figure 1　ECDIS Video of Vessel B (excerpts)

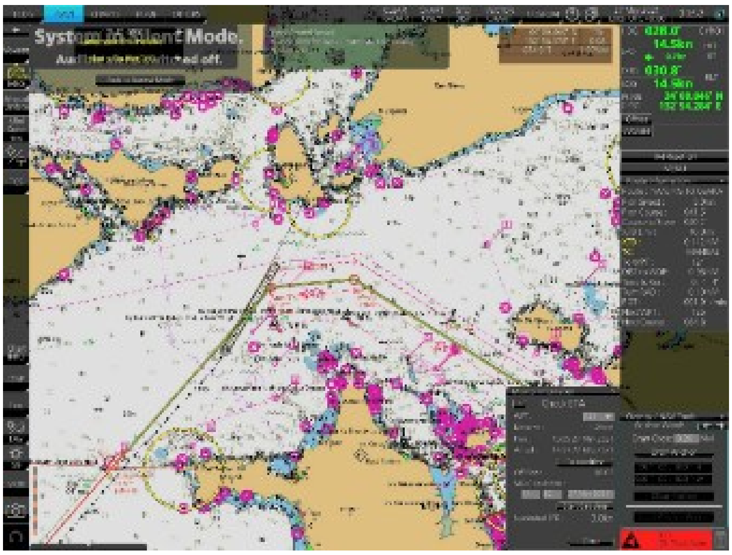
1　At around 23:47:53 (The Course of the Navigation Plan set to Nishi Suido)



2　At around 23:49:23 (Vessel B began Changing its Course from Nishi Suido to Naka Suido)



3　At around 23:52:39 (The Course Change to Naka Suido Completed)



Appendix Table 1　AIS Records for Each Vessel (excerpts)

1　AIS Records for Vessel A (excerpts)

Time (hh:mm:ss)	Vessel's Position		Course Over The Ground (°)	Heading (°)	Speed Over The Ground (kn)
	Latitude (N) (°-′-″)	Longitude (E) (°-′-″)			
23:30:03	34-06-35.2	132-59-20.4	326.9	330	15.4
23:35:07	34-07-35.2	132-59-20.9	025.9	020	12.6
23:40:03	34-08-26.2	132-58-40.8	306.4	305	16.1
23:45:03	34-09-17.3	132-57-16.1	301.5	297	17.7
23:46:08	34-09-27.0	132-56-56.3	298.3	292	17.6
23:47:05	34-09-30.2	132-56-37.4	271.7	268	16.5
23:48:03	34-09-30.3	132-56-17.5	269.9	268	17.3
23:49:03	34-09-30.2	132-55-56.2	269.7	267	17.7
23:50:03	34-09-29.3	132-55-34.8	262.6	259	17.6
23:51:03	34-09-26.5	132-55-13.4	260.4	259	18.1
23:51:27	34-09-25.3	132-55-04.8	260.7	259	18.2
23:51:46	34-09-24.3	132-54-57.9	259.8	257	18.2
23:51:54	34-09-23.8	132-54-55.4	257.2	253	18.1
23:52:05	34-09-22.8	132-54-51.3	252.4	247	17.8
23:52:15	34-09-21.6	132-54-48.0	246.5	241	17.5
23:52:25	34-09-20.3	132-54-45.3	240.0	235	17.3
23:52:35	34-09-18.5	132-54-42.2	234.5	229	17.2
23:52:43	34-09-17.2	132-54-40.4	231.3	229	17.2
23:52:53	34-09-15.1	132-54-37.4	230.0	228	17.3
23:53:02	34-09-13.6	132-54-35.3	228.9	228	17.5
23:53:16	34-09-10.7	132-54-31.3	229.4	230	17.7
23:53:27	34-09-08.7	132-54-28.2	233.4	236	17.8
23:53:32	34-09-08.1	132-54-26.9	236.1	240	17.7
23:53:35	34-09-07.5	132-54-25.7	237.9	243	17.7
23:53:39	34-09-06.9	132-54-24.4	241.2	246	17.6
23:53:57	34-09-05.9	132-54-19.8	254.2	253	13.8
23:54:05	34-09-05.4	132-54-17.6	255.4	253	13.9
23:54:27	34-09-04.0	132-54-11.3	254.5	255	14.3
23:54:45	34-09-03.0	132-54-06.4	255.8	257	13.8
23:55:07	34-09-02.0	132-54-01.0	260.8	263	11.3
23:55:23	34-09-01.9	132-53-58.1	268.8	269	9.1
23:55:43	34-09-02.4	132-53-55.1	283.9	282	7.4
23:56:05	34-09-03.5	132-53-52.7	304.0	299	6.0
23:57:05	34-09-07.6	132-53-50.0	350.9	342	4.1
23:58:09	34-09-11.3	132-53-50.7	021.4	016	3.3
23:59:09	34-09-13.9	132-53-52.7	040.4	042	2.8
00:00:09	34-09-15.6	132-53-55.1	053.6	061	2.5
00:01:06	34-09-16.7	132-53-57.4	062.4	075	2.2

00:02:06	34-09-17.6	132-53-59.6	068.4	086	1.9
00:03:10	34-09-18.2	132-54-01.8	073.2	096	1.7
00:03:59	34-09-18.5	132-54-03.3	075.2	104	1.6
00:05:00	34-09-18.9	132-54-05.2	077.8	113	1.4
00:06:02	34-09-19.2	132-54-06.9	079.1	122	1.3
00:07:03	34-09-19.5	132-54-08.4	077.9	133	1.2
00:08:03	34-09-19.8	132-54-09.8	075.4	147	1.2
00:09:05	34-09-20.1	132-54-11.2	070.1	164	1.1
00:10:08	34-09-20.6	132-54-12.6	066.6	177	1.2

*The courses over the ground and headings are indicated in true bearings.

2 AIS Records for Vessel B (excerpts)

Time (hh:mm:ss)	Vessel's Position		Course Over The Ground (°)	Heading (°)	Speed Over The Ground (kn)
	Latitude (N) (°-′-″)	Longitude (E) (°-′-″)			
23:30:05	34-04-45.8	132-50-01.5	040.7	040	14.3
23:35:05	34-05-39.8	132-50-58.5	041.4	040	14.4
23:40:05	34-06-35.3	132-51-55.7	041.0	039	14.3
23:45:11	34-07-30.1	132-52-53.3	043.1	043	14.2
23:46:11	34-07-40.2	132-53-05.1	042.7	040	14.3
23:47:11	34-07-51.3	132-53-16.7	041.6	042	14.4
23:48:05	34-08-00.8	132-53-26.7	047.8	049	14.3
23:49:05	34-08-11.8	132-53-38.7	037.8	040	14.4
23:50:05	34-08-21.9	132-53-50.8	048.3	042	14.7
23:51:05	34-08-32.9	132-54-03.2	039.2	032	14.4
23:51:29	34-08-37.2	132-54-06.9	035.2	030	14.2
23:51:41	34-08-39.9	132-54-09.2	034.0	029	14.2
23:51:53	34-08-42.3	132-54-11.0	033.2	029	14.3
23:52:05	34-08-44.5	132-54-12.8	032.9	028	14.3
23:52:17	34-08-47.2	132-54-14.7	031.8	028	14.3
23:52:23	34-08-48.5	132-54-15.6	031.1	028	14.3
23:52:41	34-08-52.0	132-54-18.1	030.8	027	14.4
23:52:53	34-08-54.2	132-54-19.8	030.4	027	14.4
23:53:05	34-08-57.2	132-54-21.8	029.9	025	14.3
23:53:17	34-08-59.5	132-54-23.3	029.2	021	14.3
23:53:27	34-09-01.4	132-54-24.5	027.7	012	14.2
23:53:31	34-09-02.2	132-54-25.1	027.5	005	14.2
23:53:41	34-09-04.7	132-54-26.3	022.0	335	13.6
23:53:56	34-09-06.2	132-54-26.3	356.8	261	6.4
23:54:07	34-09-06.4	132-54-25.5	299.7	241	3.5
23:54:21	34-09-06.3	132-54-24.8	267.4	229	2.6
23:54:47	34-09-05.9	132-54-24.0	244.1	224	1.8
23:55:17	34-09-05.3	132-54-23.3	223.0	221	1.6
23:55:35	34-09-05.0	132-54-22.9	226.9	218	1.5

23:55:59	34-09-04.5	132-54-22.5	218.3	215	1.2
23:56:17	34-09-04.3	132-54-22.3	210.6	214	1.1
23:57:30	34-09-03.3	132-54-21.9	196.4	235	0.5
23:58:01	34-09-03.2	132-54-21.8	209.3	248	0.3
23:59:17	34-09-03.3	132-54-21.5	304.6	265	0.2
00:00:17	34-09-03.6	132-54-21.3	348.8	267	0.4
00:05:07	34-09-05.8	132-54-22.8	058.2	223	0.5
00:09:48	34-09-05.9	132-54-23.8	260.7	254	1.2
00:15:26	34-09-00.0	132-54-09.0	235.6	247	1.4

*The courses over the ground and headings are indicated in true bearings.

3 AIS Records for Vessel C (excerpts)

Vessel C position indicates the locations of the GPS antenna installed above the bridge. The antenna of the Vessel was set on the deck above the bridge; the location of the antenna was 153 meters from the fore side, 16 meters from the stern side, 14 meters from the port side and 1 meter from the starboard side, and then the courses over the ground and headings are indicated in true bearings.

Time (hh:mm:ss)	Vessel's Position		Course Over The Ground (°)	Heading (°)	Speed Over The Ground (kn)
	Latitude (N) (°-′-″)	Longitude (E) (°-′-″)			
23:48:07	34-06-02.4	132-51-53.1	034.3	032	22.1
23:49:07	34-06-21.1	132-52-06.2	029.0	027	22.0
23:50:07	34-06-41.3	132-52-18.0	023.3	020	21.8
23:51:07	34-07-01.1	132-52-27.5	021.6	020	21.6
23:52:07	34-07-21.3	132-52-37.0	020.4	017	21.5
23:52:31	34-07-29.5	132-52-40.1	017.7	015	21.5
23:53:07	34-07-41.9	132-52-44.6	016.7	015	21.5
23:53:25	34-07-48.4	132-52-46.9	016.8	015	21.5
23:53:49	34-07-56.7	132-52-49.6	014.3	010	21.4
23:54:07	34-08-02.6	132-52-51.3	013.3	010	21.3

4 AIS Records for Vessel D (excerpts)

Vessel D position indicates the locations of the GPS antenna installed above the bridge. The antenna of the Vessel was set on the deck above the bridge; the location of the antenna was 69 meters from the fore side, 10 meters from the stern side, 2 meters from the port side and 11 meters from the starboard side, and then the courses over the ground and headings are indicated in true bearings.

Time (hh:mm:ss)	Vessel's Position		Course Over The Ground (°)	Heading (°)	Speed Over The Ground (kn)
	Latitude (N) (°-′-″)	Longitude (E) (°-′-″)			
23:37:07	34-08-28.2	132-58-15.7	304.4	307	10.3
23:38:36	34-08-37.3	132-58-00.9	306.1	307	10.6
23:39:07	34-08-40.7	132-57-55.4	306.2	307	10.5
23:40:07	34-08-47.1	132-57-45.2	306.4	306	10.6
23:41:07	34-08-53.5	132-57-34.9	307.5	305	10.6

23:42:07	34-09-00.0	132-57-24.7	308.5	306	10.7
23:43:07	34-09-07.0	132-57-14.7	313.5	307	10.9
23:44:16	34-09-13.8	132-57-02.2	301.6	301	10.8
23:45:07	34-09-18.2	132-56-53.0	296.0	290	10.5
23:46:07	34-09-22.1	132-56-41.4	284.9	275	10.2
23:47:16	34-09-23.2	132-56-27.4	269.9	269	10.0
23:48:07	34-09-23.3	132-56-17.3	267.9	265	10.1
23:49:07	34-09-22.5	132-56-05.0	262.4	263	10.4
23:50:07	34-09-21.1	132-55-52.4	262.0	263	10.5
23:51:17	34-09-19.9	132-55-37.6	267.8	265	10.7
23:52:07	34-09-19.4	132-55-26.8	265.5	264	10.8
23:52:26	34-09-19.1	132-55-22.5	265.6	265	10.8
23:52:46	34-09-18.8	132-55-18.6	267.1	262	10.7
23:53:07	34-09-18.4	132-55-13.9	257.6	254	10.7
23:53:26	34-09-17.4	132-55-09.8	252.2	247	10.6
23:53:46	34-09-16.3	132-55-06.2	247.5	241	10.6
23:53:51	34-09-15.9	132-55-05.0	243.7	240	10.5
23:54:16	34-09-13.7	132-55-00.4	236.1	235	10.5

Appendix Table 2　Information on each Vessel from Radar Images of Vessel B

1　Information on Vessel A from No.1 Radar Images of Vessel B and Display range

Time (hh:mm:ss)	Direction (°)	Distance (M)	COG (°)	CPA (M)	TCPA (mm:ss)	BCR (M)	BCT (mm:ss)	Display range (M)
23:43:25 ～23:49:25	-	-	-	-	-	-	-	4
23:49:40	008.6	2.026	267.9	0.520	3:53	1.262	1:30	4
23:49:55	007.6	1.897	264.3	0.485	3:35	1.236	1:16	4
23:50:10	010.0	1.785	262.0	0.468	3:19	1.073	1:22	4
23:50:25	011.2	1.670	262.1	0.434	3:08	0.959	1:23	4
23:50:40	012.4	1.531	260.9	0.396	2:53	0.828	1:22	4
23:50:55	013.8	1.420	260.3	0.362	2:41	0.730	1:21	4
23:51:10	015.3	1.280	260.4	0.335	2:27	0.622	1:18	4
23:51:25	014.9	1.169	260.7	0.317	2:15	0.583	1:10	4
23:51:40	013.8	1.054	260.7	0.302	2:02	0.556	1:00	4
23:51:55	012.0	0.924	257.2	0.262	1:46	0.513	0:47	4
23:52:10	010.9	0.801	250.6	0.198	1:32	0.425	0:42	4
23:52:25	009.1	0.672	240.0	0.105	1:18	0.298	0:40	4
23:52:40	008.6	0.540	232.4	0.056	1:02	0.184	0:37	4
23:52:55	008.2	0.415	230.0	0.042	0:48	0.140	0:27	4
23:53:10	008.8	0.278	228.5	0.035	0:31	0.089	0:17	4
23:53:25	012.0	0.151	230.9	0.037	0:17	0.049	0:07	4
23:53:40	354.9	0.055	241.2	0.050	0:03	0.022	-0:01	4

2　Information on Vessel A from No.2 Radar Images of Vessel B and Display range

Time (hh:mm:ss)	Direction (°)	Distance (M)	COG (°)	CPA (M)	TCPA (mm:ss)	BCR (M)	BCT (mm:ss)	Display range (M)
23:47:03		Standby screen						6
23:47:18	-	-	-	-	-	-	-	6
23:49:18	-	-	-	-	-	-	-	3
23:51:03	-	-	-	-	-	-	-	2
23:51:18	015.1	1.232	260.6	0.331	2:21	0.614	1:14	2
23:51:33	014.4	1.112	260.7	0.312	2:08	0.574	1:04	2
23:51:48	012.2	0.985	259.8	0.288	1:54	0.550	0:51	2
23:52:03	011.4	0.864	254.9	0.238	1:39	0.481	0:43	2
23:52:18	009.8	0.736	245.3	0.150	1:25	0.368	0:40	2
23:52:33	008.9	0.608	236.1	0.080	1:10	0.244	0:38	1.5
23:52:48	008.4	0.491	230.9	0.048	0:57	0.164	0:33	1.5
23:53:03	008.4	0.348	228.9	0.036	0:40	0.108	0:23	1.5
23:53:18	009.3	0.213	229.6	0.037	0:24	0.077	0:11	1.5
23:53:33	013.3	0.101	236.1	0.046	0:11	0.037	0:03	1.5

3 Information on Vessel D from No.2 Radar Images of Vessel B and Display range

Time (hh:mm:ss)	Direction (°)	Distance (M)	CPA (M)	TCPA (mm:ss)	BCR (M)	BCT (mm:ss)	Display range (M)
23:47:03		Standby screen					6
23:47:18	-	-	-	-	-	-	6
23:49:18	-	-	-	-	-	-	3
23:51:03	-	-	-	-	-	-	2
23:51:18	-	-	-	-	-	-	2
23:51:33	029.8	1.401	0.078	3:44	-0.213	4:09	2
23:52:33	033.1	1.025	0.128	2:43	-0.331	3:24	1.5
23:53:03	037.3	0.843	0.160	2:13	-0.399	3:05	1.5
23:53:18	044.2	0.740	0.221	1:49	-0.542	2:59	1.5
23:53:33	064.6	0.654	0.237	1:35	-0.396	2:17	1.5

Appendix Table 3　Audio Recordings of Vessel B (excerpts)

( ): Tentative translation from Japanese to English

( ): Tentative translation from Korean to English

Time (hh:mm:ss)	Audio Content
Around 23:36:57	Unknown: [sounds like putting down the receiver]
Around 23:41:40	N. Officer A_1: (Vessel D, Vessel D, this is Vessel A behind you.)
Around 23:42:03	N. Officer A_1: (Vessel D, Vessel D, this is Vessel A behind you. 06, please.) Vessel D: (Roger.)
Around 23:42:58	Unknown: [sounds like putting down the receiver]
Around 23:42:05 ～ 23:42:30	N. Officer B_1: KURUSHIMA MARTIS, KURUSHIMA MARTIS. This is Vessel B calling. Over. KURUSHIMA MARTIS: Vessel B, this is KURUSHIMA MARTIS. Change to channel 14, fourteen. Over. N. Officer B_1: 14.
Around 23:43:33 ～ 23:44:11	N. Officer B_1: KURUSHIMA MARTIS, this is Vessel B. Call sign V7OH9. Now I passed WS Line. Over. KURUSHIMA MARTIS: Vessel B, this is KURUSHIMA MARTIS. You passing WS Line, confirmed your position. Information. Tidal current South going 3.9 kn decreasing. Keep port side go to Naka Suido. And tidal current change time 00:34, North going. If you need change your course, we call you again. Over. N. Officer B_1: OK, copy that. Thank you, sir.
Around 23:46:02	Unknown: [sounds like putting down the receiver]
Around 23:46:51 ～ 23:47:21	KURUSHIMA MARTIS: Vessel B, Vessel B, this is KURUSHIMA MARTIS. N. Officer B_1: Vessel B. KURUSHIMA MARTIS: Change to channel 66, double six. N. Officer B_1: Double six. KURUSHIMA MARTIS, this is Vessel B. KURUSHIMA MARTIS: Vessel B, this is KURUSHIMA MARTIS. Information again. Now tidal current South going. Keep to port side of the fairway, go to Naka Suido. N. Officer B_1: Port side and go to Naka Suido, correct? KURUSHIMA MARTIS: That's right.
Around 23:47:58	N. Officer B_1: Zero four zero. Able Seaman B: Zero four zero.
Around 23:48:06 ～ 23:48:44	N. Officer B_1: (Thanks for being on duty.) *The audio of the conversation between Master B and N. Officer B_1 is unclear. N. Officer B_1: (Kurushima MARTIS is telling us to go through Naka Suido. Right now, they're telling us to go through Naka Suido.) Master B: (Go to Naka Suido? Why, isn't it the reverse tide flow?) N. Officer B_1: (The tide will be reverse from 00:30 and I was told to go to Naka Suido at the moment. There are a lot of vessels appearing in other

	places.) Master B: (Haven't they all come out yet?) N. Officer B_1: (No, I'm not sure.) *The audio of the conversation between Master B and N. Officer B_1 is unclear.
Around 23:49:04	*Electronic "beep-beep" sound
Around 23:49:25 ～ 23:49:46	Master B: Zero three five. Able Seaman B: Zero three five. Able Seaman B: Zero three five, sir.
Around 23:50:38 ～ 23:51:12	Master B: Zero three zero. Able Seaman B: Zero three zero. *Electronic "beep-beep" sound Able Seaman B: Zero three zero, sir.
Around 23:51:21 ～ 23:52:18	*Electronic "beep-beep" sound *Door opening/closing sound *Electronic "beep-beep" sound
Around 23:52:42	Master B: (Why is that vessel heading toward us?) Unknown: (*Audio is unclear)
Around 23:52:45	Master B: Zero two zero. Able Seaman B: Zero two zero. Unknown: Yah.
Around 23:52:49 ～ 23:52:50	Master B: (Where is that heading?) N. Officer B_1: Vessel A, Motor vessel, This is Vessel B.
Around 23:52:53 ～ 23:53:01	Master B : (*Audio is unclear) N. Officer B_1: Vessel A, Vessel A. Vessel B. N. Officer A_1: Yes, this is Vessel A. N. Officer B_1: What's your intention? N. Officer A_1: (Uh, yeah, yeah, ah.)
Around 23:53:03 ～ 23:53:06	N. Officer B_1: Port to Port, Port to Port. N. Officer A_1: (Uh,) OK.
Around 23:53:07 ～ 23:53:13	Master B: Hard port. Able Seaman B: Hard port. Master B_1: Port to Port. N. Officer A_1: OK. Unknown: Port to Port. Able Seaman B: Port to Port. Hard port.
Around 23:53:16 ～ 23:53:37	Master B : (*Audio is unclear) Master B: Stop engine, Stop engine, Stop engine. N. Officer B_1: Stop engine, Stop engine, Stop engine. N. Officer B_1: Stop engine, sir. * A jingling bell sound Master B: Full astern, Full astern, Full astern. N. Officer B_1: Full astern. Master B: Starboard, Hard starboard, Hard starboard.
Around 23:53:38	*Impact sound

Appendix Table 4 VHF Communication Records by Kurushima MARTIS (excerpts)

* According to Kurushima MARTIS, the recorded times are in minutes, so there may be a time error of approximately one minute.

1 Vessel A and Kurushima MARTIS (Tentative translation from Japanese to English)

Time	Speaker	Receiver	CH	Content
23:54	Kurushima MARTIS	Vessel A	16	Vessel A, Vessel A, this is Kurushima MARTIS.
23:55	Kurushima MARTIS	Vessel A	16	Vessel A, Vessel A, this is Kurushima MARTIS.
23:57	Kurushima MARTIS	Vessel A	16	Vessel A, Vessel A, this is Kurushima MARTIS.
00:00	Vessel A	Kurushima MARTIS	16	This is Vessel A, Vessel A. How is the sensitivity? Over. Kurushima MARTIS, this is Vessel A, Vessel A. How is the sensitivity? Over.
	Kurushima MARTIS	Vessel A	16	Vessel A, this is Kurushima MARTIS. 14 Over.
	Vessel A	Kurushima MARTIS	16	14.
00:01	Vessel A	Kurushima MARTIS	14	Kurushima MARTIS, this is Vessel A. Over.
	Kurushima MARTIS	Vessel A	14	Vessel A, this is Kurushima MARTIS.
	Vessel A	Kurushima MARTIS	14	Uh, we collided with Vessel B just now.
	Kurushima MARTIS	Vessel A	14	Collided with Vessel B. Are there any injuries or flooding?
	Vessel A	Kurushima MARTIS	14	No one was injured, but the hull is leaning rapidly. There seems to be flooding. Over.
	Kurushima MARTIS	Vessel A	14	Leaning. There seems to be flooding, Roger. What will you do now?
	Vessel A	Kurushima MARTIS	14	Yes, now. I'm reporting SOS. Now, yes, we are leaving the ship. Over.
	Kurushima MARTIS	Vessel A	14	Roger. Please contact us if you have anything.
	Vessel A	Kurushima MARTIS	14	Yes, sir.
	Kurushima MARTIS	Vessel A	14	Please note that vessels heading toward the west entrance will be leaving the channel between No.2 Buoy and No.4 Buoy. Please be careful when approaching.
	Vessel A	Kurushima	14	Roger.

		MARTIS		
00:13	Kurushima MARTIS	Vessel A	16	Vessel A, Vessel A, this is Kurushima MARTIS. Vessel A, Vessel A, this is Kurushima MARTIS.

2 Vessel B and Kurushima MARTIS

( ): Tentative translation from Japanese to English

Time	Speaker	Receiver	CH	Content
23:42	Vessel B	Kurushima MARTIS	16	KURUSHIMA MARTIS, KURUSHIMA MARTIS. This is Vessel B calling over.
	Kurushima MARTIS	Vessel B	16	Vessel B, this is KURUSHIMA MARTIS. Change to channel 14, fourteen. Over.
	Vessel B	Kurushima MARTIS	16	14.
23:43	Vessel B	Kurushima MARTIS	14	KURUSHIMA MARTIS, this is Vessel B. Call sign V7OH9. Now I passed WS Line. Over.
	Kurushima MARTIS	Vessel B	14	Vessel B, this is KURUSHIMA MARTIS. You passing WS Line confirmed your position. Information. Tidal current South going 3.9 kn decreasing. Keep port side go to Naka Suido. And tidal current change time 0034, North going. If you need change your course, we call you again. Over.
	Vessel B	Kurushima MARTIS	14	OK, copy that. Thank you, sir.
23:44	Kurushima MARTIS	Vessel B	14	Thank you, stand by 16, out.
23:46	Kurushima MARTIS	Vessel B	16	Vessel B, Vessel B, this is KURUSHIMA MARTIS.
	Vessel B	Kurushima MARTIS	16	Vessel B.
	Kurushima MARTIS	Vessel B	16	Change to channel 66, double six. Over.
	Vessel B	Kurushima MARTIS	16	Double six.
	Vessel B	Kurushima MARTIS	66	KURUSHIMA MARTIS, this is Vessel B.
	Kurushima MARTIS	Vessel B	66	Vessel B, this is KURUSHIMA MARTIS. Information again. Now tidal current South going. Keep to the port side of the fairway, go to Naka Suido.
	Vessel B	Kurushima	66	Port side and go to Naka Suido, correct?

		MARTIS		
	Kurushima MARTIS	Vessel B	66	That's right. 16 out.
23:47	Vessel B	Kurushima MARTIS	66	16.
23:53	Vessel B	Kurushima MARTIS	16	KURUSHIMA MARTIS, KURUSHIMA MARTIS. This is Vessel B, calling over.
	Kurushima MARTIS	Vessel B	16	Vessel B, KURUSHIMA MARTIS, 14.
	Vessel B	Kurushima MARTIS	16	Yes, this is Vessel B.
	Kurushima MARTIS	Vessel B	16	Vessel B, 14, fourteen.
	Vessel B	Kurushima MARTIS	16	14.
	Vessel B	Kurushima MARTIS	14	KURUSHIMA MARTIS, this is Vessel B. Now Collision, now we collision. With Vessel A, Vessel A at KURUSHIMA enter.
	Kurushima MARTIS	Vessel B	14	Collide with Vessel A? Vessel B, this is KURUSHIMA MARTIS.
	Vessel B	Kurushima MARTIS	14	This is Vessel B.
	Kurushima MARTIS	Vessel B	14	Collide with Vessel A?
	Vessel B	Kurushima MARTIS	14	I collide with Vessel A, I (Vessel B) collide with Vessel A.
	Kurushima MARTIS	Vessel B	14	Told him by port to port. Now why did you change your course to port? Over.
	Vessel B	Kurushima MARTIS	14	Umm. The KURUSHIMA MARTIS umm. Because order to me umm. Go to Naka Suido. So I (Vessel B) go to port side, but Vessel A is.
23:55	Kurushima MARTIS	Vessel B	14	OK, Vessel B. KURUSHIMA MARTIS. Please stand by out of the fairway safely. Over.
00:00	Kurushima MARTIS	Vessel B	16	Vessel B, Vessel B, this is KURUSHIMA MARTIS.
00:01	Kurushima MARTIS	Vessel B	16	Vessel B, Vessel B, this is KURUSHIMA MARTIS.
00:07	Kurushima MARTIS	Vessel B	16	Vessel B, Vessel B, this is KURUSHIMA MARTIS.
01:31	Vessel B	Kurushima MARTIS	16	KURUSHIMA MARTIS, KURUSHIMA MARTIS, this is motor tanker Vessel B.
	Kurushima MARTIS	Vessel B	16	Vessel B, change channel 14, fourteen.
	Vessel B	Kurushima		14.

		MARTIS		
01:32	Vessel B	Kurushima MARTIS	14	KURUSHIMA MARTIS, KURUSHIMA MARTIS, this is motor tanker Vessel B.
	Kurushima MARTIS	Vessel B	14	This is KURUSHIMA MARTIS. Go ahead.
	Vessel B	Kurushima MARTIS		*Vessel B replaced the crew member to one who can speak Japanese (Um, sorry. Is there anything we can help you with from our vessel?)
	Kurushima MARTIS	Vessel B	14	(Yes. Um, can you carry out rescue operations?)
	Vessel B	Kurushima MARTIS	14	(Uh, yes. Um, I think we can do it. Um, I think we can do it if we lower the ship's rescue boat and, um, move forward.)
	Kurushima MARTIS	Vessel B	14	(Oh, Roger. So, um, please do so. Well, there is a patrol boat here, so please follow instructions from the patrol boat.)
	Vessel B	Kurushima MARTIS	14	(Ah, yes, Roger.)
	Kurushima MARTIS	Vessel B	14	(Yes, and, um, if it's safe, um, um, please keep drifting. Over.)
	Vessel B	Kurushima MARTIS	14	(Uh, yes, Roger. Drifting.)
	Kurushima MARTIS	Vessel B	14	(Yes, um, can you run as you are?)
	Vessel B	Kurushima MARTIS	14	(Uh, I'm sorry, um, we can't anchor the ship. Well, we're not in a position to drop anchor right now, so we can't drop anchor, and I think we'll just stay here for a while, using the engine.)
01:33	Kurushima MARTIS	Vessel B	14	(Roger. Can you run slow?)
	Vessel B	Kurushima MARTIS	14	(Yes, slow...)
	Kurushima MARTIS	Vessel B	14	(Yes, slow and then can you run?)
	Kurushima MARTIS	Vessel B	14	(Yes, I 《Vessel B》 will return to channel 16 for now. Good-bye.)
	Vessel B	Kurushima MARTIS	14	(Yes...)

Attachment 1

Report on
Analysis Contract for Collision Accident
of Cargo Ship and Chemical Tanker

February 2023

National Maritime Research Institute,
National Institute of Maritime, Port and Aviation Technology

Table of contents

1 Introduction

1.1 Purpose of the investigation

To contribute to the investigation of the cause of the collision between a cargo ship and a chemical tanker that occurred near the west entrance of Kurushima Strait at 23:53:36 on May 27, 2021, this study evaluated the cognitive support regarding the behavior of both ships leading up to the collision based on AIS data and analyzed the navigation conditions of the ships in the surrounding sea area to identify the factors leading to the accidents.

1.2 Investigation summary

Four assessment indexes (CJ[1], SJ[2], BC[3], and OZT[4, 5]) were used to quantitatively evaluate the risk of collision for 1) the two ships that collided (the cargo ship Byakko (Ship A) and the chemical tanker ULSAN PIONEER (Ship B)) and 2) a group of ships including the two collided ships (at the time of the accident, the ferry Yamato (Ship C), which was sailing behind Ship B, and the cargo ship Daiichi Daiei Maru (Ship D), which was sailing behind Ship A). Ships other than the two ships involved in the collision (Ships C and D) were included in the analysis as ships that were navigating in the surrounding waters (within 2 to 3 nautical miles) at the time of the collision with Ships A and B, based on instructions from the consignor.

In this study, a preliminary analysis was first performed using OZT to evaluate the impact that the group of surrounding ships 2) had on the navigation of the two ships that collided. Next, a detailed analysis was conducted to consider the results of the preliminary analysis and evaluate the collision risk to the ships encountered in either 1) or 2) using the collision risk assessment indexes described above.

In the calculation of the collision risk assessment index, the reference point for the calculation was the center of the hull. Since AIS data interpolated at 10-s intervals were used as input data, the time "23:53:40" in this analysis report corresponds to the time of collision.

2 Overview of Collision Risk Assessment Indexes

The following is a summary of the collision risk assessment indexes used in this investigation. For details of the calculation method, refer to the respective original papers.

2.1 CJ (Collision Judgement) [1]

It is an index that shows the risk of collision between two ships in a one-to-one mutual positioning relationship. The collision risk is calculated from the relative distance to the other ship and its rate of change, and the change in bearing to the other ship and its rate of change. The range that CJ can take is from $-\infty$ to ∞.The CJ guideline for a 300 m long tanker when beginning to take evasive action along the coast is 0.00782.

In a previous study [6], a CJ value of 0.015 or higher was considered to be the threshold for judging that there is a risk of collision, and in an analysis of the relationship between the sense of danger [7], 0.007 or higher was considered to be the threshold for feeling a risk of collision with the other vessel and 0.013 or higher was considered to be the threshold for feeling that a collision is unavoidable.

2.2 SJ (Subject Judgement: Subjective collision risk) [2]

The distance from one ship to another and the rate of change in relative bearing are used as variables.

These variables are expressed in three fuzzy levels to account for the mutual positioning relationship, and the combination of the two is weighted to evaluate the collision risk between ships. The range that SJ can take is from -3 to 3, and the implications are as follows.

Extremely dangerous	SJ = -3	Extremely safe	SJ = +3
Dangerous	SJ = -2	Safe	SJ = +2
Somewhat dangerous	SJ = -1	Somewhat safe	SJ = +1
Can't say either way	SJ = 0		

2.3 BC (Blocking Coefficient: Degree of blockage of the collision avoidance maneuvering space) [3]

The degree to which the ship is blocked by ships in the vicinity (the degree to which the ship's maneuvering space is blocked) is calculated by multiplying the risk of collision with a group of surrounding ships when the ship performs the maneuvers of changing speed and turning course by a weighted factor that expresses the preference for the maneuvers of changing speed and turning course. The possible range of BC is from 0 to 1, and when BC is 1, the time margin is extremely small and the situation cannot be avoided by any maneuvering.

In this investigation, the accident occurred just before the entrance/exit of the Kurushima Strait Passage, and because gaining sufficient speed against the current was essential, it was considered to be a situation wherein slowing down was difficult; therefore; BC was assessed by limiting the means of avoidance to only changing the course. The range of avoidance is limited to 60° left or right from the current course in 5° increments.

2.4 OZT (Obstacle Zone by Target)[4, 5]

The OZT refers to the zone in which the ship's operating space is obstructed by the presence and movement of other ships. The concept and evaluation method of OZT are shown in Figure 2. 1. The course of a ship that results in a safety passing distance (SD) between the ship and another ship is called the collision course (C_{O1} and C_{O2} in the figure), meaning the course where the distance between the ship and another ship is SD. A capsule-shaped object with the SD as the glue allowance for the line segment of the other ship's path that is sandwiched between the collision paths is called OZT. Here, for the sake of computational simplicity, the line segment in the length direction of the capsule on the course of another ship is designated as OZT (the red line segment in (Figure 2. 1 (a)).

In this investigation, OZT was used to evaluate the effect on navigation as a preliminary analysis and collision risk assessment was conducted as a detailed analysis. The calculation and evaluation methods are shown below.

How to calculate OZT

- ✓ The targets are ships approaching within 3 NM of the own ship.
- ✓ The safe navigating distance SD is L_g [m], which is determined by the lengths of the own and other ships. L_g is defined as the length that determines the size of the exclusive area where no other ships are allowed to enter to eliminate the risk of collision [2].

$$L_g = \left\{ \frac{L_o^{\ 2} + L_t^{\ 2}}{2} \right\}^{1/2}$$

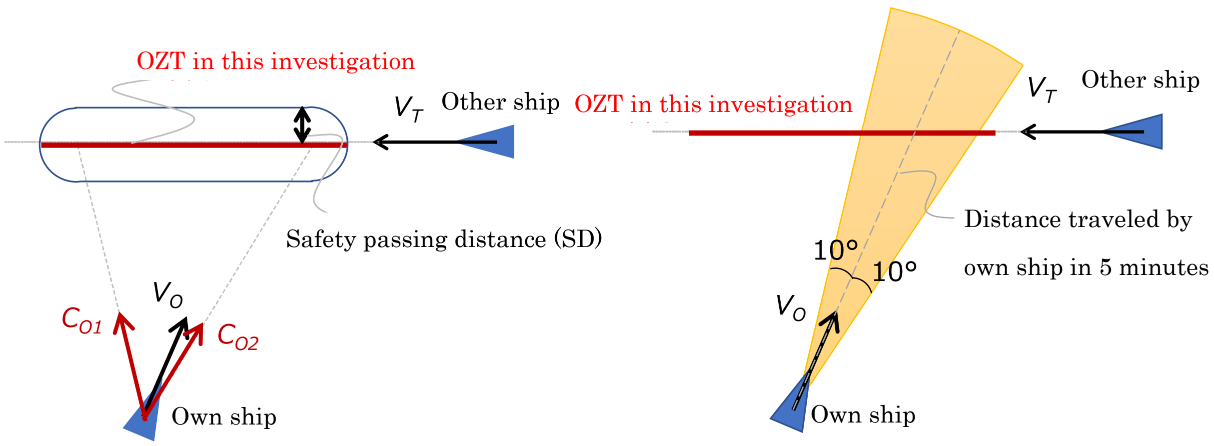
Where, L_o: Length of the own ship [m], L_t: Length of other ships [m]

Assessment of the effect of OZT on navigation (Sections 3.2 and 3.3)

- ✓ When an OZT exists ahead of the own ship, it exerts pressure on the ship's maneuvering behavior. If an OZT occurs on the own ship's course, the ship's maneuvering space will be obstructed, so this area must be avoided.
- ✓ Based on the relative positions of the own ship and the OZT, the impact on navigation was evaluated, taking into account the degree of blockage of the ship's course.

Collision risk assessment by OZT (Sections 4.2 and 4.3)

- ✓ Based on the literature [8], the direction from the own ship (within 10° left or right of the ship's course) and distance (within 5 min to reach the OZT point) that are deemed appropriate for identifying OZTs where there is a risk of collision are defined as the evaluation area (the sector-shaped range in Figure 2. 1(b)).
- ✓ OZTs that at least partially fall within the evaluation area are identified as "OZTs with high collision risk" and others as "OZTs with low collision risk."
- ✓ Based on the positional relationship between the own ship and the identified OZT and the time of occurrence, the degree of blockage of the ship's path and the margin of time were taken into account for the collision risk assessment.



(a) Collision course and OZT (b) How to identify OZT by evaluation area

Figure 2. 1 OZT concept and evaluation method

3 Preliminary analysis

3.1 Track chart

Figure 3. 1 shows the tracks of ships A and B that collided, as well as ships C and D that were sailing nearby.

The characteristics of the ships analyzed in this study are shown in Table 3. 1.Note that the ship's length L and width B in the table are the values from the AIS data used for the various analyses in this investigation.

Table 3. 1 Characteristics of the analyzed ships

	L × B
Ship A	169 [m] × 26 [m]
Ship B	90 [m] × 14 [m]
Ship C	195 [m] × 30 [m]
Ship D	79 [m] × 13 [m]

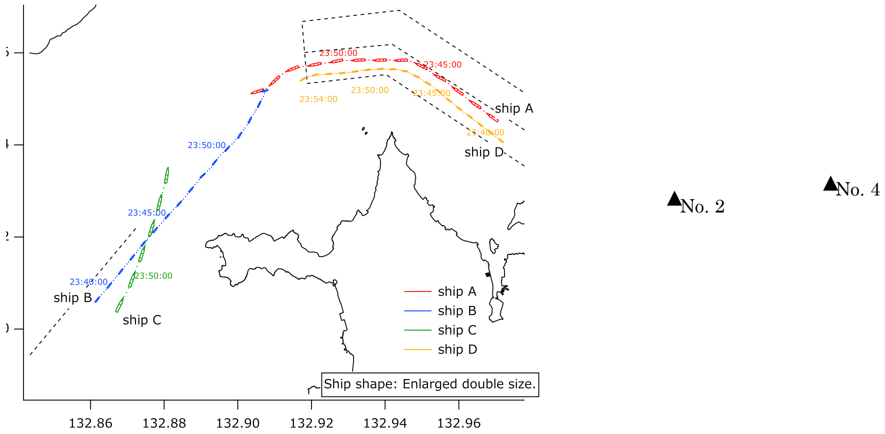


Figure 3. 1 Track chart before and after the accident

3.2 Assessment of impact on Ship A

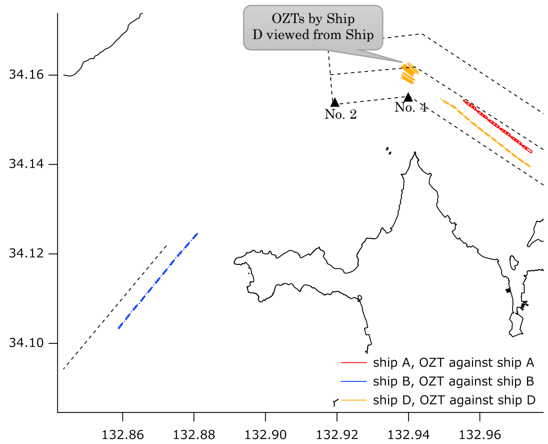
The effect of the surrounding ships on the navigation of Ship A was evaluated. The track of each ship and the location of the OZT for each ship encountered by Ship A are shown in Figure 3. 2.

The track of each ship and the OZTs generated by that ship are drawn in the same color. For example, in Figure 3. 2 (e), Ship A, indicated by the red line has OZT for two ships, the blue line indicates OZT by Ship B, and the green line indicates OZT by Ship C.

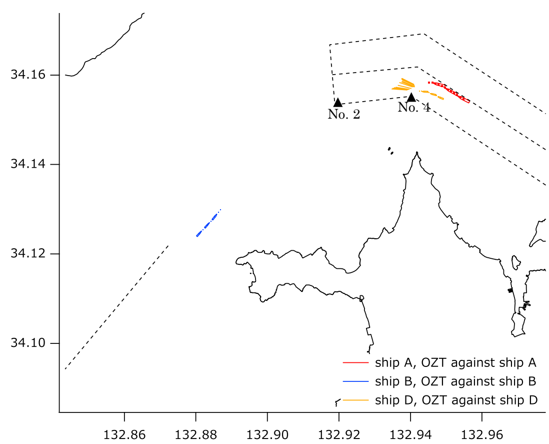
Observations are made as time progresses. From Figure 3. 2 (a) and (b), it can be seen that Ship A encountered OZTs by Ship D until around 23:46, before Ship A changed its course at the No. 4 light buoy in the Kurushima Strait Passage (hereafter referred to as the No. 4 light buoy), but these OZTs had a very small impact on the navigation of Ship A, considering the change of course of Ship A and Ship D due to the bends in the passage. By the time Ship A finished changing its course (around 23:47), Ship D had completed overtaking, and Ship A did not encounter OZT by Ship D for the rest of the time.

From Figure 3. 2 (c), Ship A encountered OZT with Ship B for the first time at around 23:47 and continued to encounter OZT with Ship B until the collision. See Section 4.3 for a collision risk assessment for OZT for Ship B. Figure 3. 2 (e) shows that Ship A encountered

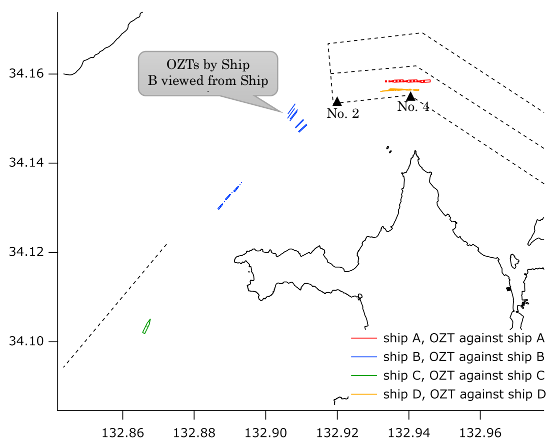
OZT with Ship C for the first time around 23:51 when Ship A left the Kurushima Strait Passage and continued to encounter OZT with Ship C thereafter. Observation of Figure 3. 2 (e) shows that Ship A encountered OZTs by Ships B and C at the exit of the Kurushima Strait course. Although the OZT by Ship C was more distant than the OZT with Ship B and the distance between the OZT with Ship B and the OZT with Ship A was considered to be sufficient for Ship A to be able to navigate, it cannot be said that the OZT by Ship C had no effect on the navigation of Ship A.



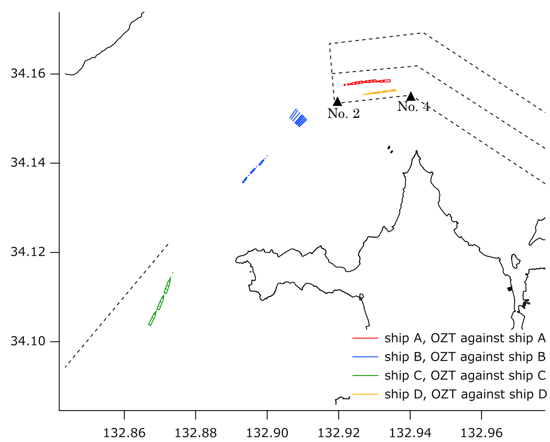
(a) (Timespan 1) until about 23:44



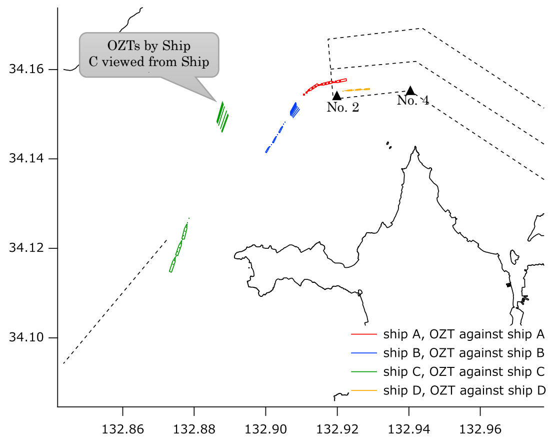
(b) (Timespan 2) about 23:45-23:46



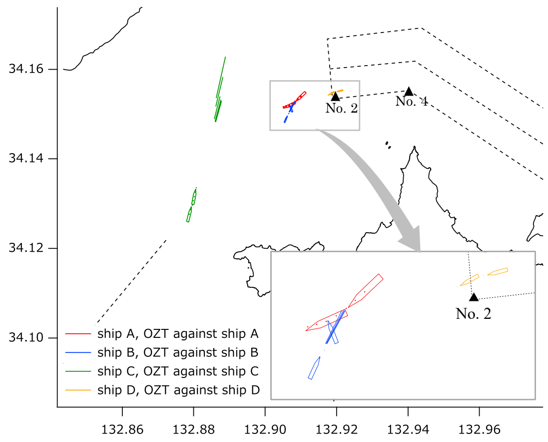
(c) (Timespan 3) about 23:47-23:48



(d) (Timespan 4) about 23:49-23:50



(e) (Timespan 5) about 23:51-23:52



(f) (Timespan 6) about 23:53-23:54

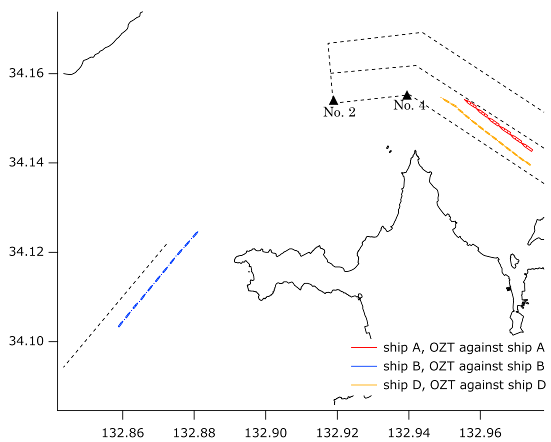
Figure 3. 2 Changes in the track and OZTs encountered by Ship A

3.3 Assessment of impact on Ship B

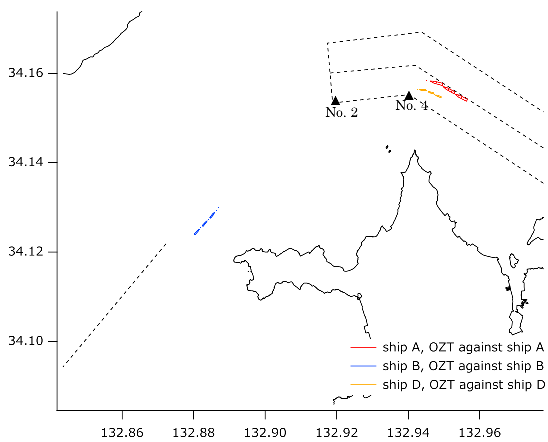
The effect of the surrounding ships on the navigation of Ship B was evaluated. Figure shows the tracks of each ship and the location of the OZT for each ship encountered by Ship B.

From Figure 3. 3 (c), Ship B encountered the OZT between ship D and Ship A for the first time at around 23:47. From Figure 3. 3 (d), Ship B encountered the OZTs by Ship A and Ship D until around 23:50, when Ship A was navigating in the Kurushima Strait. During these periods, the OZT by Ship D was on the course of Ship B and the OZT by Ship A was on the port side of the course of Ship B, and considering the course that Ship B could have taken to enter from the north side of the Kurushima Strait Passage, it cannot be said that the OZT by Ship D had no effect on the navigation of Ship B.

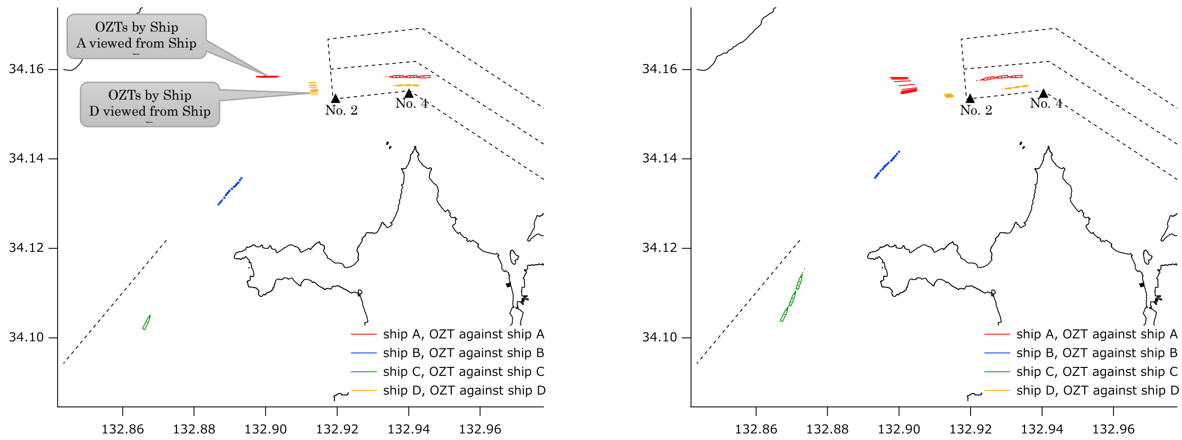
The time when Ship B encountered the OZT by Ship C is around 23:53 from Figure 3. 3 (f), and it is considered that the OZT had little effect on the navigation of Ship B.



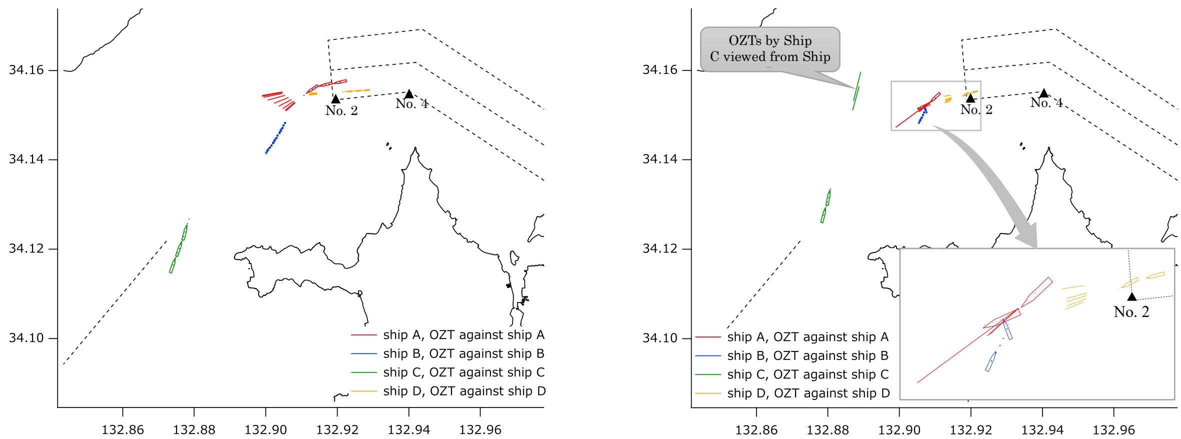
(a) (Timespan 1) until about 23:44



(b) (Timespan 2) about 23:45-23:46



(c) (Timespan 3) about 23:47-23:48 (d) (Timespan 4) about 23:49-23:50



(e) (Timespan 5) about 23:51-23:52 (f) (Timespan 6) about 23:53-23:54

Figure 3. 3 Changes in the track and OZT encountered by Ship B

4 Detailed analysis

4.1 Time variation of state quantity

The changes in the state quantity over time of the two ships (Ship A and Ship B) that collided with each other were analyzed based on the AIS data. The changes in the state and relative state quantity of Ship A and Ship B are shown from Figure 4. 1 to Figure 4. 3.From the top diagram on Figure 4. 1, these diagrams show fore heading, SOG (Speed Over Ground), and COG (Course Over Ground). Figure 4. 2 shows, from the top, the rate of change of heading and the distance between the two ships, and Figure 4. 3 shows, from the top, TCPA (Time to Closest Point of Approach), DCPA (Distance of Closest Point of Approach), and BCR (Bow Crossing Range). The black lines in the diagrams show the values common to both Ship A and Ship B, and the red and blue lines show the state quantity for Ship A and Ship B, respectively.

Note that the shaded areas in the diagrams are not included in the evaluation of collision risk because they are from the time before Ship A changes its heading at No. 4 light buoy.

① Rate of change in compass heading

The rate of compass heading change temporarily dropped below 2°/min between 23:46 and 23:47, but remained above 2°/min thereafter. According to the references [9-10], "the human ability to perceive the rate of change by sight is 1 °/min to 2°/min when there is a reference point."

② DCPA

The DCPA began to decrease at around 23:46, and by around 23:47 when Ship A completed its course maneuver at No. 4 Light Buoy, the DCPA was less than 0.5 NM, and although there were periods when it temporarily increased, the DCPA continued to decrease. In particular, around 23:52, the DCPA was less than 0.2 NM, which was extremely small.

③ BCR

The BCR of Ship A was negative, and Ship B was passing on the aft side of Ship A. The BCR of Ship A decreased to less than 1.0 NM after about 23:51, to less than 0.5 NM (about 0.43 NM from the aft end) at about 23:52, and to less than 0.2 NM (about 0.15 NM from the fore end) at about 23:53, indicating that the BCR was continuously decreasing.

On the other hand, the BCR of Ship B was positive, and Ship A was passing on the fore side of Ship B. Although there were some fluctuations, the BCR was generally around 1.0 NM before around 23:50, decreasing to below 1.0 NM at around 23:50, decreasing to below 0.5 NM (approximately 0.44 NM from the bow end) at around 23:52, and decreasing to below 0.2 NM (approximately 0.13 NM from the bow end) at around 23:53, indicating that the BCR was continuing to decrease.

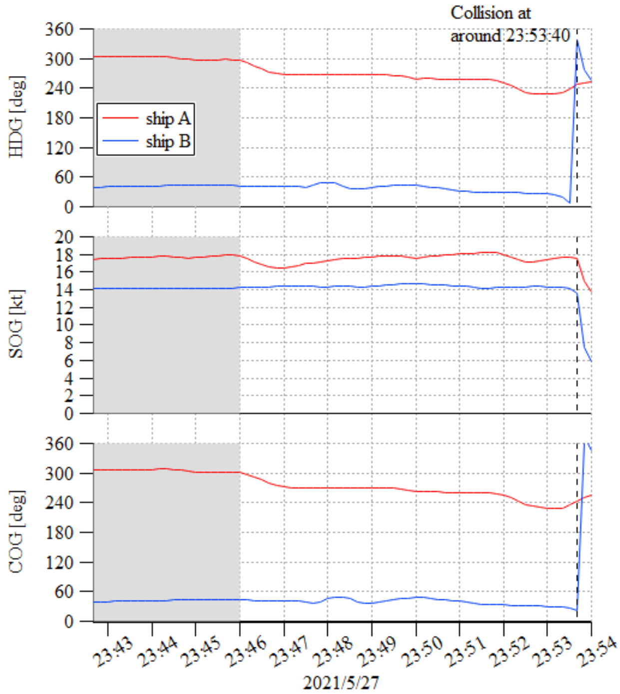


Figure 4. 1　Time change of state quantity

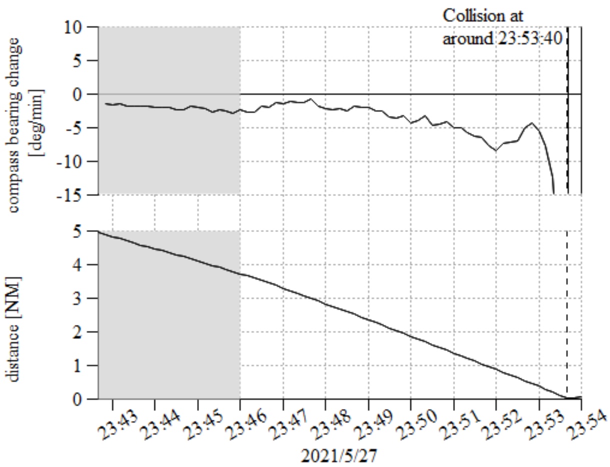


Figure 4. 2　Time change of relative state quantity (1)

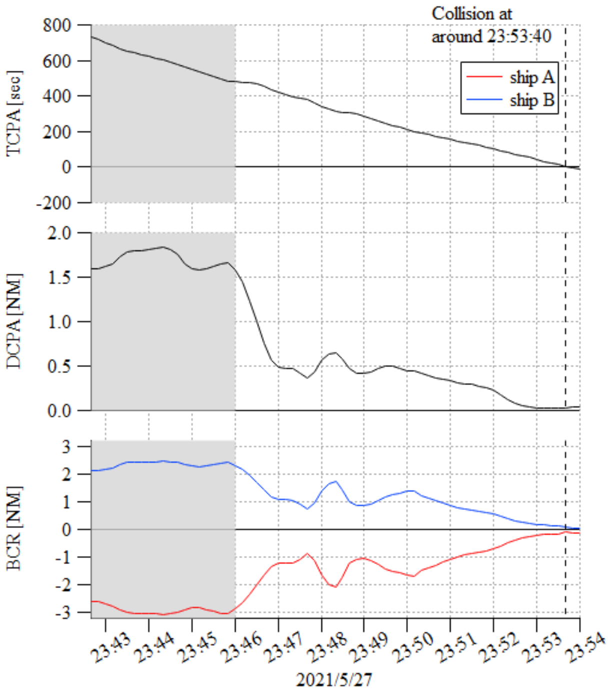


Figure 4. 3　Time change of relative state quantity (2)

4.2　Collision risk assessment using collision risk index

Based on the results of the preliminary analysis in Chapter 3, it was considered that Ship A may have been affected by Ship C and Ship B may have been affected by ship D, and therefore, the collision risk was evaluated by considering each ship.

Figure 4. 4 shows the change in the risk of collision over time as seen from Ship A, and

Figure 4. 5 shows the change in the risk of collision over time as seen from Ship B. Both diagrams show, from the top, CJ, SJ, and BC. Note that the red line in Figure 4. 4 and the blue line in Figure 4. 5 indicate the risk of collision between own ship (Ship A or Ship B) and only one other ship (Ship B or Ship A). The green line in Figure 4. 4 and the yellow line in Figure 4. 5 represent the risk of collision for CJ and SJ of the own ship (Ship A or Ship B) against only a third ship (Ship C for Ship A, and Ship D for Ship B), while for BC they represent the risk of collision of own ship (Ship A or Ship B) against not only the other ship (Ship B or Ship A) but also a third ship.

① CJ

Observations are made for Ship). The shows for Ship A, that although the graph fluctuated with respect to Ship B, it increased rapidly after 23:52, suggesting that the risk of collision may have increased. For the third ship (Ship C), negative values were observed for most of the time, suggesting that the risk of collision was small.

Looking at Ship B, the graph rose sharply to the positive side from around 23:51 relative to Ship A, suggesting that there may have been an increased risk of collision. For the third ship (Ship D), there was a time from 23:51 to 23:52 when the value was temporarily almost the same as that for Ship A, but after that, the value was negative, suggesting that the risk of collision was small.

② SJ

For Ship A, although there was a period of time when the graph was temporarily positive (indicating the safe side), the values on the graph were negative (indicating the dangerous side) after around 23:50, and just before 23:53, the values were below -2, suggesting that the risk of collision was extremely high. For the third ship (Ship C), the values were always positive, suggesting that there was little risk of collision.

Let us look at Ship B. For Ship A, the graph was negative from 23:51 to 23:53 and was less than -2 at 23:53, suggesting that the risk of collision was extremely high. For the third ship (Ship D), the graph became negative around 23:51 and continued to decrease until around 23:53, indicating that the risk of collision was increasing, but was lower than the risk of collision with Ship A.

③ BC

Observations are made for Ship A. For Ship B only, there was a time period from 23:50, just before leaving Kurushima Strait Passage, to 23:53, just before the collision, when the value on the graph was almost zero, suggesting that the degree of maneuvering difficulty may have been extremely low. During the other time periods, the maximum value was 0.22, suggesting that the degree of maneuvering difficulty may have been low. When the third ship (Ship C) is considered, since the graph values are larger than those for Ship B alone after about 23:49. This suggests that the influence of the third ship (Ship C) may have increased the maneuvering difficulty level somewhat, but the maximum value was approximately 0.39 just before the collision, which is considered to have been lower than the maneuvering difficulty level for Ship B relative to Ship A, as described below.

Observations were made for Ship B. Only for ship A, the graph value had been continuously increasing since around 23:46, before Ship A changed its heading at No. 4 light buoy, suggesting the possibility that the ship was in a state of increasing maneuvering difficulty. In particular, the value increased sharply just before 23:53, and the maximum value was approximately 0.90 just before the collision, suggesting that the ship was in a situation that could hardly be avoided by any maneuvering. When a third ship (Ship D) is considered, the trend is similar to the case of only Ship A. However, it is possible that the third ship (Ship D) had an effect on the degree of maneuvering difficulty in the time period before approximately 23:53.

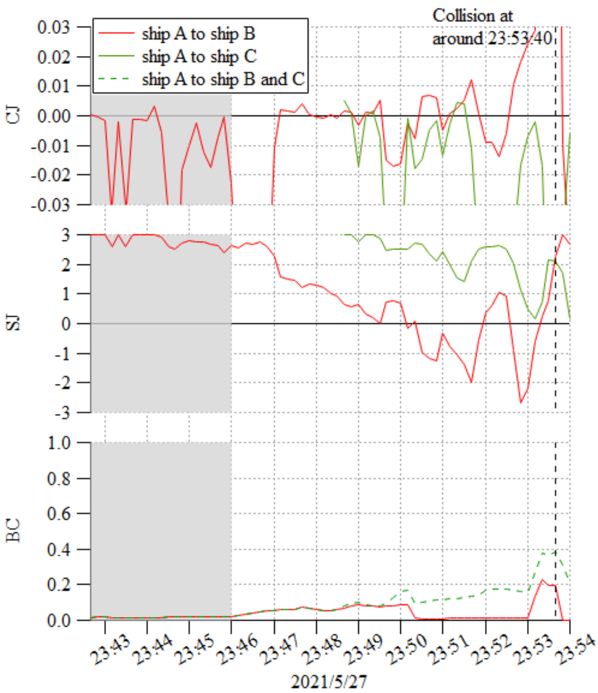


Figure 4. 4 Changes in collision risk assessment index over time (Ship A)

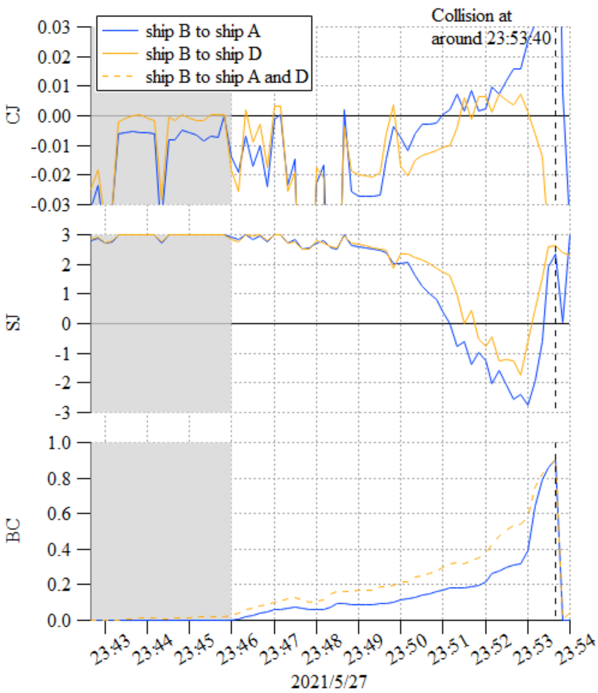


Figure 4. 5 Changes in collision risk assessment index over time (Ship B)

4.3 Collision risk assessment by OZT

As in the previous section, the collision risk was evaluated using OZT for Ship A considering Ship C, and Ship B considering Ship Figure 4.6 presents a timeline showing OZTs (Figure 3. 2 and Figure 3. 3) encountered by Ships A and B, identifying the risk according to the assessment area and indicating the time of encounter. The red arrows indicate the time of encounter with OZTs with high collision risk (see Section 2.4), and the orange arrows indicate the time of encounter with OZTs with low collision risk (see

Section 2.4).

① **Ship A**

Observations are made about Ship A in conjunction with Figure 3. 2.Ship A encountered the OZT with Ship B since about 23:47:40, and until around 23:52:00, encountered the OZT with a low risk of collision slightly to the port side of Ship A's bow. Due to Ship A changing its heading at the exit (Figure 4. 1), until around 23:53:30, Ship A encountered an OZT with high risk of collision, which was almost directly in front of it. From this, it can be assumed that from the time Ship A first encountered the OZT, the OZT had been on a course close to directly in front of the bow, and that the margin of time was gradually becoming shorter. In particular, it is possible that the risk of collision was extremely high after about 23:52:00. Ship B changed its heading slightly after 23:50 (Figure 4. 1), which may have affected the change in the position of OZT.

The third ship (Ship C) encountered the OZT for the first time at around 23:51:50, and encountered the OZT with a high risk of collision until around 23:52:10, but the position of the OZT from Figure 3. 2 was farther away than that of Ship B, and therefore, It is considered that there was a relatively large margin of time before a collision or close approach with Ship B occurred. After that time, until around 23:53:30, the OZT of Ship A was at a lower risk of collision due to the change of its heading after it left Kurushima Strait Passage.

② **Ship B**

Observations are made about Ship B in conjunction with Figure 3. 3. Ship B encountered the OZT with Ship A since 23:47:40, and until around 23:52:10 it encountered the OZT with a low risk of collision on the port side of Ship B's bow. Due to Ship A changing its heading by approximately 30° at the exit and Vessel B changing its heading slightly, they encountered the OZT with a high risk of collision, almost directly in front of Ship B from approximately 23:52:10 to 23:53:30. Ship B is considered to have been in a situation where the margin of time was gradually shortening as the position of the OZT gradually moved closer to the course of Ship B from the time it first encountered the Ostin particular, it is possible that the risk of collision was extremely high after about 23:52:10.

For the third ship (Ship D), the first OZT was encountered at 23:47:20, followed by the low collision risk OZT until 23:49:50, the high collision risk OZT from 23:50:00 to 23:52:00, and then again, the low collision risk OZT until 23:53:40. However, based on Figure 3. 3, from around 23:50 onward, since the OZT's position was farther away than the OZT of Ship A, it is possible that there was a relatively large margin of time before a collision or abnormal approach with Ship A occurred.

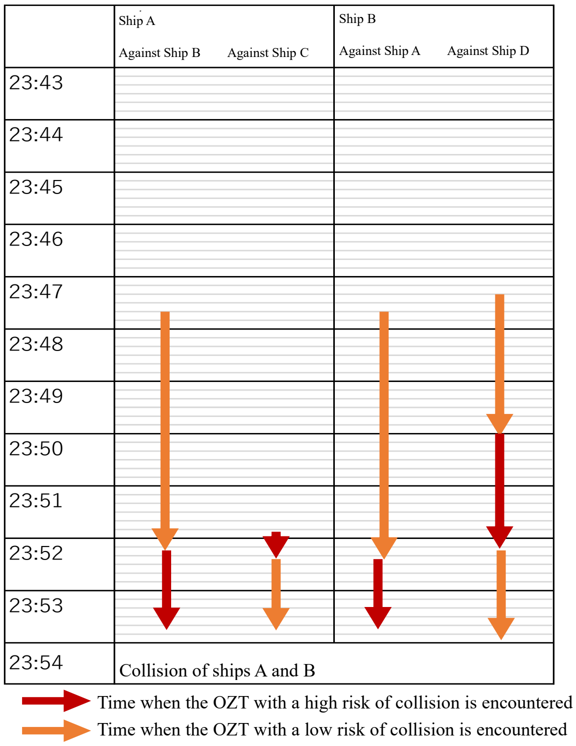


Figure 4. 6　Risks and timelines of OZTs encountered by ships A and B

5　Summary

The analysis results of this investigation are presented below.

Navigational impact assessment

OZT was used to evaluate the effect of the surrounding group of ships on the navigation of the two ships that collided. As a result, it is considered that it cannot be said that Ship A was not affected by Ship C and Ship B was not affected by Ship D.

Situational results due to time changes in state quantity

The rate of change of compass heading temporarily dropped below 2°/min for a period of time, but thereafter remained above 2°/min. The DCPA was continuously decreasing, although there were periods of temporary increases, and at around 23:52, the DCPA was extremely small at less than 0.2 NM. Regarding BCR, Ship B was passing on the aft side of Ship A and Ship A was passing on the bow side of Ship B. Although BCR fluctuated for both ships, there was a continuous downward trend after around 23:49, and in particular, around 23:53, the BCR of each ship was below 0.20 NM.

Collision risk assessment using collision risk index

Regarding CJ, it is possible that Ship A was in a state where the risk of collision with Ship B was rapidly increasing from around 23:52 onward, and Ship B was in a state where the risk of collision with Ship A was rapidly increasing from around 23:51 onward. The risk of collision for both ships with third ships (Ship C for Ship A and Ship D for Ship B) may have been small.

Regarding the SJ values, the risk of collision of Ship A and Ship B possibly increased rapidly after 23:50 and 23:51, respectively. Both ships had SJ values below -2 around 23:53, indicating that the risk of collision was extremely high. Both ships were at an increased risk of collision with third ships (Ship C for Ship A and Ship D for Ship B), but the risk of collision was considered lower than the risk of collision between Ship A and Ship B.

Regarding BC, there was a time when Ship A's maneuvering difficulty temporarily reached almost zero, and it is possible that the maneuvering difficulty was low with respect to Ship B. Even taking into account the third ship (Ship C), it is considered to have been lower than the maneuvering difficulty of Ship B with respect to Ship A. Ship B's maneuvering difficulty began to increase continuously around 23:46, and especially around 23:53, the BC value rose sharply to approximately 0.90, indicating that the ship may have been in a situation that could hardly be avoided by any maneuvering. When the third ship (Ship D) is considered, it is possible that the third ship (Ship D) may have made maneuvering more difficult during the time period before about 23:53.

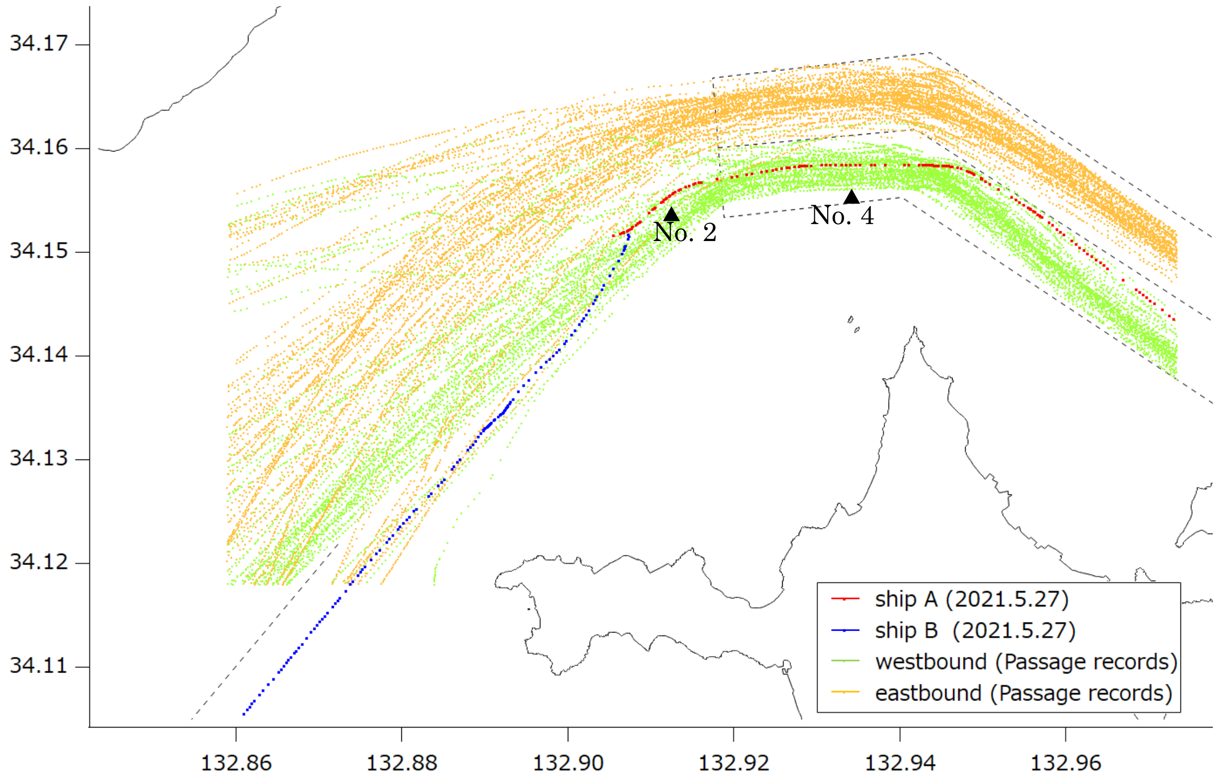
Collision risk assessment by OZT

From around 23:47:40, when Ship A first encountered Ship B's OZT, the OZT was on a course close to directly in front of the bow, and the margin of time was gradually becoming shorter. In particular, it is possible that the risk of collision was extremely high after about 23:52:00. For the third ship (Ship C), after encountering the OZT for the first time around 23:51:50, it temporarily encountered the OZT with a high collision risk, but since it was further away than the OZT of Ship B, there is a possibility that it had relatively more margin than the margin of time until collision or abnormal approach against Ship B.

Ship B first encountered Ship A's OZT in front of Ship B's port side at around 23:47:40, and then encountered the OZT with a high collision risk almost directly in front of it from around 23:52:10 to around 23:53:30. As the position of OZT gradually approached the path of Ship B, the margin of time was considered to be gradually shortening. In particular, it is possible that the risk of collision was extremely high after about 23:52:10.For the third ship (Ship D), after encountering the OZT for the first time around 23:47:20, it temporarily encountered the OZT with a high collision risk, but since it was further away than the OZT of Ship B, there is a possibility that it had relatively more margin than the margin of time until collision or abnormal approach against Ship A.

References

As a reference for the possible paths that ships could have taken in the tidal current (southward current) of Kurushima Strait at the time of the accident, only tracks of the ships that had passed through Kurushima Strait on April 30, 2021, May 28, 2021, and June 28, 2021 were extracted from AIS data, and the tracks of the two colliding ships were superimposed.



Reference diagram: Navigation conditions during southward current and ship tracks during the accident

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1 Hiroaki Kobayashi: Analysis of Ship Avoidance Maneuver - From the Viewpoint of Human-Machine System Analysis, Transactions of the Japan Institute of Navigation, No. 56, pp. 101-109, 1976. (In Japanese)

2 Kiyoshi Hara: Effectiveness of the Avoidance Maneuvering Standard in Congested Waters, Transactions of the Japan Institute of Navigation, No. 85, pp. 33-40, 1991. (In Japanese)

3 Akira Nagasawa: Simulation of Marine Traffic Considering Avoidance, Navigation, pp. 28-34, 1984. (In Japanese)

4 Hayama Imazu: OZT Calculation Method Using Collision Course, Journal of the Japan Institute of Navigation, Navigation, No. 188, pp. 78-81, 2014. (In Japanese)

5 H. Imazu, Evaluation Method of Collision Risk by Using True Motion, J. TransNav, Vol.11, No.1 , pp. 65-70, 2017. (In Japanese)

6 Japan Transport Safety Board: Ship Accident Investigation Report, https://www.mlit.go.jp/jtsb/ship/rep-acci/2018/MA2018-2-2_2016tk0008.pdf (as of February 7, 2022)

7 Rina Miyake, Shinsuke Urushidani: Situational Awareness Evaluation Using Collision Risk Index in Accident Analysis - Quantitative Collision Risk Index-, Proceedings of the Japan Institute of Navigation, Vol.9, No.2, pp.63-66, 2021. (In Japanese)

8 Rina Miyake, Shinsuke Urushidani: Situational Awareness Evaluation Using Collision Risk Index in Accident Analysis - OZT (Obstacle Zone by Target) -, Proceedings of the Japan Institute of Navigation, Vol.10, No.1, pp.70-73, 2022. (In Japanese)

9 Kiyoshi Hara: A Study on Avoiding Ship Maneuvering, Doctoral Dissertation, Osaka Universi ty, 1983, https://ir.library.osaka-u.ac.jp/repo/ouka/all/33738/ (as of February 7, 2022)

10 Keisuke Tsuji, Takayuki Ito: On the Rate of Azimuth Change, Transactions of the Japan Institute of Navigation, No. 117, pp. 67-73, 2007.

Attachment 2

Report on
Analytical Investigation of Sinking Accident (Sinking of Cargo Ship A)

March 2022

National Maritime Research Institute,
National Institute of Maritime, Port and Aviation Technology

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Preface

This report summarizes the results of a contract research, “Analytical Investigation of Sinking Accident (Sinking of Cargo Ship A)” conducted by the National Maritime Research Institute, National Institute of Maritime, Port and Aviation Technology (hereafter referred to as “NMRI”).

This analytical investigation was conducted to contribute to the investigation of the sinking of Cargo Ship A near the west entrance of Kurushima Strait on May 27, 2021. The investigation included the following tasks:

(1) Estimation of the vessel’s stability

(2) Estimation of circumstances leading to capsizing and sinking

The specific contents of the analysis and investigation were as follows:

(1) Estimation of the vessel’s stability

The stability of Cargo Ship A (hereinafter referred to as “the ship”) before the accident (collision) was estimated based on the condition of the ship at the time of departure from the Port of Kobe, and compliance with the stability criteria was confirmed.

(2) Estimation of circumstances leading to capsizing and sinking

1) Situation from the occurrence of a breach due to collision until the lashing broke

By estimating the amount of water flooding into the compartment where the outer plating was damaged and a breach occurred after the collision and calculating the angle of heel, it was possible to estimate the extent to which the ship would heel due to water flooding through the breach and the state of heeling until the lashing was broken.

2) Situation after the lashing broke

The state of heeling was estimated based on the assumed heeling moment caused by the movement of the loaded vehicles across the ship’s width after the lashings broke.

3) Situation leading to the capsizing

Based on the results of the investigation described in 2) above, it was estimated that the ship’s stability was reduced due to flooding, and the onboard vehicles moved in the width direction of the ship, generating a heeling moment that would lead to the ship capsizing.

4) Situation leading to the sinking

It is estimated that the collision damaged the outer plating, reducing buoyancy, and allowed seawater to flow into the ship through openings other than the breach, leading to the sinking of the ship.

(3) Report preparation

In order to facilitate the smooth implementation of the investigation, close contact was maintained with Japan Transport Safety Board (JTSB). The following person was primarily responsible for this analytical investigation.

Fluids Engineering & Ship Performance Evaluation Department: Harukuni Taguchi

If you have any questions about the details, please contact Taguchi at taguchi@m.mpat.go.jp.

1. Estimation of the vessel’s stability

Based on the condition of the ship at the time of departure from the Port of Kobe, the ship’s stability before the accident (collision) was estimated and its compliance with the stability criteria was confirmed.

1.1 Estimation of stability before the accident

1.1.1 Setting the weight and center of gravity

Based on the vessel’s stability curves and stability documents provided by the investigator, the operator’s report (total weight of vehicles on each deck), the oil recovery company’s report (amount of fuel oil and other oil recovered), and the shipowner’s report (amount of fresh water and ballast water on board, and draft at the time of departure from the Port of Kobe on the day of the accident), we performed weight and center of gravity calculations, as well as estimated draft and displacement, and confirmed the consistency of the data.

As a result, the ship’s displacement and center of gravity (fore-aft and up-down) before the accident were determined as follows.

① The displacement and fore-aft position of the center of gravity were set based on displacement calculations using the draft at the time of departure from Kobe Port (bow draft: dF = 5.50 m, aft draft: dA = 7.50 m). In this case, the fore-aft position of the center of gravity was treated as coinciding with the fore-aft position of the center of buoyancy.

② The height of the center of gravity (the vertical position of the center of gravity) was calculated as the sum of the light load weight shown in the stability data and the gravity moment in vertical direction of the vehicles and other items on board on the day, divided by the displacement, as in the normal weight and center of gravity calculations.

The displacement (W) and center of gravity (fore-aft position: mid-G, vertical position: KG) used to estimate the stability before the accident are shown in Table 1.1.1. The table also shows the values for standard loading condition 3-1 at the time of departure, which has roughly the same displacement, as listed in the stability documents prepared at the time of construction (hereinafter referred to as “standard loading condition at the time of construction”) Note that GG’ in Table 1.1.1 is the apparent rise in the center of gravity due to the liquid with a free surface in various tanks (free water effect).

Table 1.1.1 Weight and center of gravity (before accident and standard loading condition at the time of construction)

	W (tf)	mid-G (m)	KG (m)	GG' (m)
Before the accident	13,082	8.17	11.66	0.62
Standard loading condition at the time of construction	12,933	6.6	12.29	0.26

1.1.2 Stability calculation results

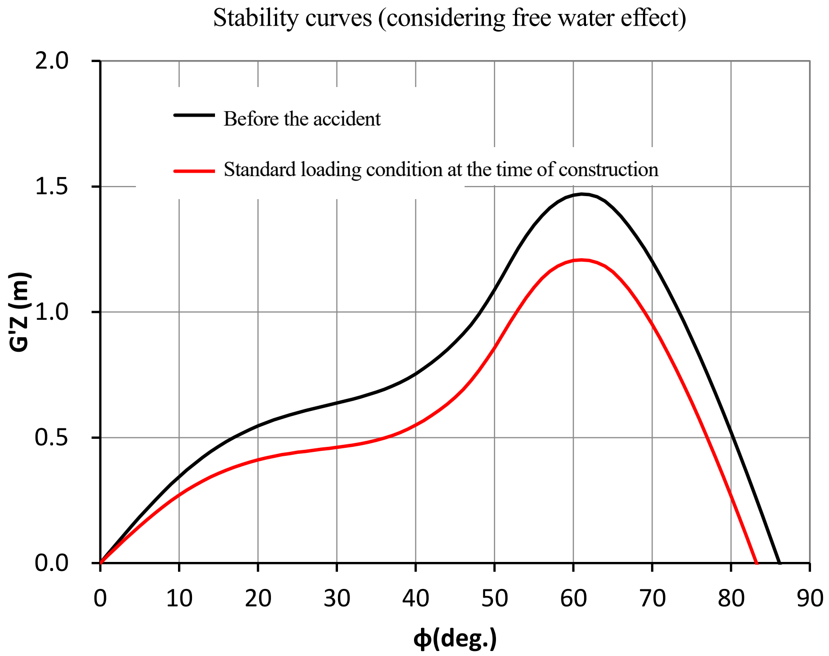

Fig. 1.1.1 Stability curves (before accident and standard loading condition at the time of construction)

Figure 1.1.1 shows the results of the stability calculation (righting lever G'Z) considering the free water effect in the various tanks of the ship before the accident using the weight and center of gravity shown in Table 1.1.1. The calculation results of the metacentric height (G'M), draft (df: bow draft, da: aft draft, dm: average draft), seawater inflow angle (φ_{W_2}), and No. 2 deck (upper deck) port end submergence angle (φ_{D_2}) at the center of the hull, taking into account the effects of free water, are summarized in Table 1.1.2. The seawater inflow location is at a ventilation system installed on the mooring deck at No. 2 deck level.

Table 1.1.2 Calculation results of metacentric height, draft, seawater inflow angle and upper deck port end submergence angle (before the accident and standard loading condition at the time of construction)

	G'M (m)	df (m)	da (m)	dm (m)	ϕ_{W2} (deg.)	ϕ_{D2} (deg.)
Before the accident	2.15	5.47	7.65	6.56	71.14	51.47
Standard loading condition at the time of construction	1.76	5.88	7.24	6.56	69.51	51.59

Figure 1.1.1 and Table 1.1.2 also show, for reference, the calculation results for the standard loading condition at the time of construction described in the stability documents. These diagrams show that before the accident, the ship's initial stability (G'M) and stability at large heeling (G'Z) were in good condition compared to the standard loading condition when the stability performance was verified at the time of construction.

1.2 Confirmation of compliance with stability criteria

The displacement (W = 13,082 tf) calculated from the draft at the reported draft mark position (dF = 5.50 m, dA = 7.50 m) shown in Table 1.1.1, the fore-aft position of the center of gravity (mid-G = 8.17 m), and the vertical position of the center of gravity (KG = 11.66 m) determined from the weight and center of gravity calculations were used as the pre-accident conditions to confirm compliance with the stability criteria (Table 1.2.1, Figure 1.2.1). The table also shows the values for the standard loading condition at the time of construction (Figure 1.2.2), which has approximately the same displacement.

Table 1.2.1 Compliance with stability criteria

	A_{30} (m-rad)	A_{40} (m-rad)	A_{30-40} (m-rad)	$G'Z_{max}$ (m)	ϕ_{max} (deg.)	G'M (m)	G'Z(30) (m)	ϕ_0 (deg.)	A(b)/A(a) (=c)
Before the accident	0.215	0.335	0.120	1.47	61	2.15	0.64	4.95	3.08
Standard loading condition at the time of construction	0.163	0.249	0.086	1.21	61	1.76	0.46	6.38	2.15
Criteria	≧0.055	≧0.09	≧0.03	≧0.20	≧25(30)	≧0.15	≧0.20	≦16	≧1

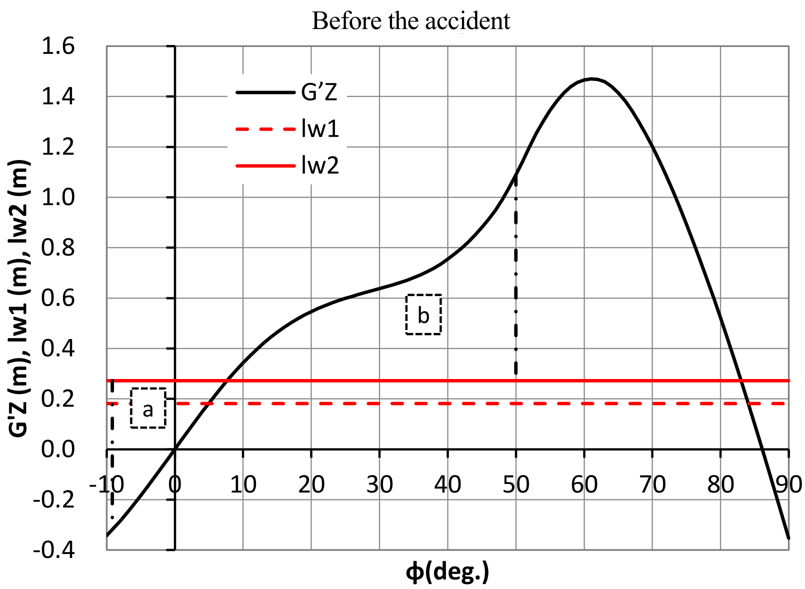

Figure 1.2.1 Verification calculations of compliance with the stability criteria (C-factor criteria) Note 1) (before the accident)

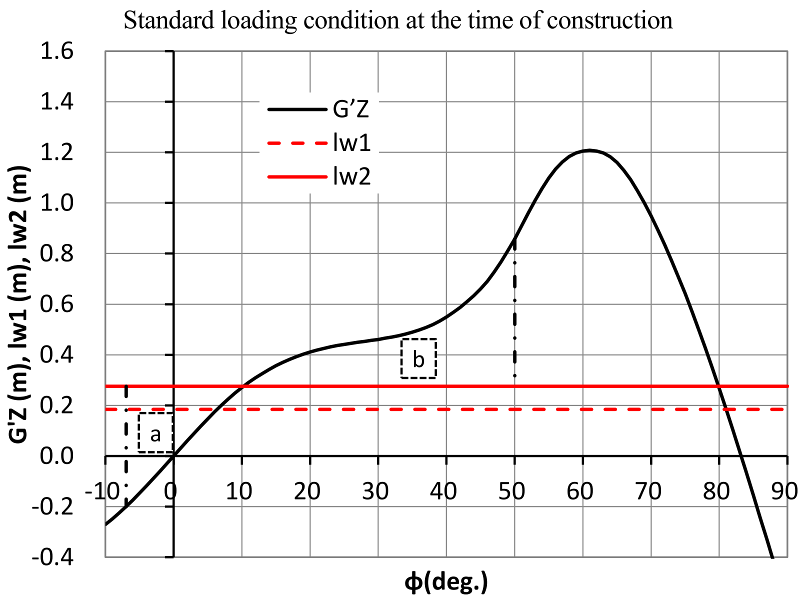

Figure 1.2.2: Verification calculation of compliance with the stability criteria (C-factor criteria Note 1) (standard loading condition at the time of construction)

In Table 1.2.1, A30, A40, A30-40 are the areas enclosed by the horizontal axis and the stability curve for heel angles up to 30°, up to 40°, and 30°–40°, respectively; $G'Z_{max}$ and φ_{max} are the maximum values of the righting lever (G'Z) and the heel angle at which the maximum value occurs; G'Z(30) is the righting lever at a heel angle of 30°; φ0 is the heel angle due to a steady crosswind with a wind speed of 26 m/s; and A(b)/A(a) (Note 2) is the so-called C-factor.

From Table 1.2.1, Figure 1.2.1 and Figure 1.2.2, it can be seen that the ship, in the condition before the accident, 1) met the stability criteria and 2) had a better stability performance than when it left port in the standard loaded condition at the time of construction.

Note 1) In Figures 1.2.1 and 1.2.2, lw1 is the heeling couple lever due to a steady crosswind of 26 m/s, and lw2 is the heeling couple lever 1.5 times greater than lw1 assuming gusty wind. In addition, "a" indicates the range of energy acting on the tilt side in the assumed situation based on the C-factor criterion, and "b" indicates the range of energy acting on the restoration side.

Note 2) In Table 1.2.1, A(b)/A(a) corresponds to the area ABC/area BDE specified in Article 11.2.5 of the Ship Stability Regulations.

2. Estimation of the circumstances leading to capsizing and sinking

The collision caused a breach in the outer shell plating of the ship's port side near the center of the hull, causing water to leak into the ship through the breach, causing it to heel to port, capsize and sink. The circumstances after the collision as described by investigators were as follows.

① Around 23:54: Collision occurred

② Around 23:55: The ship is tilted (confirmed by rescue ship)

③ Around 0:01: The captain decided to abandon ship (contacted Kurushima MARTIS), the ship was half submerged and tilted to the left (confirmed by a rescue ship)

④ Around 0:10: The ship turned sideways (contact with other ships), and there was no response to the call from Kurushima MARTIS

⑤ Around 2:45: Sinking

The investigators explained that crew members had said that they heard the sound of lashings breaking between (1) and (3), that at the time of (3) the ship's hull was tilted by more than 45°, that up to the No. 2 deck (upper deck) was submerged in seawater, and that between (3) and (4) the handrails on the No. 4 deck (living area) were submerged in seawater.

Here, we consider a situation in which the collision causes a break in the outer shell plating, resulting in water flooding the interior compartments, reducing the ship's stability and reducing its reserve buoyancy, causing the ship to heel, the lashings to break, and the vehicles on board to move widthwise (laterally), leading to the ship capsizing and sinking.This situation is examined by determining the quasi-static balance state of the restoring force and assumed heeling moment, taking into account the effects of water flooding inside the ship.

2.1 Assumed flooding conditions

According to the results of an ROV inspection of the sunken hull, the damage area in the vertical (depth/height) and longitudinal (length) directions was a trapezoidal shape measuring approximately 11m in height between the B3 deck level (2.55m above the baseline on the ship's side; hereafter simply referred to as "height" for simplicity) and No. 1 deck level (height 13.61m) near the center of the hull on the port side, approximately 1m at the lower side (B3 deck level) and approximately 16m at the upper side (No. 1 deck level). Although the results of the investigation of the breach did not indicate the extent of the damage in the horizontal (ship's width) direction, it is assumed that parts of the B2 deck, B1 deck, and No. 1 deck around the breach in the outer shell plating were also damaged. On the other hand, as shown in Table 1.1.2, the draft (mean draft) at the center of the hull before the accident is estimated to be 6.56 m, and B2 deck is considered to have been below the water surface when the collision caused a breach in the ship's outer shell plating.

Therefore, based on the general arrangement plan and central cross-sectional views of the ship, the flooding path was assumed to be as follows in the present analysis.

1) Immediately after the collision caused the breach, B3 deck level No. 4 W.B.T. (P) and B2 deck vehicle compartment were flooded.
2) Some of the water that flooded into the B2 deck vehicle compartment flowed down through the rampway opening in that space into the B3 deck vehicle compartment.
3) Due to an increase in draft caused by the increased weight due to flooding inside the ship and a lateral heel caused by asymmetric flooding into No. 4 W.B.T. (P), after the B1 deck end was submerged, water flooded into the B1 deck vehicle compartment in addition to the B2 deck vehicle compartment through the breach in the ship's outer shell plating.

It is also assumed that seawater entering B1 deck vehicle compartment might flood into No. 1 deck vehicle compartment through the assumed damage area on No. 1 deck around the breach in the ship's outer shell plating. In each vehicle compartment, there were several ventilation openings leading to the ventilation system installed on No. 4 deck. Therefore, it was assumed that as the flooding progressed, the air in the vehicle compartments escaped to the outside, and did not prevent the flooding.

2.2 Examination of circumstances leading to capsizing

2.2.1 Circumstances examined

Appendix 1 shows the approximate amount of water flooding into the ship under accident conditions, based on the results of the breach investigation provided by the investigators. Assuming parallel sinking, it was confirmed that from the breach caused by the collision described in Section 2.1, by the time the captain decided to abandon ship (approximately 7 min after the collision), flooding on board had occurred on a scale exceeding the displacement before the accident (13,082 tf), the draft at the center of the hull had increased to 11.80 m (1.81 m below No. 1 deck), and an equilibrium state had been reached in which the water level in the flooded compartments and the water level outside the ship were equal.

Therefore, up until the time when the captain decided to abandon the ship, the flooded area was considered to be No. 4 W.B.T. (P) and the vehicle compartments from B3 deck to B1 deck, and regarding to the situation afterward when the hull turned sideways and capsized, it was decided to consider that the No. 1 deck vehicle compartment was also flooded.

2.2.2 Review of the situation up to the point when the captain decided to abandon the ship

According to the rescue ship and crew members, by the time the captain decided to abandon the ship about 7 min after the collision, the ship heeling that began immediately after the collision had increased and the lashings had broken, causing the ship heel to reach 45° or more, and seawater had reached the No. 2 deck (upper deck). Here, the flooded area was assumed to be No. 4 W.B.T. (P) and the vehicle compartment on decks B3 to B1, and the situation described by the rescue boat and crew members was examined by determining the quasi-static balance state of the restoring force and assumed heeling moment, taking into account the effects of water flooding inside the ship before and after the lashings broke. At that time, since it was considered possible that the ship had reached an equilibrium state by the time the captain decided to abandon ship (Appendix 1), it was decided to consider the final state (equilibrium state) of flooding within the above range. Some consideration was also given to the intermediate stage of flooding[1)], which may be more hazardous than the final state (Appendix 2).

<u>(1) Situation before the lashing broke</u>

The stability was estimated by the lost buoyancy method[2)], while taking into account the effect of water flooding inside the ship, which was used to examine the situation before the lashing broke. At that time, the No. 4 W.B.T. (P), which was partially loaded with ballast water, was estimated to be full to capacity, and the flooding rate in the vehicle compartment was estimated to be 90%. However, due to limitations of the stability calculation program used, the flooding of No. 4 W.B.T. (P) and the B3 deck vehicle compartment was treated using the added weight method[2)] (included in weight and center of gravity calculations).

The heeling moment before the lashing broke was assumed to be the increase in weight moment across the ship's width (transverse direction) due to the No. 4 W.B.T. (P), which was partially loaded with ballast water before the accident, becoming full of water.

(a) Weight and center of gravity

The displacement (W) and center of gravity (fore-aft position: mid-G, vertical position: KG) used to estimate the stability are shown in Table 2.2.1. The displacement and center of gravity at the final state (equilibrium state) of flooding within the assumed range take into account the changes in weight and weight moment due to the full flooding of the No. 4 W.B.T. (P), which was partially loaded with ballast water (loading weight 179 tf), and the flooding rate of 90% in the B3 deck vehicle compartment. In that case, the full load volume of No. 4 W.B.T. (P) is assumed to be 272 m^3 as indicated in the stability documents, and the volume of B3 deck vehicle compartment is assumed to be 2,119 m^3, which is the area of the vehicle compartment indicated in the stability documents multiplied by the vertical distance between B3 and B2 decks (deck-to-deck height).

Table 2.2.1 shows, for reference, the values before the accident (at the time of departure from Port of Kobe), and the values assuming that only No. 4 W.B.T. is flooded due to the collision. The weight of flooding to No. 4 W.B.T. (P), which was partially loaded with ballast water is 100tf, and the weight of flooding to B3 deck vehicle compartment, assuming the flooding rate of 90% is 1,960tf. Note that the flooding of the vehicle compartments on B2 and B1 decks is handled in the lost buoyancy method and is not reflected in the weight and center of gravity calculations. GG' shown in Table 2.2.1 is the apparent gravity center rise (free water effect) due to liquids with free surface in various tanks, free water effects of No. 4 W.B.T. (P) are considered only for pre-accident conditions.

Table 2.2.1 Weight and center of gravity (the situation up to the time when the captain decided to abandon the ship)

	W (tf)	mid-G (m)	KG (m)	GG' (m)
Flooded equilibrium condition	15,142	6.78	10.61	0.52
Before the accident	13,082	8.17	11.66	0.63
No. 4 W.B.T. (P) only is full (assumption)	13,182	8.08	11.62	0.60

(b) Restoring force

Figure 2.2.1 shows the stability curves calculated by the lost buoyancy method for the flooded vehicle compartments on decks B2 and B1 using the weights and centers of gravity shown in Table 2.2.1. The restoring force (righting lever G'Z) shown in Figure 2.2.1 also takes into account the free water effects of the various tanks. Table 2.2.2 summarizes the calculation results for metacentric height (G'M), draft (df: fore draft, da: aft draft, dm: mean draft), sea water inflow angle (φ_{W_2}), submergence angle at the port end of No. 2 deck (upper deck) (φ_{D_2}), and submergence angle at the port end of No. 1 deck (φ_{D_1}), taking free water effects into consideration. φ_{D_2} and φ_{D_1} are both calculated at the center position of the hull. Figure 2.2.1 and Table 2.2.2 also show the calculation results before the accident and under the assumption that only No. 4 W.B.T.(P) was flooded and full of water, for reference.

In the equilibrium state with the flooded areas being No. 4 W.B.T. (P) and the vehicle compartments on decks B3 to B1, the upright state becomes unstable when the metacentric height is negative (G'M = -1.64 m: Table 2.2.2), and the ship becomes stable at an heel of approximately 33° (an intersection of the stability curve shown in Figure 2.2.1 with the horizontal axis other than the origin). The submergence angle φ_{D_1} at the port end of No. 1 deck shown in Table 2.2.2 is approximately 10°, which means that the port end of No. 1 deck is submerged in water in the tilted stable condition, and it is possible that water may enter the vehicle compartment of No. 1 deck from the assumed damage to a part of the deck.

Note that the displacement of the ship in an undamaged condition with no breaks in the outer shell plating at the flooded equilibrium draft (df = 14.60 m, da = 8.68 m) calculated using the lost buoyancy method shown in Table 2.2.2 is 29,640 tf. Considering that the displacement of the flooding of No. 4 W.B.T. (P) and B3 deck vehicle compartment shown in Table 2.2.1, calculated using the added weight method, is 15,142 tf, and assuming a flooding rate of 90% in the vehicle decks used in the lost buoyancy method, the flooded weight in the vehicle compartments of the B2 and B1 decks at flooding equilibrium was estimated to be approximately 13,000 tf.

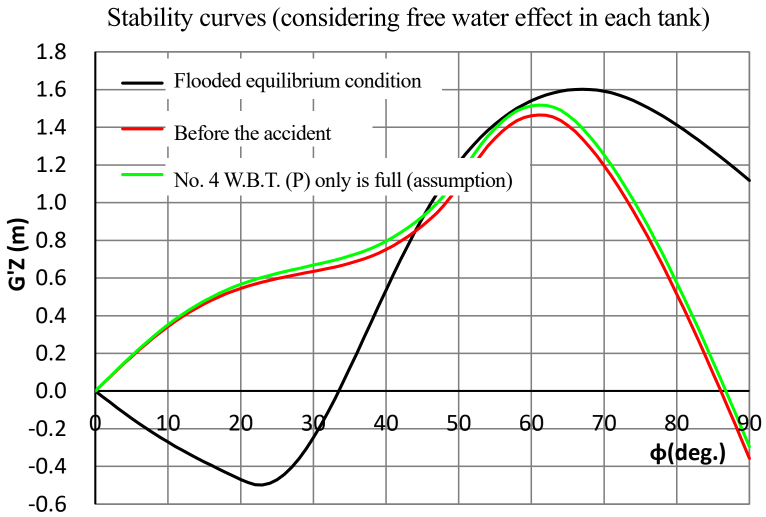

Figure 2.2.1 Stability curves (situation up to the time when the captain decided to abandon the ship)

Table 2.2.2 Calculation results of metacentric height, draft, seawater inflow angle and shipboard submergence angle (situation up to the time when the captain decided to abandon the ship)

	G'M (m)	df (m)	da (m)	dm (m)	ϕ_{W2} (deg.)	ϕ_{D2} (deg.)	ϕ_{D1} (deg.)
Flooded equilibrium condition	−1.64	14.60	8.68	11.64	48.35	36.98	10.14
Before the accident	2.14	5.47	7.65	6.56	71.14	51.47	32.58
No. 4 W.B.T. (P) only is full (assumption)	2.20	5.53	7.66	6.59	70.86	51.32	32.40

(c) Heeling moment

The heeling moment before the lashing broke was assumed to be the increase in lateral weight moment due to No. 4 W.B.T. (P) becoming full of water due to flooding. The increase in weight (δw) due to No. 4 W.B.T.(P) becoming full of water was 100tf, and the corresponding change in the position of the center of gravity in the lateral direction was read from the diagram in the stability documents, resulting in an increase in the lateral weight moment (δw・ℓ) of 956 tf-m. Note that the heeling moment was assumed to act as the increase in lateral weight moment multiplied by cosφ (δw-ℓcosφ) when the heeling angle was set to φ.

(d) Hull condition

The heeling of the hull in the flooded equilibrium state was calculated using equation (2.2.1) as the heeling angle φ_E in the quasi-static equilibrium state of the assumed heeling moment and the restoring force taking into account the effect of flooding inside the ship.

$$W \cdot G'Z(\phi_E) = \delta w \cdot l cos\phi_E \qquad (2.2.1)$$

Table 2.2.3 shows the hull heeling for the flooded equilibrium condition. For reference, the table also shows the calculation results assuming that only No. 4 W.B.T.(P) is flooded and full of water. For comparison, the shipboard submergence angle (φ_{D_2}) of the No. 2 deck (upper deck) at the center of the hull is also shown. As shown in Table 2.2.3, in the equilibrium state with the flooded area being the No. 4 W.B.T. (P) and the vehicle compartments on decks B3 to B1, it is estimated that the ship will heel to the side at approximately 34° due to asymmetric flooding of No. 4 W.B.T. (P), and a large heel of the No. 2 deck end would occur, with a submergence angle approaching 37°.

Table 2.2.3 Hull heeling (before the lashing broke)

	ϕ_E (deg.)	ϕ_{D2} (deg.)
Flooded equilibrium condition	34.15	36.98
No. 4 W.B.T. (P) only is full (assumption)	1.91	51.32

(2) Situation after the lashings broke

After the lashing broke and the vehicles onboard moved laterally, the restoring force considering the effect of flooding in the ship is assumed to be the same as before the lashing broke. The assumed heeling moment was calculated by taking into account the increase in lateral weight moment caused by the No. 4 W.B.T. (P), which had been partially loaded with ballast water before the accident, becoming full of water due to flooding, as well as the lateral weight moment caused by the lateral movement of the loaded vehicles.

(a) Heeling moment

The operator's information provided by the investigators regarding the loading status of vehicles on the ship at the time of the accident was the number, weight and approximate location of each type of vehicle on each deck (B2 deck to No. 3 deck). The actual location of each vehicle was unknown. The operator indicated that the ship's personnel would adjust the ballast after a meeting based on the loading plan before loading the vehicles, and that information on the planned loading position of the chassis and loading specifications were provided by the operator.

In addition to the above, this analysis assumed the vehicle loading intervals and gaps between the side walls at the time of the accident based on the chassis and passenger car loading intervals listed in the vehicle loading number table (planned values) in the stability documents presented by the investigator, as well as photographs of the interior of the ship. The lateral weight moment was estimated assuming that the gaps between the sidewall and the vehicles and the vehicle stacking intervals would disappear after the lashing broke and the loaded vehicles moved laterally in the ship's width direction.

As a result, the total weight of the loaded vehicles at the time of the accident (w_{car}) calculated from the information provided by the operator was 1,788.8 tf, and the lateral weight moment ($w_{car} \cdot \ell_s$) that would have occurred if all the loaded vehicles had moved laterally after the lashing broke until the assumed gap between the side wall and the vehicles and the intervals between the loaded vehicles disappeared was 4,525 tf-m.

The heeling moment due to the lateral movement of the loaded vehicles was assumed to be the lateral weight moment multiplied by cosφ ($w_{car} \cdot \ell_s \delta \cos\varphi$) when the heeling angle was φ.

(b) Hull heeling

The heel of the hull after the lashing broke in a flooded equilibrium condition was calculated using equation (2.2.2) as the heeling angle $\varphi_{E\_car\ shift}$ in the quasi-static balance of stability considering the effect of flooding of the ship, the heeling moment assumed due to the No. 4 W.B.T. (P) being full of water and the lateral movement of the onboard vehicles.

$$W \cdot G'Z\left(\phi_{E\_car\,shift}\right) = (\delta w \cdot l + w_{car} \cdot l_s) cos\phi_{E\_car\,shift} \qquad (2.2.2)$$

Table 2.2.4 shows the hull heeling after the lashing broke in the flooded equilibrium state. For comparison, the table also shows the submergence angle (φ_{D_2}) of the No. 2 deck (upper deck) end at the center of the hull, as well as the submergence angle (φ_{HR_4}) of the handrail at the center of the living area of the No. 4 deck accomodation area). As shown in Table 2.2.4, in a flooded equilibrium state with the flooded area being No. 4 W.B.T. (P) and the vehicle compartment of the decks B3 to B1, it is estimated that if the onboard vehicles move laterally, the heeling angle will be approximately 37°. This is a large heeling state corresponding to the submergence water angle φ_{D_2} at the port end of No. 2 deck, and the port side of the vehicle compartment on No. 1 deck is considered to be below the water surface. However, the situation described by the crew, in which the hull heeling angle was more than 45° by the time the captain decided to abandon ship, cannot be explained by the calculation results, which assumed a flooding equilibrium state with the flooded area limited to No. 4 W.B.T. (P) and the vehicle compartments of decks B3 to B1. It is therefore assumed that at the time of the accident the ship was in the intermediate stage of flooding as described in Appendix 2 or that there was flooding in the No. 1 deck vehicle compartment as well, as explained in Section 2.2.3.

Table 2.2.4 Hull heeling (after the lashings broke)

	$\phi_{E\_Car\ shift}$ (deg.)	ϕ_{D_2} (deg.)	ϕ_{HR_4} (deg.)
Flooded equilibrium condition	37.04	36.98	52.98

2.2.3 Examination of the circumstances under which the ship capsized

Section 2.2.2 describes the situation up to the time when the captain decided to abandon the ship, with the final state (equilibrium state) of flooding assumed to cover the No. 4 W.B.T. (P) and the vehicle compartments of decks B3 to B1. As a result, assuming that the No. 4 W.B.T. (P) became full of water due to flooding and the onboard vehicles moved laterally, it was estimated that in a quasi-static equilibrium state, a large heeling of approximately 37° would occur, corresponding to the shipboard submergence angle of the No. 2 deck end as described by the crew. On the other hand, the explanation of the crew that the hull inclination was more than 45° cannot be explained by the final state (equilibrium state) of flooding described above.

In this section, we will consider the circumstances under which the ship turned sideways and capsized after the captain decided to abandon ship, assuming that the collision also damaged No. 1 deck near the breach in the outer shell plating near the center of the port side of the ship, and that the vehicle compartment of No. 1 deck was also flooded in addition to No. 4 W.B.T. (P) and the vehicle compartments of decks B3 to B1.

<u>(1) Final state of flooding in No. 1 deck vehicle compartment (equilibrium state)</u>

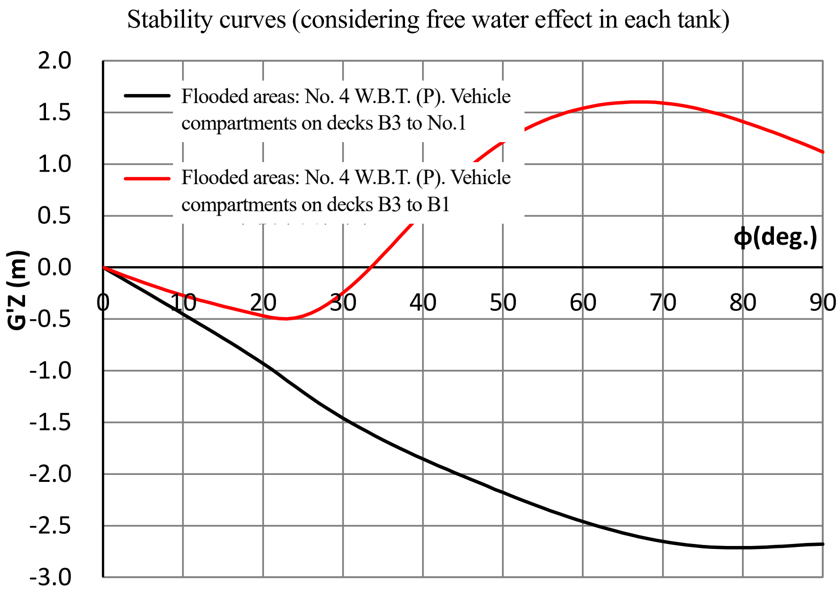

Figure 2.2.2 Stability curves (situation when the ship turned sideways: final state (equilibrium state))

First, the flooding of the vehicle compartment of No. 1 deck in addition to B2 deck and B1 deck was treated using the lost buoyancy method with a flooding rate of 90%, and the final state (equilibrium state) was examined. In this case, the displacement and center of gravity used to calculate the stability taking into account the effects of flooding of the ship were the values for the "flooded equilibrium state" in Table 2.2.1, which took into account the changes in weight and weight moment due to the No. 4 W.B.T. (P), which was partially loaded with ballast water (loading weight 179 tf), becoming full of water and the flooding of the B3 deck vehicle compartment with a flooding rate of 90%.

Figure 2.2.2 shows the restoring force for the flooding of the vehicle compartments on decks B2 to No. 1 obtained by the lost buoyancy method. The restoring force (righting lever G'Z) shown in Figure 2.2.2 also takes into account the effects of free water in various tanks. Table 2.2.5 summarizes the calculation results of the metacentric height (G'M), draft (df: fore draft, da: aft draft, dm: mean draft), seawater inflow angle (φ_{W_2}), submergence angle at the center of the hull (φ_{D_2}) on the port end of No. 2 deck (upper deck), and submergence angle of the handrail at the center of the living area (φ_{HR_4}) on No. 4 deck (living area), taking the effects of free water into account. Figure 2.2.2 and Table 2.2.5 also show, for reference, the calculation results for the condition described in Section 2.2.2 with the flooding area limited to No. 4 W.B.T.(P) and the vehicle compartments on decks B3 to B1 (flooding equilibrium condition in Section 2.2.2).

Table 2.2.5 Calculation results for metacentric height, draft, seawater inflow angle and port end, and handrail submergence angle (Situation when the ship is overturned: final state (equilibrium state))

Assumed flooded areas	G'M (m)	df (m)	da (m)	dm (m)	ϕ_{W_2} (deg.)	ϕ_{D_2} (deg.)	ϕ_{HR_4} (deg.)
No. 4 W.B.T. (P). vehicle compartments on decks B3 to No.1	−2.56	15.09	8.59	11.84	29.21	29.30	42.60
No. 4 W.B.T. (P). vehicle compartments on decks B3 to B1	−1.64	14.60	8.68	11.64	48.35	36.98	52.98

In the equilibrium state in which the vehicle compartment of No. 1 deck is flooded in addition to the No. 4 W.B.T. (P) and the vehicle compartments of decks B3 to B1, the metacentric height is negative (G'M = -2.5 6m: Table 2.2.5), making the upright state unstable, and there is no stable state (any point of intersection between the stability curve shown in Figure 2.2.2 and the horizontal axis other than the origin) within the tilt range of up to 90°. Therefore, it is assumed that the flooding in No. 1 deck vehicle compartment had not reached an equilibrium state when the ship turned sideways after the time when the captain decided to abandon the ship.

The flooding of the No. 1 deck vehicle compartment shown in Table 2.2.5 is calculated using the lost buoyancy method with a flooded equilibrium draft (df = 15.09 m, da = 8.59 m), and the displacement in an undamaged state with no breaches in the outer shell plating is 30,389 tf. Considering that the displacement of No. 4 W.B.T. (P) and the flooding of the B3 deck vehicle compartment shown in Table 2.2.1 calculated using the added weight method is 15,142 tf, and that the flooding rate into the vehicle deck was set at 90% in the lost buoyancy method, the flood weight in the vehicle compartments of decks from B2 to No. 1 in the flooding equilibrium state is estimated to be approximately 13,700 tf.

(2) Intermediate stage of No. 1 deck vehicle compartment flooding

For the intermediate stage before the flooding of No. 1 deck vehicle compartment reaches equilibrium, the flooding of the vehicle compartments of decks B2 and B1 was calculated using the lost buoyancy method [2)] as in Section 2.2.2, while the assumed flooding of No. 1 deck vehicle compartment was calculated and investigated using the added weight method [2)]. Due to the limitation of the stability calculation program used, the flooding of No. 4 W.B.T. (P) and B3 deck vehicle compartment were calculated by the added weight method (included in the weight and center of gravity calculations) as described in Section 2.2.2.

(a) Weight and center of gravity

Table 2.2.6 shows the results of weight and center of gravity calculations for the case where No. 1 deck vehicle compartment is treated as an onboard tank in the balance calculation program and the flooding volume to the compartment is assumed to be 500 m^3 to 3,000 m^3. GG' is the apparent center of gravity rise due to the liquid with free surface in various tanks (free water effect), and the free water effect of No. 4 W.B.T. (P) is not included.

The weights and center of gravity shown in Table 2.2.6 are the results of calculations performed by inputting the weights and center of gravity used to calculate the flooded equilibrium state for the flooded areas shown in Section 2.2.2, No. 4 W.B.T. (P) and the vehicle compartments of decks B3 to B1 (No. 4 W.B.T. (P) is full of water, and the B3 deck car space is flooded with a flooding rate of 90%) as the initial state of flooding in the No. 1 deck vehicle compartment (flooded volume: 0 m^3), and the assumed flooded volume in the No. 1 deck vehicle compartment (500 m^3 to 3,000 m^3) as the amount of liquid (seawater) loaded in the onboard tank. In the stability calculation program, the liquid in the onboard tank is adjusted so that the liquid level is horizontal according to the ship's attitude while keeping the volume constant. Therefore, when the amount of liquid on board (amount of flooding) is small, as in actual conditions, the calculation is performed with seawater present only in a portion of the No. 1 deck vehicle compartment, which is treated as an onboard tank. Therefore, the fore-aft position of the center of gravity (mid-G) shown in Table 2.2.6 changes significantly depending on the amount of flooding.

Table 2.2.6 Weight and center of gravity (Situation when the ship is overturned: intermediate stage of flooding into No. 1 deck vehicle compartment)

※ Flooding volume in table: Flooding volume to No. 1 deck vehicle compartment

Flooding volume (m^3)	W (tf)	mid-G (m)	KG (m)	GG' (m)
0	15,142	6.78	10.61	0.52
500	15,654	−4.71	10.72	0.51
1,000	16,167	−2.94	10.84	0.49
1,500	16,679	−1.37	10.97	0.48
2,000	17,192	−0.02	11.09	0.46
2,500	17,704	1.25	11.21	0.45
3,000	18,217	2.33	11.33	0.44

(b) Restoring force

Figure 2.2.3 shows the restoring force (righting lever G'Z that also takes into account the free water effect in various tanks) calculated based on the weight and center of gravity shown in Table 2.2.6 and taking into account flooding of the No. 1 deck vehicle compartment.

The restoring force taking into account the flooding of the No. 1 deck vehicle compartment shown in Figure 2.2.3 was calculated in the stability calculation program by adjusting the volume in the onboard tank (corresponding to the flooded water in the No. 1 deck vehicle compartment) so that the liquid level is horizontal according to the ship's attitude while keeping the volume constant, and then including the weight moment of flooding evaluated using the volume center in the calculation of the ship's stability (restoring moment).

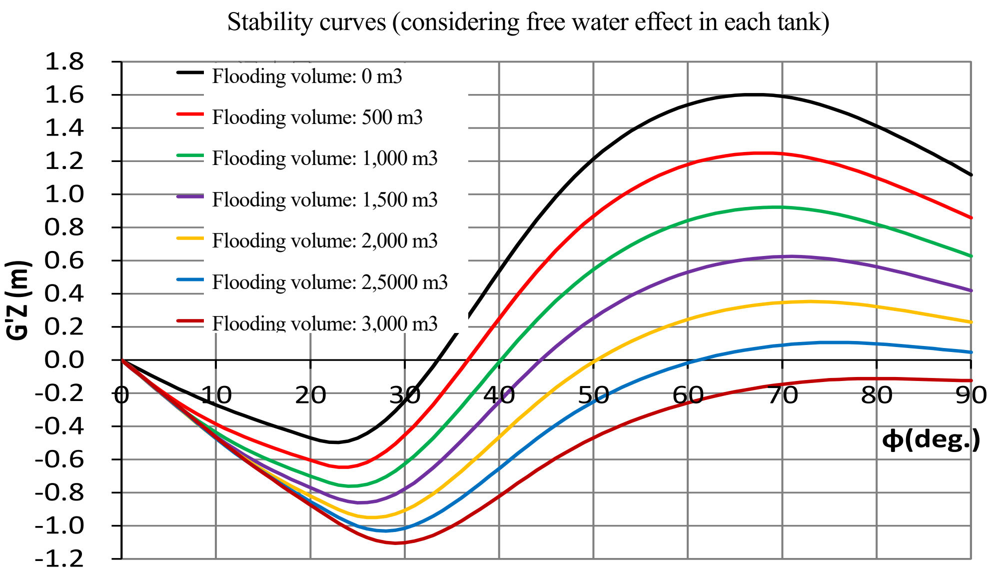

Figure 2.2.3 Stability curves (Situation when the ship is overturned: intermediate stage of flooding into No. 1 deck vehicle compartment)

※ No. 4 W.B.T (P) and B3 deck - B1 deck vehicle compartment lost buoyancy

※ Flooding volume in legend: flooding volume to No. 1 deck vehicle compartment

Table 2.2.7 summarizes the calculation results of the metacentric height (G'M), draft (df: fore draft, da: aft draft, dm: mean draft), seawater inflow angle (φ_{W_2}), submergence angle at the center of the hull (φ_{D_2}) on the port end of No. 2 deck (upper deck), and submergence angle of the handrail at the center of the living area (φ_{HR_4}) on No. 4 deck (living area), taking the effects of free water into account. Figure 2.2.3 and Table 2.2.7 also reproduce the calculation results for the initial state of flooding in the No. 1 deck vehicle compartment, assuming the flooded area described in Section 2.2.2 is No. 4 W.B.T. (P) and the vehicle compartments of decks B3 to B1 (flooding volume in the No. 1 deck vehicle compartment is 0 m^3).

Figure 2.2.3 shows that, as the amount of flooding into the No. 1 deck vehicle compartment increases, the heeling angle of the stable tilted state corresponding to the intersection of the stability curve and the horizontal axis other than the origin increases, and at a flooding volume of 2,500 m^3, the stable state is reached at a heeling of approximately 60°, while at a flooding volume of 3,000 m^3, there is no stable state within the heeling range up to 90°. Furthermore, Table 2.2.7 shows that as the volume of water flooding into the No. 1 deck vehicle compartment increases, the bow trim increases and the seawater inflow angle φ_{W_2}, which is calculated by setting the seawater inflow position into the ventilation system installed on the mooring deck at No. 2 deck level, decreases. The metacentric height G'M is negative (unstable in the upright state) regardless of the flooding volume, and is smallest at G'M = -3.45 m when the flooding volume is 1,500 m^3. This G'M corresponds to the metacentric height when flooding of the No. 1 deck vehicle compartment (seawater loaded in the onboard tank in the stability calculation program) is treated as the so-called free water effect (apparent rise in the center of gravity). On the other hand, the righting lever, which correctly treats the effect of flooding in the No. 1 deck vehicle compartment shown in Figure 2.2.3 as a change in weight moment due to heeling, becomes smaller as the volume of flooding increases.

Table 2.2.7 Calculation results for metacentric height, draft, seawater inflow angle and board end, and handrail submergence angle (Situation where the ship is overturned: intermediate stage of flooding into No. 1 deck vehicle compartment)

※ Flooding volume in table: Flooding volume to No. 1 deck vehicle compartment

Flooding volume (m^3)	G'M (m)	df (m)	da (m)	dm (m)	ϕ_{W_2} (deg.)	ϕ_{D_2} (deg.)	ϕ_{HR_4} (deg.)
0	−1.64	14.60	8.68	11.64	48.35	36.98	52.98
500	−2.13	15.37	8.55	11.96	46.00	35.90	51.96
1,000	−2.45	15.91	8.48	12.19	43.73	34.80	51.03
1,500	−3.45	16.37	8.43	12.40	41.42	33.69	50.13
2,000	−2.64	16.77	8.40	12.59	39.02	32.56	49.27
2,500	−2.89	17.16	8.37	12.76	36.33	31.41	48.43
3,000	−2.77	17.50	8.35	12.93	32.92	30.17	47.61

(c) Heeling moment

The heeling moment in the intermediate stage of the flooding of No. 1 deck vehicle compartment was assumed to be the increase in the lateral weight moment due to No. 4 W.B.T. (P), which was partially loaded with ballast water before the accident, becoming full of water, as well as the lateral weight moment caused by the lateral movement of the loaded cars, similar to the situation after the lashing was broken as described in Section 2.2.2 (2). The heeling moment was calculated by multiplying the assumed lateral weight moment by $\cos\varphi$ when the heel angle was φ.

(d) Hull condition

The heeling of the hull at the intermediate stage of flooding of No. 1 deck vehicle compartment was obtained using equation (2.2.3) (equation (2.2.2) repeated) as the inclination angle $\varphi_{E\_car\,shift}$ in the quasi-static equilibrium state between the restoring force and the assumed heeling moment, taking into account the effects of flooding of the ship.

$$W \cdot G'Z\left(\phi_{E\_car\,shift}\right) = (\delta w \cdot l + w_{car} \cdot l_s) cos\phi_{E\_car\,shift} \tag{2.2.3}$$

Table 2.2.8 shows the hull heeling after lashing breakage at the intermediate stage of flooding in the No. 1 deck vehicle compartment. In the table, the seawater inflow angle φ_{W_2}, the submergence angle φ_{D_2} at the port end of No. 2 deck (upper deck) at the center of the hull, and the handrail submergence angle φ_{HR_4} at the center of the living area on No. 4 deck (living area) are shown again for comparison.

From Table 2.2.8 the following facts can be inferred.

1) When the volume of flooding in the vehicle compartment on No. 1 deck is 1,000 m^3, the heeling angle in the balanced state is about 44°, which exceeds the seawater inflow angle of the ventilation system installed on the mooring deck at No. 2 deck level and is close to the 45° angle described by the crew as the situation when the captain decided to abandon ship.
2) When the volume of flooding is 1,500 m^3, the heeling angle reaches about 49°, and the situation is such that the handrail on No. 4 deck (living area) is almost submerged (the submergence angle of the handrail is about 50°).
3) When the volume of flooding reaches 2,500 m^3, the heeling angle becomes about 72°, and the hull is almost overturned.
4) When the volume of flooding exceeds 2,500 m^3 and before it reaches 3,000 m^3, the ship will not be in equilibrium at any heeling angle up to 90°, and will capsize.

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Table 2.2.8 Hull heeling (intermediate stage of flooding in No. 1 deck vehicle compartment)

※ Flooding volume in table: Flooding volume to No. 1 deck vehicle compartment

Flooding volume (m^3)	$\phi_{E\_Car\ shift}$ (deg.)	ϕ_{W_2} (deg.)	ϕ_{D_2} (deg.)	ϕ_{HR_4} (deg.)
0	37.04	48.35	36.98	52.98
500	40.24	46.00	35.90	51.96
1,000	44.03	43.73	34.80	51.03
1,500	49.03	41.42	33.69	50.13
2,000	56.52	39.02	32.56	49.27
2,500	71.54	36.33	31.41	48.43
3,000	−	32.92	30.17	47.61

2.3 Examination of circumstances leading to sinking

As a result of the consideration of the situation leading to the capsizing in Section 2.2, it was estimated that the collision caused a breach in the ship's outer shell plating, which caused water to flood the No. 4 W.B.T. (P) until it was full of water, and that the vehicle compartments on decks B3 to B1 lost buoyancy, causing water to flood the No. 1 deck vehicle compartment. When the volume of water flooding in the No. 1 deck vehicle compartment reached 2,500 m^3, the hull would heel at approximately 72°, causing the ship to almost tip over on its side, and that by the time the volume of flooding exceeded 2,500 m^3 and reached 3,000 m^3, the ship would capsize.

In this section, we consider the circumstances that led to the sinking in the following steps.

1) Calculation of the total buoyancy below the upper deck (No. 2 deck)

2) Confirmation of the flooding volume and possibility of flooding in vehicle compartments (No. 1 to No. 3 decks) when the ship's outer shell plating is undamaged

3) Comparison of displacement and total buoyancy when vehicle compartments are flooded

2.3.1 Calculation of the total buoyancy below the upper deck (No. 2 deck)

The total buoyancy below the upper deck (No. 2 deck), which was included in the buoyancy calculation range in the stability documents, was calculated for three states: 1) a state in which there were no damage in the outer shell plating before the accident (collision) (undamaged state), 2) a state in which the vehicle compartments of decks B3 to B1 had lost buoyancy due to the breach of the outer shell plating caused by the collision, and 3) a state in which, in addition to 2, the vehicle compartment on No. 1 deck had also lost buoyancy.

Table 2.3.1 Buoyancy below the upper deck

	Total buoyancy (tf)	Reserve Buoyancy (tf)
Before collision damage	60,336	47,254
Buoyancy loss in decks B2 to B1	41,957	26,815
Buoyancy loss in decks B2 to No.1	24,314	9,172

The calculation results for the total buoyancy below the upper deck are shown in Table 2.3.1, including the reserve buoyancy obtained by subtracting the corresponding displacement. Due to limitations of the calculation program, the loss of buoyancy in B3 deck vehicle compartment was treated as an increase in displacement using the added weight method. Therefore, the displacement used to determine the reserve buoyancy was 13,082 tf before the collision damage (before the accident) and 15,142 tf after the breach of the ship's outer shell plating due to the collision, including the flooding until No. 4 W.B.T. (P) was full of water (Table 2.2.1).

2.3.2 Confirmation of flood volume and possibility of flooding in vehicle compartments (No. 1 to No. 3 decks) with outer shell plating undamaged

As explained in Section 2.1, an ROV survey of the sunken hull revealed a breach in the outer shell plating, approximately between the B3 deck level and the No. 1 deck level, near the center of the hull on the port side. In this section, the possible flooding volume of the vehicle compartments on decks No. 1 to No. 3, where no damage to the ship's outer shell plating was observed, is estimated, and the possibility of flooding of these vehicle compartments is also confirmed.

Table 2.3.2 shows the approximate results of estimating the volume that can be flooded and the weight (upper limit) that would be flooded if the ship were full of water based on the area and the height between decks for the vehicle compartment of each deck, assuming a flooding rate of 90%. The table also includes, for reference, approximate results for the vehicle compartments on decks B3 to B1, which were considered to have lost buoyancy at the time of the accident.

Table 2.3.2 Floodable volume and flooded weight (upper limit) of vehicle compartments

	Area (m^2)	Height between decks (m)	Flooding volume (m^3)	Flooding weight (tf)
Deck B3	827	2.569	1,912	1,960
Deck B2	1,564	2.975	4,187	4,292
Deck B1	2,165	5.510	10,734	11,002
Deck No.1	3,345	5.040	15,175	15,554
Deck No.2	3,416	3.040	9,347	9,580
Deck No.3	3,263	2.910	8,547	8,761

Next, the flooding paths to the vehicle compartments on each deck were examined. The general arrangement plan confirmed that numerous ventilation devices were installed on both sides of the No. 4 deck, with multiple ventilators leading to each vehicle compartment. Therefore, it was assumed that when the hull tilted heavily and the top surface of the ventilators was submerged, the vehicle compartments, where no damage to the outer shell plating was observed, would be flooded through the ventilators.

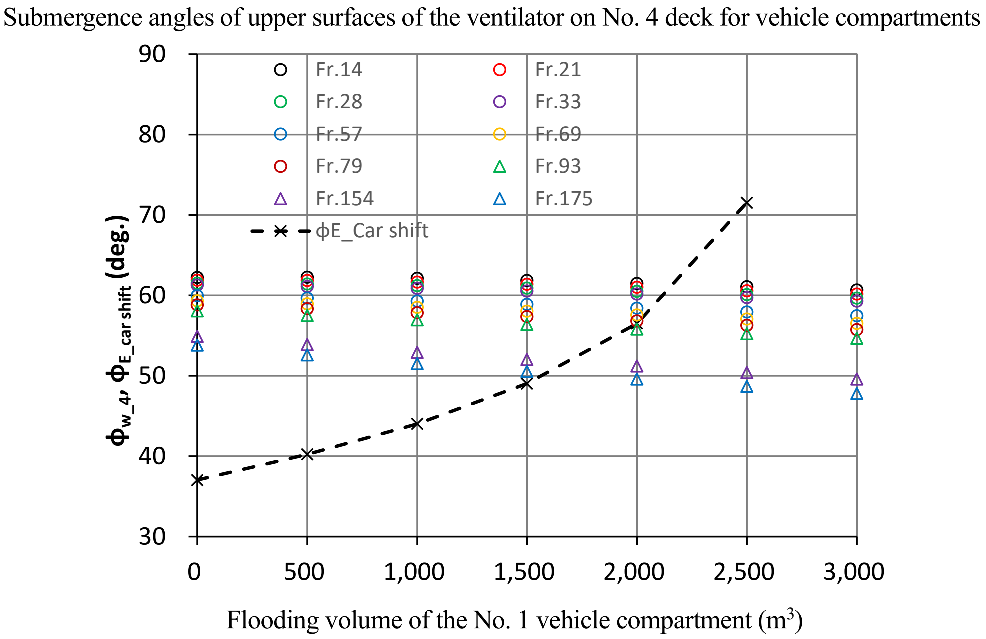

Figure 2.3.1 Submerged water angle of the upper surface of the ventilators on No. 4 deck

In Section 2.2.3(2), it was assumed that the No. 1 deck around the breach in the outer shell plating near the center of the port side of the ship was also damaged by the collision. Figure 2.3.1 shows the results of the calculation of the submergence angle (φ_{w_4}) of the top surface of the ventilators on the No. 4 deck for the condition studied for the intermediate stage of flooding, where the amount of flooding from the damage to the No. 1 deck vehicle compartment was taken as a parameter. Since the ventilators are distributed over a wide area near both port and starboard sides on No. 4 deck, Figure 2.3.1 shows the submerged angles of the topsides of 10 representative ventilators from frame numbers Fr.14 to Fr.175 (Fr.14 on the aft side and Fr.175 on the fore side). For comparison, the figure also shows the hull heeling angle ($\varphi_{E\_car\ shift}$) at which the restoring force and heeling moment are quasi-statically balanced for each flooding condition.

The following facts can be inferred from Figure 2.3.1.

1) When the flooding volume in No. 1 deck vehicle compartment exceeds 1,500 m^3, the top of the ventilation system on the fore side (F. 175) will be submerged, and flooding will begin in each deck vehicle compartment.
2) When the flooding volume reaches 2,000 m^3, the top of the ventilators from Fr.79 to Fr.175 will be submerged.
3) When the flooding volume reaches 2,500 m^3, the topsides of all ventilators on the port side on deck No. 4 will be submerged, and the vehicle compartments on decks No. 1 to No. 3, where no damage was observed on the outer shell plating, will be also completely flooded

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2.3.3 Comparison of displacement and total buoyancy when vehicle compartments are flooded

The ship will sink if the displacement of the vehicle compartment when flooded exceeds the buoyancy below the upper deck as specified in Section 2.3.1. In this section, the circumstances leading to sinking are examined by comparing the flooding weight of the vehicle compartment with the reserve buoyancy.

Table 2.3.3 shows a comparison between the reserve buoyancy when buoyancy is lost due to a breach in the outer shell plating caused by a collision and the maximum weight of water that can be flooded into the vehicle compartment. For reference, the table also shows the condition in which the ship's outer shell plating was undamaged before the accident (collision).

Table 2.3.3 Comparison of reserve buoyancy and allowable weight (upper limit) of water entering the vehicle compartments

	Reserve buoyancy (tf)		Max flooding weight in vehicle compartments (tf)	Vehicle compartments assumed flooded (ship's outer shell plating undamaged)
Before collision damage	47,254	<	49,897	Decks B3 to No.3
Buoyancy loss in decks B2 to B1	26,815	<	33,068	Decks No.1 to No.3
Buoyancy loss in decks B2 to No.1	9,172	<	17,894	Decks No.2 to No.3

From Table 2.3.3, it is assumed that the ship will sink before the relevant vehicle compartments become full (i.e., the flooding weight reaches the upper limit), since the reserve buoyancy in any state is less than the upper flooding weight of the vehicle compartments where loss of buoyancy is not assumed. For example, if the vehicle compartments below B1 deck, where the breach of the ship's outer shell plating was confirmed, lose buoyancy, the reserve buoyancy is 26,815 tf, and If flooding of approximately 80% of the maximum flooding weight (33,068 tf) occurred in any of the vehicle compartments on decks No. 1 to No. 3, the weight of water entering the ship would exceed the reserve buoyancy and the ship would sink.

As explained in Section 2.1, it is assumed that part of No. 1 deck around the breach in the outer shell plating near the center of the port side was also damaged by the collision. Therefore, after the port end of No. 1 deck was submerged due to flooding of the vehicle compartments below B1 deck, No. 1 deck vehicle compartment could also be flooded. As shown in Section 2.3.2, when the volume of flooding in the vehicle compartment on No. 1 deck reached 2,500 m^3 (flooded weight: 2,562 tf), the top of the ventilators on deck No. 4 was submerged and flooding of the vehicle compartments on decks No. 1 to No. 3 where no damage was confirmed in the outer shell plating began through the ventilation tubes. Therefore, it is considered realistic to assume that the accident caused the ship to sink due to flooding of water in the ship in excess of its reserve buoyancy (26,815 tf).

References

1) Tomoharu Morita: Ships Restoration Theory - Fundamentals and Applications-, pp.197-199, Kaibundo, April 1985. (In Japanese)
2) Masanobu Ogushi: Theoretical Ship Engineering (vol.1) Newly revised edition, pp.21-25, Kaibundo, October 1984. (In Japanese)

3. Summary

To contribute to the investigation into the sinking of Cargo Ship A, which occurred near the west entrance of the Kurushima Strait on May 27, 2021, this analytical investigation analyzed the stability of the ship at the time of the accident and examined the circumstances that led to its capsizing and sinking. The main findings of this analytical investigation are as follows.

(Stability at the time of the accident)

- Based on the ship's condition at the time of departure from Port of Kobe, the ship's stability before the accident (collision) was estimated and its compliance with the stability criteria was confirmed. As a result, it was determined that the ship's stability before the accident was (1) in compliance with the stability criteria and (2) its stability performance was better than that at the time of departure in the standard loading condition considered at the time of construction (Figure 1.1.1, Table 1.2.1).

(Circumstances leading to capsizing)

The final state of flooding (equilibrium state) was examined up to the time when the captain decided to abandon the ship, with the flooding area being No. 4 W.B.T. (P) and vehicle compartments on decks B3 to B1. Assuming a heeling moment created by No. 4 W.B.T. (P) being full due to flooding and the loaded vehicles moving sideways, it was estimated that a large heel of approximately 37° would occur in the quasi-static equilibrium state, corresponding to the submergence angle of the No. 2 deck end as described by the crew (Figure 2.2.1, Table 2.2.4).

- The circumstances under which the ship would capsize after the captain decided to abandon ship were investigated assuming that the vehicle compartments in decks from B3 to B1 had lost buoyancy and that the No. 1 deck vehicle compartment was flooded. As a result of the investigation into the intermediate stage of flooding, it was estimated that when the volume of flooding in the No. 1 deck vehicle compartment reached 2,500 m^3, the ship would heel to approximately 72°, causing it to tip over, and that by the time the amount of flooding exceeded 2,500 m^3 and reached 3,000 m^3, the ship would have capsized (Figure 2.2.3, Table 2.2.8).

(Circumstances leading to sinking)

- The floodable volume and flooding route of the vehicle compartments (No. 1 to No. 3 decks) where the outer shell plating was undamaged were confirmed, and the displacement volume at the time of flooding in the vehicle compartments was compared with the total buoyancy. As a result, if the vehicle compartments on B1 deck and below lost buoyancy and the flooding volume in the No. 1 deck vehicle compartment reached 2,500 m^3 (flooded weight: 2,562 tf), the top of the ventilation system installed on the No. 4 deck would be submerged, and water would begin to flood into the vehicle compartments on the No. 1 to No. 3 decks (total floodable weight limit: 33,068 tf) through the ventilation tubes. Therefore, it is considered realistic to assume that at the time of the accident, water would have flooded the ship in excess of the reserve buoyancy (26,815 tf), leading to the sinking of the ship (Table 2.3.3).

Appendix 1 Estimation of the amount of water flooding into the ship

To have a better prospect for the analysis, we estimated the amount of flooding into the ship based on the results of the investigation of the breach in the ship's outer shell plating (Section 2.1) provided by the investigators. The calculations were performed using the added weight method[1)], and assuming that the amount of water flooding into the onboard compartments was equal to the increase in displacement due to the sinking of the hull (approximately calculated by multiplying the waterline area of the flooded draft before the accident by the increase in draft), the amount of water flooding and the time required to reach an equilibrium state (state of balance) where the water level in the flooded onboard compartments and the water level outside the ship were the same were calculated quasi-statically[1)]. In doing so, the following assumptions were made.

① Comparing the location of the breach with the ship's general arrangement plan and central sectional view, seawater outside the ship flooded into the ship through the ship-side breach from B2 deck (height 5.125 m) to No. 1 deck (height 13.610 m), and the damage at B3 deck (height 2.550 m) level was limited to No. 4 W.B.T. (P), with no direct flooding to the vehicle compartment, and there was no direct flooding of the vehicle compartment.

② The flooded area inside the ship was only the vehicle compartments on each deck, and B3 deck vehicle compartment was flooded via B2 deck vehicle compartment.

③ There was no change in hull position (trim, heel) due to flooding, and the hull sunk uniformly (parallel sinking).

④ Water entered the ship starting from the lowest vehicle compartment on the B3 deck, and after the vehicle compartment on each deck were filled with water, water began to flood the vehicle compartment on the deck above. In this case, it can be assumed that the presence of the deck, which is the ceiling of each vehicle compartment, can be ignored.

⑤ The flooding volume of the vehicle compartment is equal to the area of each vehicle compartment shown in the stability documents multiplied by the height between the decks.

The rate of flooding into the ship's interior compartment (dv_i/d_t), with v_i as the volume of flooding into the interior compartment and t as the time elapsed since the occurrence of the breach, was evaluated by setting the flow coefficient (C) to 0.6, the area of the breach below the uniformly sunk draft line ($A_{DO}(d)$) and the real water depth ($h_{DO}(d)$) at the area center position of the breach (hereinafter simply referred to as "real water depth"), and the evaluation was performed using equation (A1.1). The real water depth $h_{DO}(d)$ (corresponding to the difference in water pressure between the inside and outside of the ship at the location of the area center of the breach) was evaluated using equation (A1.2) until the water level of inboard flooding reached the center height of the breach area (H(d)) below the uniformly sunk draft line, and using equation (A1.3) when the water level of inboard flooding was higher than the center of the breakwater area.

$$\frac{dv_i}{dt} = CA_{DO}(d) \times \sqrt{2gh_{DO}(d)} \tag{A1.1}$$

where, g is the acceleration of gravity.

$$h_{DO}(d) = d - H(d) \tag{A1.2}$$

$$h_{DO}(d) = d - d_w \tag{A1.3}$$

where, d is the draft when evaluating equation (A1.1) and d_w is the water level of inboard flooding.

The calculation results of the flooding volume v_i and the evaluation results of the flooding velocity dv_i/dt, etc. used in the calculations are shown in Figures A1.1 and A1.2.A'_{DO} with "'" is the breach area below the waterline that is above B2 deck, and the draft d', etc. are the values taken with respect to B2 deck height (5.125 m).

The following facts can be inferred from Figures A1.1 and A1.2.

① Assuming quasi-static uniform sinking, approximately 330 s (5 min 30 s) after the breach occurs, the amount of water flooding into the ship v*i* will reach approximately 15,600 m^3, and the draft d' based on the B2 deck height will reach approximately 6.68 m (the baseline draft approximately 11.80 m), resulting in a state of equilibrium.

② The water level d'_w of the inboard flooding in the equilibriium condition is also about 6.68 m above B2 deck and reaches 3.70 m above B1 deck.

③ Approximately 180 s (3 min) after the start of flooding, the water level d'_w inside the ship reaches the height H' at the center of the breach area below the waterline, and the actual water depth h_{DO} decreases thereafter.

④ The flooding velocity dv_i/dt, which is also a function of the breach area below the waterline A_{DO}, begins to decrease from about 250 s (4 min and 10 s) after the occurrence of the breach, later than the time when the real water depth h_{DO} decreases

. The displacement before the accident was estimated to be 13,082 tf (Table 1.1.1), which corresponds to about 1.2 times the volume of flooding inside the ship under balanced conditions.

The ship began to heel immediately after collision, and the situation of flooding into the ship is assumed to be different from the situation shown in Figures A1.1 and A1.2, where the trim and heel do not change due to flooding into the ship and the hull is assumed to settle uniformly. However, the flooding inside the ship caused by the breach of the ship's outer shell plating caused by the collision reached an equilibrium state by the time the captain decided to abandon the ship (approximately 7 min after the collision). It is possible that the amount of flooding was large enough to exceed the displacement before the accident occurred.

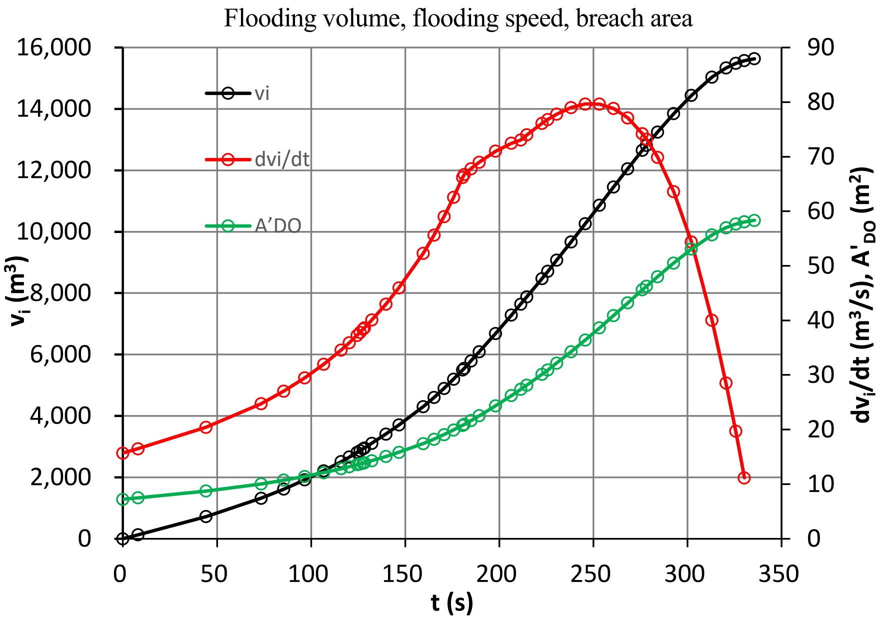


Figure A1.1 Volume of water in the ship v_i, the flooding rate dv_i/d_t, and the area of the breach below the waterline above the B2 deck A'_{DO}

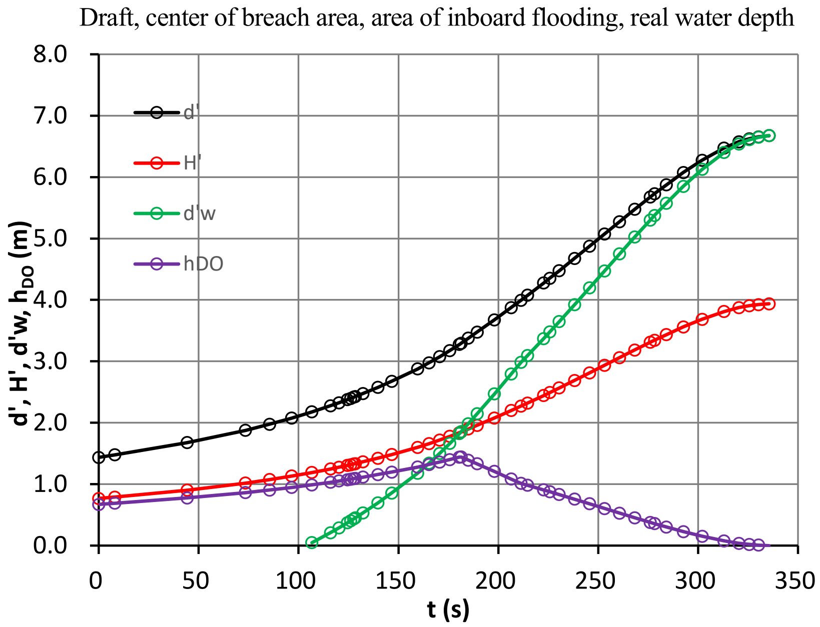


Figure A1.2 Draft d', the center height H' of the breach area below the waterline, the water level d'_w of inboard flooding, and the real water depth h_{DO} based on the B2 deck height.

References

1) Masanobu Ogushi: Theoretical Ship Engineering (vol.1) Newly revised edition, pp.21-25, Kaibundo, October 1984. (In Japanese)

Appendix 2: Consideration of intermediate stages of flooding

Based on the estimated draft before the accident (Table 1.1.2), the results of the investigation into the breach in the outer shell plating provided by the investigator (Section 2.1), the general arrangement plan, and the central section diagram, it is assumed that immediately after the breach occurred due to the collision, the ship was first flooded 1) in No. 4 W.B.T. (P) and the B2 deck vehicle compartment, which were below waterline (and the B3 deck vehicle compartment was also flooded via the rampway opening in the same space). Subsequently, due to an increase in draft caused by flooding and heeling caused by flooding of No. 4 W.B.T. (P) (asymmetric flooding), the B1 deck end became submerged, and it is assumed that 2) in addition to the B2 deck vehicle compartment, the B1 deck vehicle compartment also became flooded at the same time.

The main text (Section 2.2.2) presented the calculation results of the hull heeling at the stage when the above-mentioned flooding has progressed sufficiently and the equilibrium state (final state) is reached, in which the water level in the flooded internal compartments and the water level outside the hull are equal. On the other hand, since it is expected that more dangerous conditions may exist between the start of flooding and the final state (the intermediate stages), the damage stability criteria require sufficient stability even during the intermediate stages of flooding[1)].

In this section, the intermediate stage of flooding is examined by estimating the hull heeling based on the assumption of the following two conditions for the volume of flooding: 1) the vehicle compartment of No. 4 W.B.T. (P), B2 deck and B3 deck were flooded immediately after the breach caused by the collision described above, and 2) the port end of B1 deck was submerged and the vehicle compartment of B2 deck and B3 deck as well as the vehicle compartment of B1 deck were flooded at the same time.

A2.1 State immediately after the breach caused by collision

As an intermediate stage of flooding immediately after the occurrence of the breach caused by the collision, a situation is assumed in which seawater flowed onto the B2 deck through the breach in the ship's outer shell plating and accumulated in the vehicle compartment on the same deck, with some of it flowing down through the rampway opening into the vehicle compartment on the B3 deck, where it also accumulated. At the time, since No. 4 W.B.T. (P), which has a volume of 272 m^3, had 174 m^3 (weight 179 tf) of ballast water loaded into it, which was approximately 64% of its capacity, before the accident occurred, it is considered that the tank would become full to capacity in a short period of time. The initial state of No. 4 W.B.T. (P) was set to be full of water (flooded weight: 100 tf), and the amount of seawater flowing into B2 deck was used as a parameter to calculate the heel angle at which the quasi-static balance between the restoring force (considering the effect of flooding inside the ship) and the inclination moment caused by No. 4 W.B.T. (P) being full of water was obtained.

A2.1.1 Assumption of flooding conditions and handling of vehicle compartments

The proportion of seawater flowing from the rampway opening to B3 deck vehicle compartment out of the seawater entering B2 deck was assumed to correspond to the proportion of the area of the rampway opening to the area of B2 deck vehicle compartment. As a result, the proportion of seawater that flows down and stays in B3 deck vehicle compartment out of the seawater that flows into B2 deck was set as 1/24 of the total amount of flooding.

The vehicle compartments were approximated as equivalent rectangular parallelepiped tanks based on the average area of the floor and ceiling and the compartment length. In this case, the height (depth) of the tank was set equal to the height between the decks. Table A2.1.1 shows the length (LT), bottom area (AT) and volume (VT) of the equivalent rectangular parallelepiped tanks that approximate the vehicle compartments on B2 and B3 decks.

Table A2.1.1 Parameters of the equivalent rectangular parallelepiped tanks approximating vehicle compartments

	L_T (m)	A_T (m^2)	V_T (m^3)
B3 Deck	69.60	827	2,125
B2 Deck	82.40	1,889	5,630

A2.1.2 Estimation of hull heeling during the intermediate stage of flooding

The following procedure was used to estimate the heeling of the hull during the intermediate stage of flooding.

1) Treat the inboard flooding as a heavy object and calculate the restoring force.
2) Calculate the heeling moment due to the movement of inboard flooding caused by the heeling of the hull and add it to 1) to obtain the restoring force that takes into account the effect of inboard flooding.
3) Find the heeling angle at which the quasi-static balance between the heeling moment due to No. 4W.B.T. (P) becoming full of water and the restoring force considering the effect of inboard flooding in 2) is obtained.

(a) Weight and center of gravity

Table A2.1.2 shows the results of weight and center of gravity calculations for the initial flooding condition (No. 4 W.B.T. (P) full of water, seawater inflow to B2 deck: 0 m^3) and for the assumed seawater inflow to B2 deck (total amount of flooding in the vehicle compartment on B2 deck and B3 deck) of 90 m^3 to 450 m^3. The assumed inflow of seawater was assumed to be loaded into equivalent rectangular tanks with flat surfaces that approximated each vehicle compartment with the parameters explained in Section A2.1.1, with a flooding rate of 90%, and the water level in the tanks was assumed to be constant. The values before the accident (at the time of departure from Port of Kobe) are also shown in the table for reference. The GG' shown in Table A2.1.2 is the apparent center-of-gravity rise due to liquid with free surface (free water effect) for various tanks except for the equivalent rectangular parallelepiped tanks that approximate the vehicle compartments, and the free water effect for No. 4 W.B.T. (P) is considered only for the pre-accident condition.

Table A2.1.2 Weight and center of gravity (intermediate stage of flooding: Immediately after the occurrence of the breach due to collision)

※ Flooding volume in table: Total flooding volume of vehicle compartments on B2 and B3 decks

Flooding volume (m^3)	W (t)	mid-G (m)	KG (m)	GG' (m)
0	13,182	8.08	11.62	0.60
90	13,274	8.04	11.57	0.60
180	13,366	8.00	11.53	0.59
270	13,459	7.95	11.48	0.59
360	13,551	7.91	11.44	0.59
450	13,643	7.87	11.40	0.58
Before the accident	13,082	8.17	11.66	0.63

(b) Restoring force with inboard flooding treated as a heavy object

Figure A2.1.1 shows the results of calculating the restoring force with the weights and centers of gravity shown in Table A2.1.2. The restoring force (restoring lever G'Z) shown in Figure A2.1.1 takes into account the free water effects of the various tanks. Table A2.1.3 summarizes the calculation results for metacentric height (G'M), draft (df: fore draft, da: aft draft, dm: mean draft), sea water inflow angle (φ_{W_2}), submergence angle at the port end of No. 2 deck (upper deck) at the center of the hull (φ_{D_2}), and submergence angle at the port end of B1 deck (φ_{D_B1}) at the center of the hull, taking free water effects into consideration. Figure A2.1.1 and Table A2.1.3 also show the calculation results for the pre-accident condition for reference.

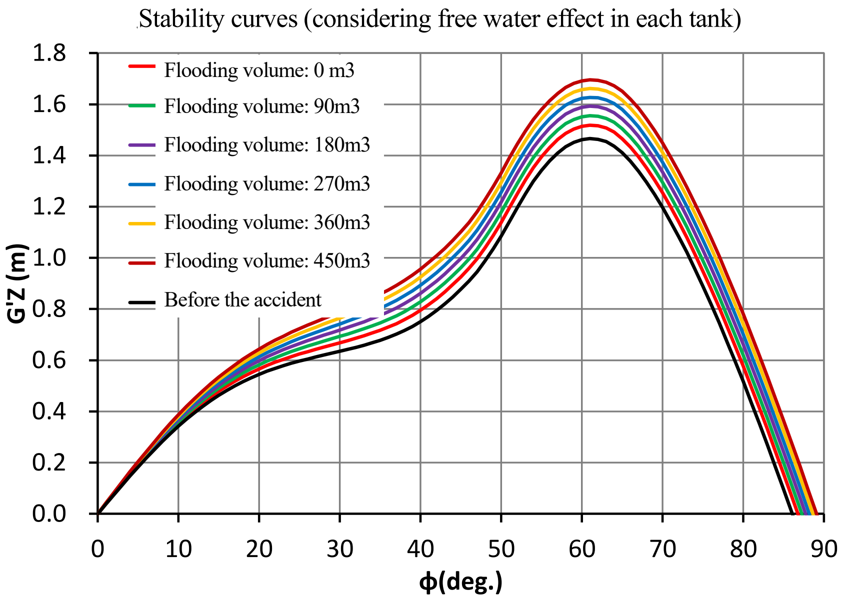


Figure A2.1.1 Restoring force curve (when inboard flooding is treated as a heavy object)
(Intermediate stage of flooding: Immediately after the occurrence of the breach due to collision)
※ Flooding volume in legend: Sum of flooding volumes of vehicle compartments on B2 and B3 decks

Since the vehicle compartments on B2 and B3 decks are below the pre-accident center-of-gravity height (KG = 11.66 m), as shown in Table A2.1.2, when the flood water in the ship is treated as a heavy object, the flooding volume increases, the center-of-gravity height decreases, and the initial restoring force (metacentric height G'M: Table A2.1.3) and the large heel restoring lever (G'Z: Figure A2.1.1) both increase. The submergence angle φ_{D_B1} at the port end of B1 deck shown in Table A2.1.3 is about 6° to 7°, and it is necessary to assume that the vehicle compartment of B1 deck is also flooded at a heel angle larger than φ_{D_B1}. Here the calculations are performed assuming that the flooded area includes No. 4W.B.T. (P) and vehicle compartments of decks B2 and B3.

Table A2.1.3 Calculation results for metacentric height, draft, seawater inflow angle, and shipboard submergence angle
(Intermediate stage of flooding: Immediately after the occurrence of the breach due to collision)
※ Flooding volume in table: Total flooding volume of vehicle compartments on B2 and B3 decks

Flooding volume (m^3)	G'M (m)	df (m)	da (m)	dm (m)	ϕ_{W2} (deg.)	ϕ_{D2} (deg.)	ϕ_{D_B1} (deg.)
0	2.20	5.53	7.66	6.59	70.86	51.32	6.80
90	2.24	5.57	7.68	6.62	70.63	51.20	6.66
180	2.27	5.62	7.69	6.65	70.46	51.06	6.51
270	2.30	5.67	7.71	6.69	70.18	50.93	6.37
360	2.34	5.72	7.72	6.72	69.94	50.80	6.22
450	2.37	5.77	7.74	6.75	69.77	50.68	6.06
Before the accident	2.14	5.47	7.65	6.56	71.14	51.47	6.96

(c) Restoring force taking into account the effects of inboard flooding

The restoring force was calculated by treating the inboard flooding as a heavy object. The effect of inboard flooding was taken into account by adding the lateral weight moment (acting as the heeling moment) due to the movement of seawater (corresponding to inboard flooding) in the equivalent rectangular parallelepiped tanks, which approximate the vehicle compartments, as a result of the inclination of the ship. The heeling moment due to the movement of seawater in the equivalent rectangular parallelepiped tanks approximating the vehicle compartments was evaluated using the formula given in Reference 2).

Figure A2.1.2 shows the calculated heeling moment (w･gz) due to the movement of seawater in the equivalent rectangular parallelepiped tanks divided by the ship's displacement W. In the figure, the heeling couple lever is shown by the dashed line when the flooding volume (the amount of water in the tank) is 90 m^3 and the tank is treated as a so-called free-water effect. Since the assumed flooding volume (the amount of water in the tank) is small, it can be seen that the treatment as a free water effect can only be applied to a very small range of heeling angles of about 1°.

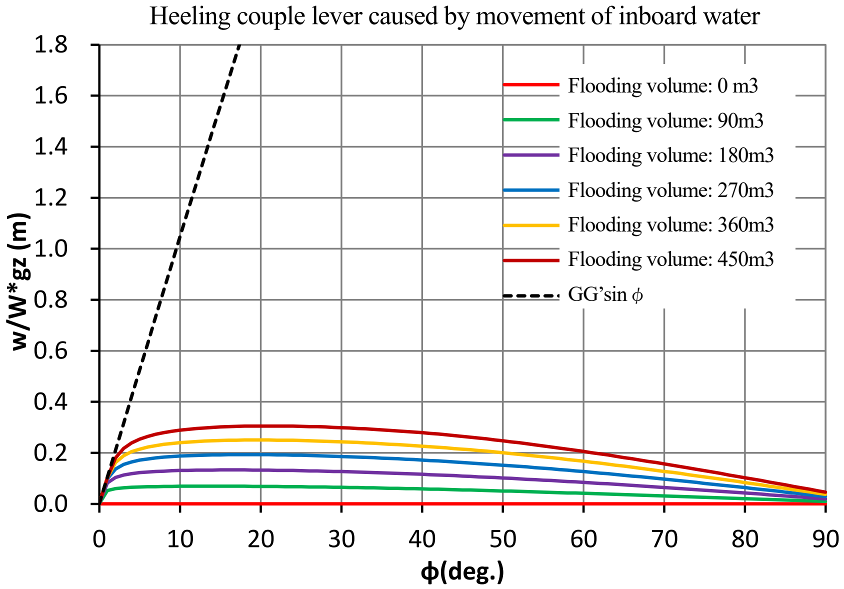


Figure A2.1.2 Heeling couple lever due to movement of flooding in the ship (intermediate stage of flooding: Immediately after the occurrence of the breach due to collision)

※ Flooding volume in legend: Sum of flooding volumes of vehicle compartments on B2 and B3 decks

Figure A2.1.3 shows the restoring force (G'Z- w/W･gz) considering the effect of inboard flooding. From Figure A2.1.3, it can be seen that the upright state becomes unstable due to flooding of the ship, and the ship stabilizes at the tilted state (the intersection of the restoring force curve shown in Figure A2.1.3 and the horizontal axis other than the origin).

Stability curves (including free water effect in each tank and effect of movement of inboard water)

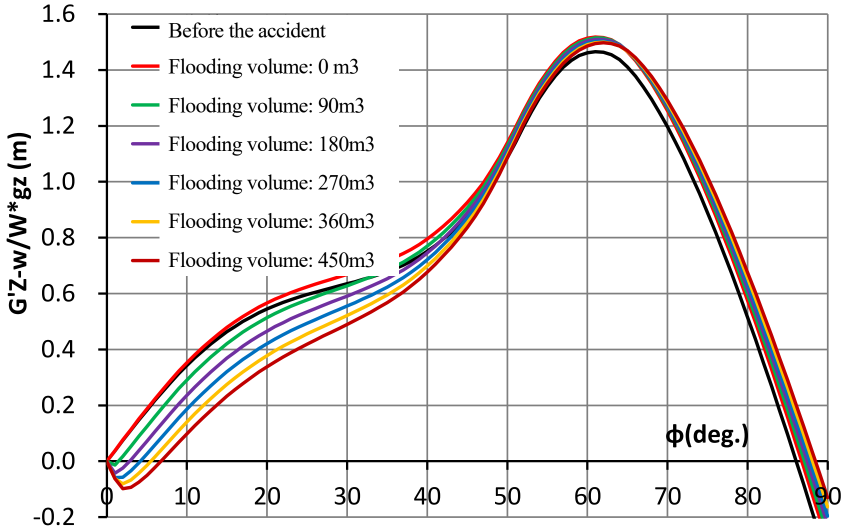


Figure A2.1.3 Restoring force curve (including the heeling couple lever due to movement of inboard flooding)
(Intermediate stage of flooding: Immediately after the occurrence of the breach due to collision)

※ Flooding volume in legend: Sum of flooding volumes of vehicle compartments on B2 and B3 decks

(d) Heeling moment

The heeling moment in the intermediate stage of flooding immediately after the occurrence of the breach due to collision was assumed to be the increase in the lateral weight moment due to No. 4 W.B.T. (P) becoming full of water due to flooding. The increase in weight (δw) due to No. 4 W.B.T. (P) becoming full of water was 100tf, and the corresponding change in the position of the center of gravity in the lateral direction was taken from the figure in the stability documents, resulting in an increase in the lateral weight moment (δw・ℓ) of 956 tf-m. Note that the heeling moment was assumed to act as the increase in lateral weight moment multiplied by cosφ (δw-ℓcosφ) when the heeling angle was set to φ.

(e) Hull condition

The heeling of the hull at the intermediate stage of flooding into No. 4W.B.T. (P) and the vehicle compartments on the B2 and B3 decks, which was assumed to be the situation immediately after the occurrence of the breach due to the collision, was calculated using equation (A2.1.1) as the heeling angle φ_E in the quasi-static equilibrium state of the restoring force and the assumed heeling moment, taking into account the effects of flooding inside the ship.

$$W \cdot G'Z(\phi_E) - w \cdot gz(\phi_E) = \delta w \cdot l cos\phi_E \qquad (A2.1.1)$$

Table A2.1.4 shows the hull heeling angles at the intermediate stage of flooding immediately after the occurrence of the breach. The table also shows the port end submergence angle of B1 deck at the center of the hull φ_{D_B1} for comparison. As shown in Table A2.1.4, when the seawater inflow to B2 deck (the total flooding of the vehicle compartments on B2 and B3 decks) exceeds 270 m^3, φ_E becomes larger than φ_{D_B1}, and the port end of B1 deck is estimated to be submerged under the quasi-static balance between the restoring force (considering the effect of inboard flooding) and assumed heeling moment. Therefore, considering the approximate results of the flooding volume in the ship shown in Appendix 1 (Figure A1.1), it is assumed that the flooding of B1 deck vehicle compartment began in the early stages of flooding immediately after the occurrence of the breach.

Table A2.1.4 Hull heeling (intermediate stage of flooding: immediately after the occurrence of the breach caused by the collision)

※ Flooding volume in table: Total flooding volume of vehicle compartments on B2 and B3 decks

Flooding volume (m^3)	ϕ_E (deg.)	$\phi_{D\ B1}$(deg.)
0	1.91	6.80
90	3.53	6.66
180	4.99	6.51
270	6.38	6.37
360	7.72	6.22
450	9.04	6.06

A2.2 State after the port end of B1 deck is submerged

As an intermediate stage of flooding after the port end of the B1 deck is submerged, assuming a situation where the vehicle compartments on the B1 deck were flooded at the same time, in addition to the vehicle compartments on the B2 and B3 decks, using the amount of seawater flowing into the ship as a parameter, we calculated the heeling angle to be quasi-statically balanced between the restoring force considering the effect of inboard flooding and No. 4 W.B.T. (P) being full of water, plus the inclination moment caused by the lashing breakage and lateral movement of the on-board vehicles. The initial condition was assumed to be the situation following the intermediate stage of flooding immediately after the breach as discussed in Section A2.1, when No. 4 W.B.T. (P) was full of water (flooding weight: 100 tf) and the volume of seawater flowing into the B2 deck was 270 m^3 (total flooding weight of the vehicle compartments on the B2 and B3 decks: 277 tf), where the initial condition was that the B1 port end was submerged.

A2.2.1 Assumption of flooding conditions and handling of vehicle compartments

The volume of seawater flowing into each vehicle compartment was set by assuming that seawater flowing in through the breach in the ship's outer hull would flow into B2 and B1 decks in proportion to the area of the breach below the assumed draft (the area of the breach between B2 deck and B1 deck and the area of the breach between B1 deck and the assumed draft). The assumed draft used to calculate the ratio of seawater flowing into the B2 deck and the B1 deck from the breach was determined to be the draft corresponding to half the deck height between the B1 deck and the No. 1 deck (dm = 10.86 m), based on the average draft (dm = 11.64 m) when upright, when the final state (equilibrium state) of flooding was considered for the flooded range of No. 4 W.B.T. (P) and the vehicle compartments on decks B3 to B1 in Section 2.2.2 of the text. As a result, the ratio of seawater entering B2 deck to that entering B1 deck out of the seawater entering through the breach in the ship's outer hull was set to 1:1.54 to determine the amount of flooding to each deck. As in the intermediate stage of flooding immediately after the occurrence of the breach as discussed in Section A2.1, the proportion of seawater that flows into B2 deck and flows down and stays in B3 deck vehicle compartment was assumed to be 1/24.

The B1 deck vehicle compartment was also approximated as an equivalent rectangular parallelepiped tank based on the average area of the floor and ceiling surfaces and the compartment length, as were the vehicle compartments on B2 and B3 decks. In this case, the height (depth) of the tank was set equal to the height between the decks. Table A2.2.1 shows the length (L_T), bottom area (A_T) and volume (V_T) of the equivalent rectangular parallelepiped tanks used to approximate B1 deck vehicle compartment, together with values for tanks used to approximate B2 and B3 deck vehicle compartments.

Table A2.2.1 Parameters of equivalent rectangular parallelepiped tanks approximating vehicle compartments

	L_T (m)	A_T (m^2)	V_T (m^3)
Deck B1	106.40	2,530	13,939
Deck B2	82.40	1,889	5,630
Deck B3	69.60	827	2,125

A2.2.2 Estimation of hull heeling during the intermediate stage of flooding

The estimation of the hull heeling during the intermediate stage of flooding after the port end of B1 deck was submerged followed the same procedure as for the intermediate stage of flooding immediately after the occurrence of the breach discussed in Section A2.1.

(a) Weight and center of gravity

Table A2.2.2 shows the results of weight and center of gravity calculations for the initial condition (No. 4 W.B.T. (P) full of water, inflow to B2 deck: 270 m^3) and the subsequent sea water inflow into the ship (total sea water inflow to B2 deck and B1 deck) assumed to be 900 m^3 to 4,500 m^3. The assumed inflow of seawater was assumed to be loaded into equivalent rectangular tanks with flat surfaces that approximated each vehicle compartment with the parameters explained in Section A2.2.1, with a flooding rate of 90%, and the water level in the tanks was assumed to be constant. The flooding volume shown in Table A2.2.2 is the total amount of seawater assumed to have entered and remained in the vehicle compartments of each deck after the breach, plus the volume of water that entered B2 deck under initial conditions (270 m^3). The table also shows, for reference, the values when only No. 4 W.B.T. (P) was full of water (inflow into the vehicle compartment: 0 m^3) and before the accident (at the time of departure from Port of Kobe). The GG' shown in Table A2.2.2 is the apparent center-of-gravity rise due to liquid with free surface (free water effect) for various tanks except for the equivalent rectangular parallelepiped tanks that approximate the vehicle compartments, and the free water effect for No. 4 W.B.T. (P) is considered only for the pre-accident condition.

Table A2.2.2 Weight and center of gravity (Intermediate stage of flooding: after the port end of B1 deck is submerged)

※ Flooding volume in the table: Total flooding volume of vehicle compartments on decks B1, B2 and B3

Flooding volume (m^3)	W (t)	mid-G (m)	KG (m)	GG' (m)
0	13,182	8.08	11.62	0.60
270	13,459	7.95	11.48	0.59
1,170	14,381	7.25	11.20	0.55
2,070	15,304	6.64	10.96	0.52
2,970	16,226	6.10	10.77	0.49
3,870	17,149	5.61	10.61	0.46
4,770	18,071	5.17	10.48	0.44
Before the accident	13,082	8.17	11.66	0.63

(b) Restoring force with inboard flooding treated as a heavy object

Figure A2.2.1 shows the results of calculating the restoring force with the weights and centers of gravity shown in Table A2.2.2. The restoring force (restoring lever G'Z) shown in Figure A2.2.1 also takes into account the free water effects of the various tanks. Table A2.2.3 summarizes the calculation results for metacentric height (G'M), draft (df: fore draft, da: aft draft, dm: mean draft), sea water inflow angle (φ_{W_2}), submergence angle at the port end of No. 2 deck (upper deck) at the center of the hull (φ_{D_2}), and submergence angle at the port end of No. 1 deck (φ_{D_1}) at the center of the hull, taking free water effects into consideration.

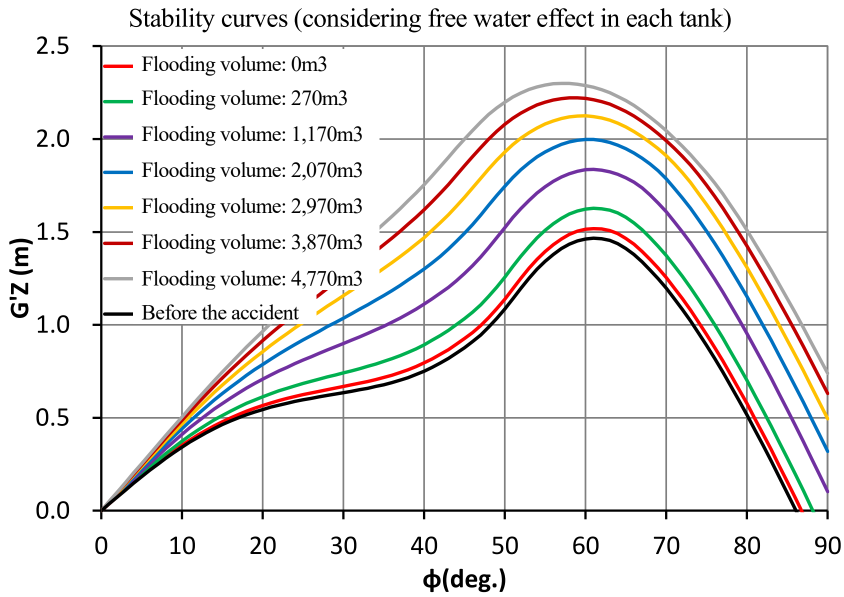


Figure A2.2.1 Restoring force curve (when inboard flooding is treated as a heavy object)
(Intermediate stage of flooding: after the port end of B1 deck is submerged)

※ Flooding volume in legend: Sum of flooding volumes of vehicle compartments of decks B1, B2 and B3

Since the vehicle compartments on decks from B3 to B1 are below the pre-accident center-of-gravity height (KG = 11.66 m), as shown in Table A2.2.2, when the flood water in the ship is treated as a heavy object, the flooding volume increases, the center-of-gravity height decreases, and the initial restoring force (metacentric height G' M: Table A2.2.3) and the large heel restoring lever (G'Z: Figure A2.2.1) both increase.

Table A2.2.3 Calculation results for metacentric height, draft, seawater inflow angle, and shipboard submergence angle
(Intermediate stage of flooding: after the port end of B1 deck is submerged)

※ Flooding volume in the table: Total flooding volume of vehicle compartments on decks B1, B2 and B3

Flooding volume (m^3)	G'M (m)	df (m)	da (m)	dm (m)	ϕ_{W2} (deg.)	ϕ_{D2} (deg.)	ϕ_{D1} (deg.)
0	2.20	5.53	7.66	6.59	70.86	51.32	32.40
270	2.30	5.67	7.71	6.69	70.18	50.93	31.93
1,170	2.47	6.26	7.78	7.02	67.73	49.60	30.29
2,070	2.61	6.82	7.86	7.34	65.82	48.30	28.71
2,970	2.73	7.37	7.95	7.66	64.12	47.02	27.17
3,870	2.84	7.89	8.04	7.97	62.46	45.77	25.67
4,770	2.91	8.40	8.14	8.27	60.80	44.55	24.25
Before the accident	2.14	5.47	7.65	6.56	71.14	51.47	32.58

(c) Restoring force taking into account the effects of inboard flooding

The restoring force considering the effect of inboard flooding was calculated in the same way as in the intermediate stage of flooding immediately after the occurrence of the breach as discussed in Section A2.1, by using the heeling moment due to the movement of seawater (corresponding to inboard flooding) caused by ship heeling in the equivalent rectangular parallelepiped tank, which approximates a vehicle compartment, in the calculation of the restoring force in which the inboard flooding was treated as a heavy object.

Figure A2.2.2 shows the calculated heeling moment (w・gz) due to the movement of seawater in the equivalent rectangular parallelepiped tanks divided by the ship's displacement W. In the figure, the dashed line shows the heeling couple lever when flooding is treated as a so-called free water effect, assuming that the total amount of flooding in the vehicle compartments (amount in the tank) is 1,170 m^3 and flooding in all vehicle compartments from deck B3 to deck B1 occurs. Since the estimated volume of flooding (amount in the tank) was small, it was clear that the free water effect could only be treated as being applicable to an extremely small range of inclination angles of about 2°.

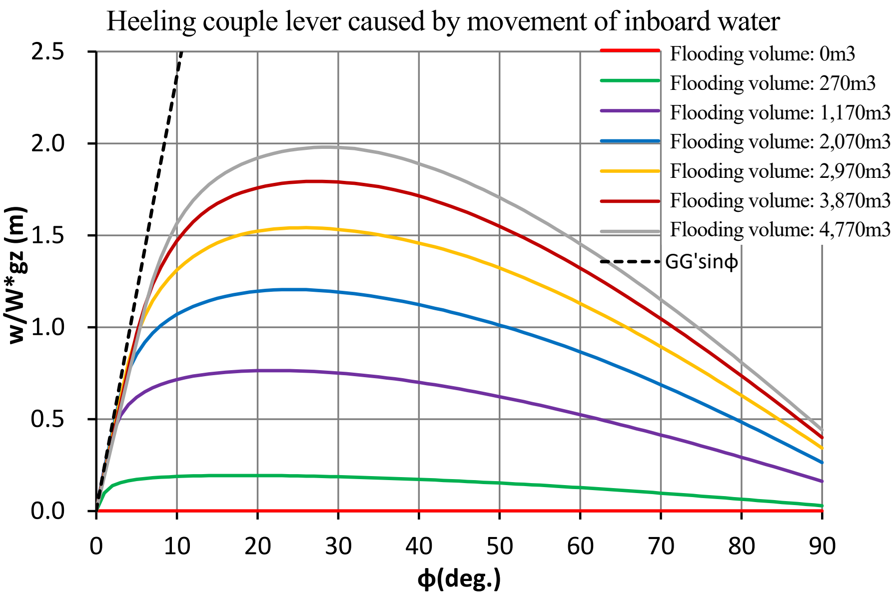


Figure A2.2.2 Heeling couple lever caused by movement of inboard water

(Intermediate stage of flooding: after the port end of B1 deck is submerged)

※ Flooding volume in legend: Sum of flooding volumes of vehicle compartments of decks B1, B2 and B3

Figure A2.2.3 shows the restoring force (G'Z- w/W-gz) considering the effect of inboard flooding. From Figure A2.2.3, it can be seen that the upright state becomes unstable due to flooding of the ship, and the ship stabilizes at the tilted state (the intersection of the restoring force curve shown in Figure A2.2.3 and the horizontal axis other than the origin). In particular, for a total flooding volume (volume in the tank) of 2,970 m^3 or more, assuming that B1 deck vehicle compartment is also flooded, the heeling angle in the stable state is estimated to be 35° or more, which is larger than the port end submerged water angle φ_{D_1} for No. 1 deck shown in Table A2.2.3 even when no heeling moment is applied.

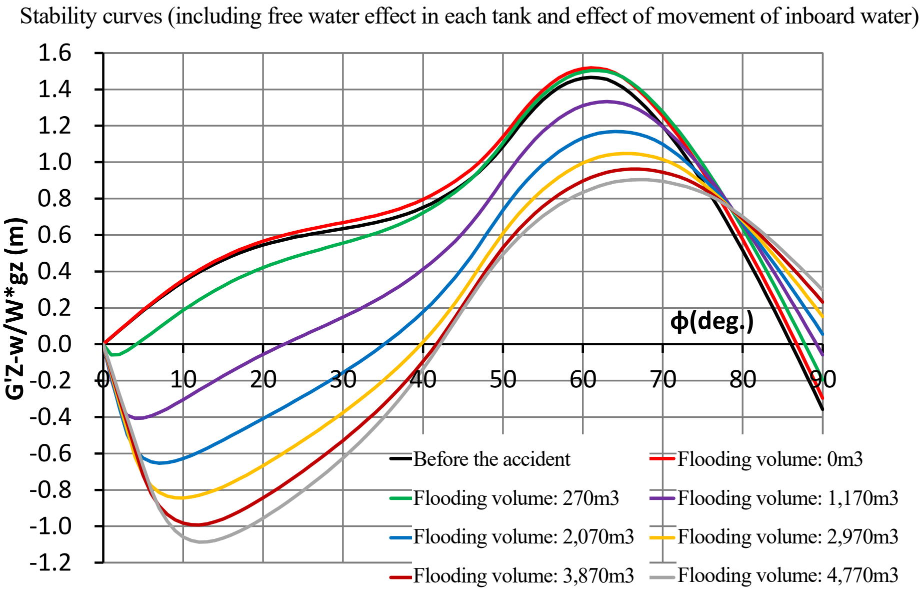


Figure A2.2.3 Restoring force curve (including the heeling couple lever due to movement of inboard flooding)
(Intermediate stage of flooding: after the port end of B1 deck is submerged)

※ Flooding volume in legend: Sum of flooding volumes of vehicle compartments of decks B1, B2 and B3

(d) Heeling moment

The heeling moment in the intermediate stage of flooding after the port end of B1 deck was submerged was assumed to be the increased lateral weight moment due to No. 4 W.B.T. (P) becoming full of water due to flooding, plus the lateral weight moment caused by the lashing breaking at a large tilt and the lateral movement of the loaded vehicles. As explained in Section A2.1.2 (d), the increase in the lateral weight moment (δw･ℓ) due to No. 4 W.B.T. (P) being full of water is 956 tf-m. On the other hand, the total weight of the loaded vehicles at the time of the accident (w_{car}) calculated from the information provided by the operator was 1,788.8 tf, and the lateral weight moment (w_{car}･$ℓ_s$) was 4,525 tf-m.

When the heel angle is φ, the heeling moment is calculated as (δw･ℓ + wcar･ℓs) cosφ, which is the sum of the two types of lateral weight moments mentioned above multiplied by cosφ.

(e) Hull condition

The heeling of the hull in the intermediate stage between No. 4W.B.T. (P) and the flooding of the vehicle compartments on decks B3 to B1, assumed as the situation after B1 deck port end was submerged, was calculated as the heeling angle $φ_{E\_car\ shift}$ in the quasi-static balance state between the restoring force and the assumed inclination moment considering the effect of inboard flooding, as shown in (A2.2.1).

$$W \cdot G'Z\left(\phi_{E\_car\,shift}\right) - w \cdot gz\left(\phi_{E\_car\,shift}\right) = (\delta w \cdot l + w_{car} \cdot l_s)cos\phi_{E\_car\,shift} \quad \text{(A2.2.1)}$$

Table A2.2.4 shows the heeling of the hull at the intermediate stage of flooding after the port end of B1 deck is submerged. The table also shows, for reference, the heeling angle $φ_E$ in a quasi-static balance state assuming only an increase in the lateral weight moment (δw･ℓ) due to No. 4 W.B.T. (P) becoming full of water due to flooding as the heeling moment, and the angle of submergence $φ_{D\_2}$ at the port end of No. 2 deck (upper deck) at the center of the hull is also shown for comparison. As shown in Table A2.2.4, if the total volume of water flooding into each car compartment (amount in the tanks) exceeds 3,870 m^3, the heel angle $φ_{E\_car\ shift}$ in the quasi-static balance state of the restoring force and the assumed heel moment taking into account the effects of water flooding inside the ship will exceed 45°, and it is estimated that the end of the No. 2 deck will be submerged. This corresponds to the state described by the crew up to the point when the captain decided to abandon ship (the heel that began immediately after the collision increased and the lashings broke, the hull heel reached 45° or more, and the No. 2 deck (upper deck) was submerged in seawater).

Table A2.2.4 Hull heeling (Intermediate stage of flooding: after the port end of B1 deck is submerged)

※ Flooding volume in the table: Total flooding volume of vehicle compartments on decks B1, B2 and B3

Flooding volume (m^3)	$\phi_{E\_car\ shift}$ (deg.)	ϕ_E (deg.)	ϕ_{D_2} (deg.)
0	−	1.91	51.32
270	−	6.38	50.93
1,170	36.61	25.60	49.60
2,070	42.02	36.63	48.30
2,970	44.28	40.68	47.02
3,870	45.17	42.35	45.77
4,770	45.34	42.72	44.55

References

1) Tomoharu Morita: Ships Restoration Theory - Fundamentals and Applications-, pp.197-199, Kaibundo, April 1985. (In Japanese)

2) Tomoharu Morita: Ship Restoration Theory - Fundamentals and Applications-, pp.223-224, Kaibundo, April 1985. (In Japanese)

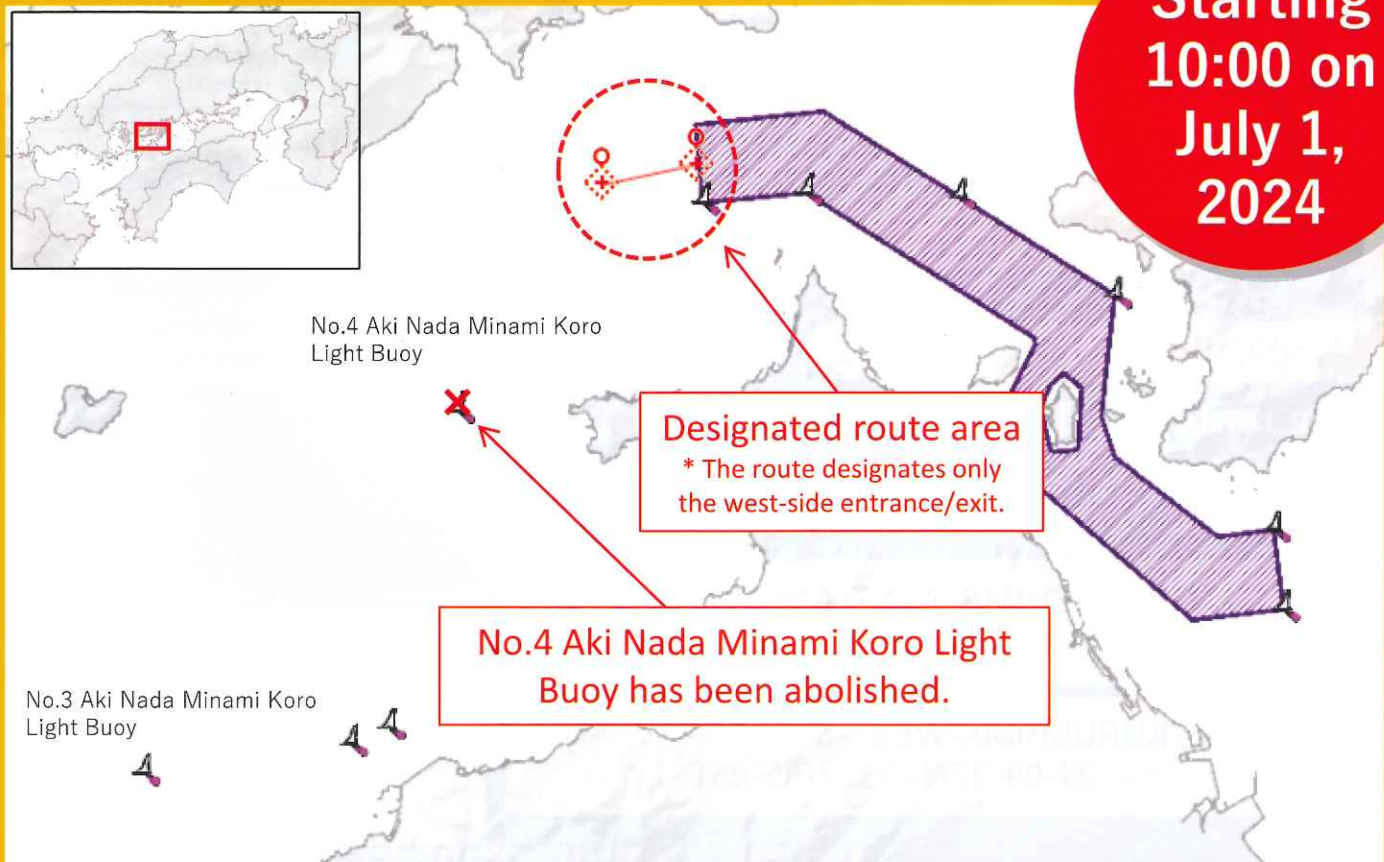
Attachment 3

Japan Coast Guard

Establishment of a new "route" for entering and going out Kurushima Kaikyo Traffic Route

Vessels navigating Kurushima Kaikyo Traffic Route must navigate the route designated by public notification based on Article 25-2 of the Act on Maritime Traffic Safety. (See the reverse side for an overview of the route.)
With the designation of this route, No.4 Aki Nada Minami Koro Light Buoy has been abolished and the nearby recommended traffic route has been shortened.

Starting 10:00 on July 1, 2024



Source: MDA Situational Indication Linkages (URL: https://www.msil.go.jp/)

For details concerning the route designation, indication of virtual AIS route markings, and abolition of the light buoy, see the 6th Regional Coast Guard Headquarters homepage.

☞ https://www.kaiho.mlit.go.jp/06kanku/safety/kurushima-keiroshitei.html

Inquiries

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6th Regional Coast Guard Headquarters
3-10-17 Ujina Kaigan, Minami-ku, Hiroshima, Hiroshima Prefecture
082-251-5111 (front desk)

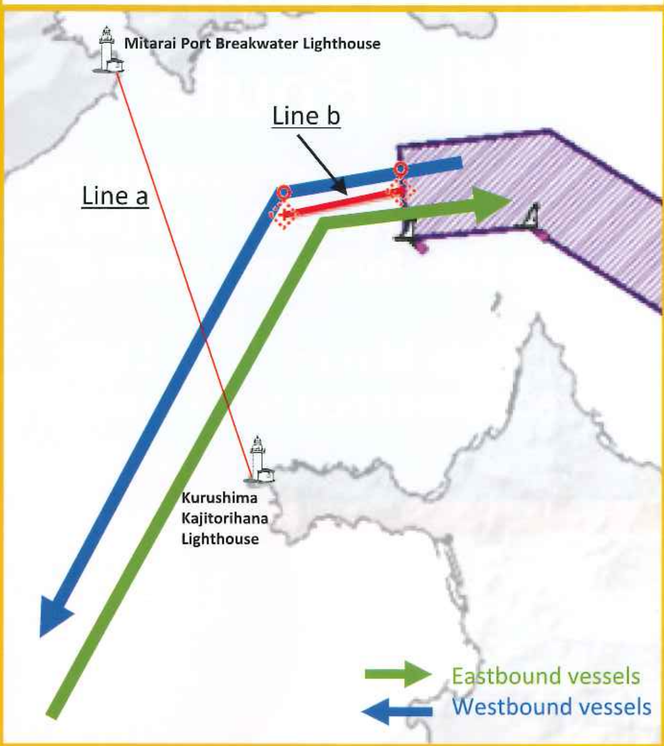
6th Regional Coast Guard Headquarters homepage

Starting 10:00 on July 1, 2024

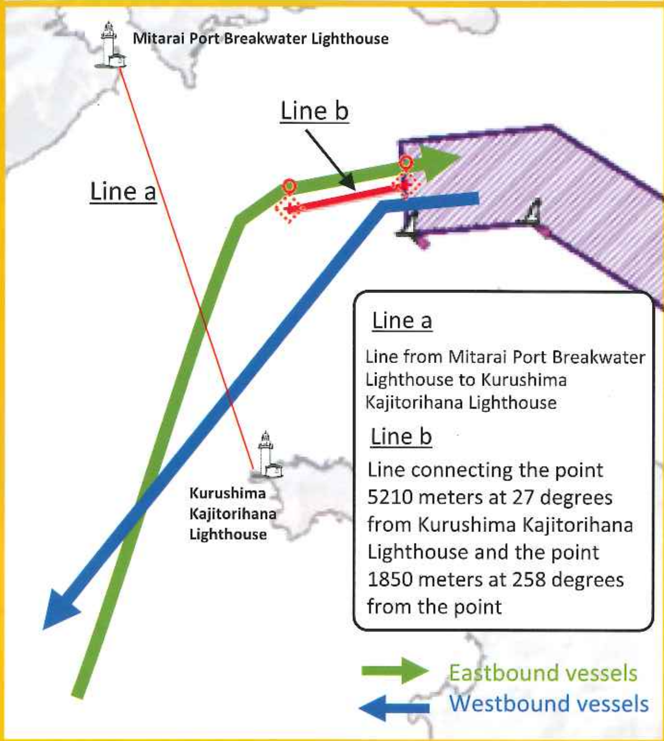
<Route overview>

1. Vessels intending to navigate westward through Kurushima Kaikyo Traffic Route and then intending to cross Line a should not cross Line b.
2. Vessels intending to navigate eastward to Kurushima Kaikyo Traffic Route after crossing Line a should not cross Line b.

<North current>



<South current>



Source: MDA Situational Indication Linkages

* Image of navigation route for vessels navigating Aki Nada Minami Koro

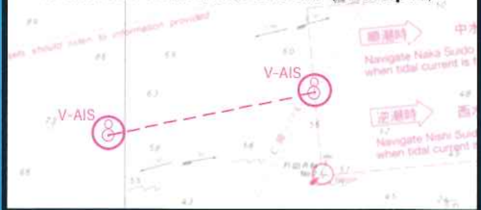
Indication of route ends

The route is indicated at the east end and west end by virtual AIS route markings. Actual light buoys are not installed.

V/KURUSHIMA-WEST-A 34-09-24 N 132-53-55 E
V/KURUSHIMA-WEST-B 34-09-37 N 132-55-05 E

<Radar screen (example)>

<Nautical chart indication (example)>



Request for vessels not equipped with AIS

Virtual AIS route markings utilize AIS signals to indicate route markings that do not physically exist as symbols on navigational radar and electronic nautical charts. Virtual AIS route markings are not indicated on vessels not equipped with AIS. Such vessels should check the route using the most recent nautical charts, and enter the positions into a GPS plotter or similar device.

Created March 2024