[MSI Report 2022-001]

Marine Safety Investigation Report

- Sinking of VLOC, Stellar Daisy -

Date of Accident: 31st March 2017

Date of Publication: 23rd June 2022

Korea Maritime Safety Tribunal
Marine Safety Investigation Team

Note

This marine safety investigation report aims to identify the causes of the marine accidents and prevent similar marine accidents or incidents in the future under Article 18.3 of the Act on the Investigation of and Inquiry into Marine Accidents. It is therefore advised that this report not be used for assigning blame or determining liability.

The names of the relevant acts and agencies described in this report were quoted at the time of its writing.

This investigation report was originally written in Korean, and was subsequently translated into English. In the event of any discrepancy between the two versions, the Korean text shall prevail.

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Executive Summary

1. Executive Summary

1.1 Stellar Daisy is a single-hulled very large crude oil carrier (VLCC) with 146,950 tons in gross tonnage, 264,165 tons in deadweight tonnage, 311.89 meters in length, 58.00 meters in breadth, and 29.50 meters in depth. She was built at the Mitsubishi Heavy Industries, Ltd. in Nagasaki, Japan. Her keel was laid on 23 July 1992.

1.2 Stellar Daisy was modified and converted into a very large ore carrier (VLOC) at COSCO Zhoushan Shipyard, in China, on 21 January 2009. After the conversion, her length, beam, and depth remained the same. However, the gross tonnage and the deadweight tonnage were increased to 148,431 tons and 266,141 tons, respectively due to structural changes of cargo hold hatches and an increase in the load line.

1.3 Stellar Daisy berthed at Guaiba Island Terminal (GIT) in Brazil and loaded 260,003 tons of iron ore fines from 08:25 (LT) on 23 March to 21:24 (LT) on 25 March 2017. The ship set sail for Qingdao in China at around 22:54 (LT) on the same day. There were 24 crewmembers onboard, including 8 Koreans and 16 Filipinos.

1.4 The Noon Report, written at 12:00 (LT) on 31 March 2017, was sent from the ship to the shipping company through the computer system at around 13:03 (LT) on the same day. At that time, the ship was reported to be sailing at about 11.09 knots on a course of about 110°. At around 13:05 (LT) on that day, the second officer (2/O) who was on watch sent a social media message to the superintendent with his business mobile asking about inspections of the ship's immersion suits.

1.5 At around 13:20 (LT), the superintendent received a social media message from the ship that said, "Emergency. The ship's No. 2 Port is leaking. The ship is rapidly inclining to port." The superintendent asked the ship to call via satellite phone but heard no response from the ship. At around 13:21 (LT) about one minute after the message was received, a distress signal of Stellar Daisy was received via INMARSAT-C Digital Selective Calling (DSC).

1.6 Later, the Marine Rescue Coordination Center Uruguay (MRCC Uruguay), who was in charge of the area where the accident occurred, requested adjacent vessels to assist in search and rescue operations. Then on 1 April, the two crewmembers, one able seaman A (AB A) and one No. 1 oiler, who had been on the liferaft, were rescued by M/V Elpida at around 12:50 (UTC[1)]). However, none of the other 22 crewmembers were ever found.

1.7 The surviving crewmembers stated they had felt strong vibrations and the ship had suddenly sunk as she had heeled to port rapidly. AB A said he had gone up to the bridge after hearing the master's announcement. However, he jumped into the sea from the port bridge wing as the ship inclined further to port and seawater was about to flood the bridge. The No. 1 oiler mentioned he had tried to launch the portside liferaft but the significant inclination prevented him from doing so. He was holding onto the handrails and washed overboard by huge wave.

1.8 Given the positions written in the Noon Report prior to the accident and indicated by INMARSAT-C DSC, Stellar Daisy is presumed to have sunk at a location of 34°23'S, 018°30'W, about 1,550 miles southeast of Santos, Brazil at around 14:21 (UTC) on 31 March 2017.

1.9 The results of the accident investigation suggest Stellar Daisy was gradually losing hull structural strength and fatigue strength over more than 24 years of operation. Under such condition, the asymmetric loads caused by asymmetric pressures (ASP) would have placed excessive stress on the lower shell plate where WBT No. 2 (P) was located, causing structural damage to the ship, and the seawater would have first entered the damaged area. Also, it is presumed that the transverse bulkheads collapsed due to an increasing heel angle, causing the flooding of WBT No. 2 (P) to expand onto other compartments, including WBT Nos. 3 and 4 (P), and that the ship ended up sinking.

1.10 Meanwhile, the Korean government ordered the deep-sea search operations to be conducted in the accident location to identify the hull location of Stellar Daisy and retrieve the ship's voyage data recorder (VDR), if possible, in February 2019. The results found out that the hull debris had been scattered into numerous pieces and were unidentifiable. Moreover, only tracking data were recovered from the retrieved VDR, leading to the conclusion that the data would be of limited utility for analyzing the causes of damage and sinking of the ship.

1) Coordinated Universal Time (UTC); the ship's time on Stellar Daisy conformed to UTC-01:00 when the accident occurred.

section

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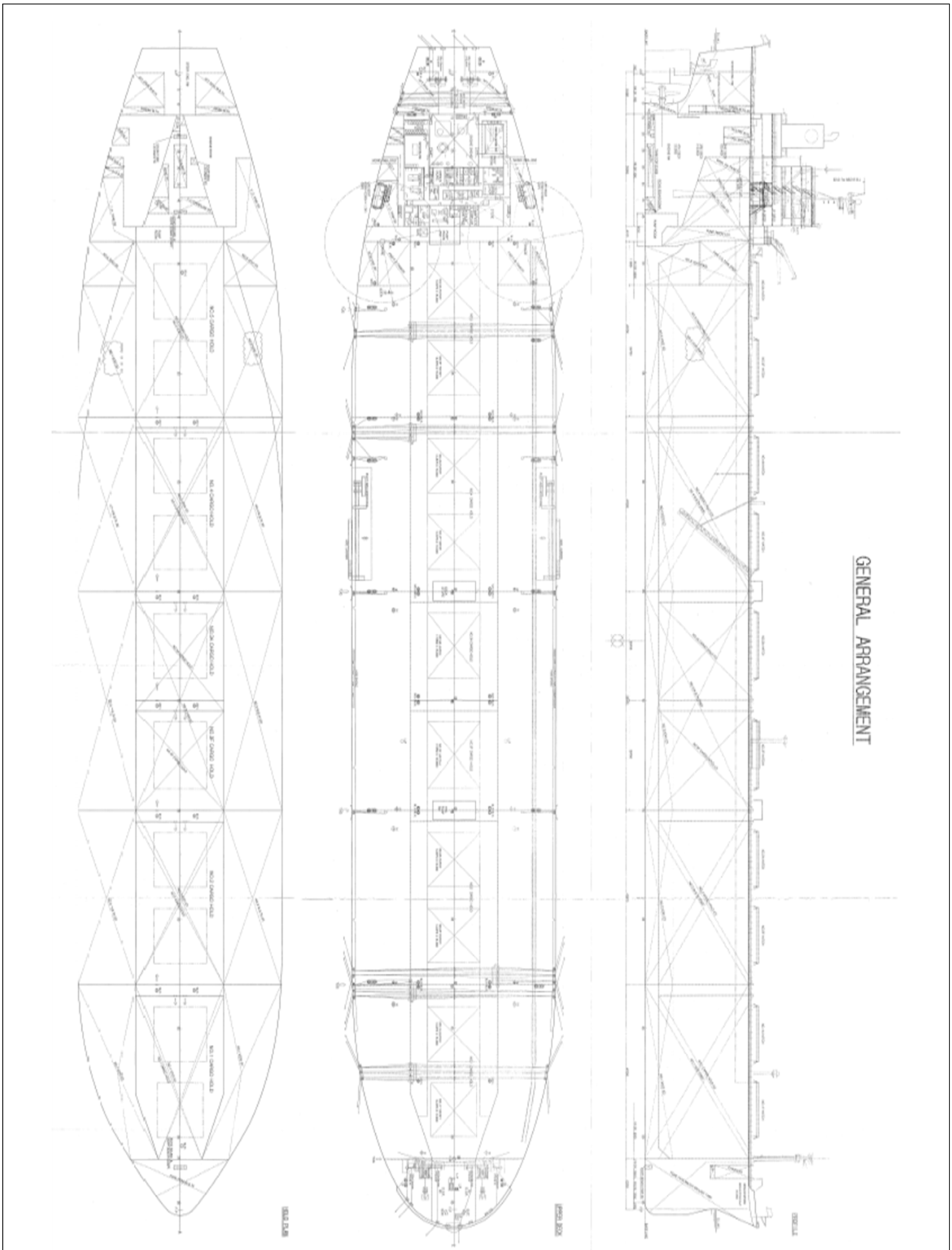
Findings of Fact

2. Findings of Fact

2.1 Principal particulars of Stellar Daisy

Ship Name	STELLAR DAISY
Flag State	Republic of the Marshall Islands (RMI)
Port of Registry	Port of Majuro
Call Sign	V7RD9
IMO No.	9038725
Ship Type	Very Large Ore Carrier (VLOC)
Owner / Operator	VP-14 Shipping Inc. / Polaris Shipping Co., Ltd.
Max. No. of Crew	30
Builder	Mitsubishi Heavy Industries, Ltd.
Date of Keel Lay / Date of Launch	23 Jul. 1992 / 25 Feb. 1993
Date of Conversion (Modification)	21 January 2009
Classification Society, Recognized Organization	Korean Register of Shipping (KR)
Length (m)	311.89
Beam (m)	58.00
Depth (m)	29.50
Gross Tonnage (t)	148,431
Deadweight Tonnage (t)	266,141
Summer Load Water Line (m)	20.327
Main Engine	1 unit of Mitsubishi UE Marine Diesel, "9UEC75LSII"
Max. Output	29,800HP × 76RPM
Propeller	1 (Screw-type propeller)
Rudder	1
Design Speed (Knots)	15.5



[Figure 1] General arrangement of Stellar Daisy

[Figure 2] Photo of Stellar Daisy

2.1.1 Stellar Daisy is a single-hulled VLCC with a gross tonnage of 146,950 tons, a deadweight tonnage of 264,165 tons, a length of 311.89 meters, a beam of 58.00 meters, and a depth of 29.50 meters. She was completed at the Mitsubishi Heavy Industries, Ltd. in Nagasaki, Japan. Her keel was laid on 23 July 1992.

2.1.2 Stellar Daisy was modified and converted from a VLCC to a VLOC on 21 January 2009. Due to structural changes of her cargo hold (C/H) hatches the gross tonnage increased to 148,431 tons while her length, beam, and depth remained the same. Also, the deadweight tonnage was increased to 266,141 tons as her load line was changed from 19.849 meters to 20.327 meters.[2)]

2.2 Ownership of Stellar Daisy

2.2.1 Polaris Shipping Co., Ltd. (hereinafter "Polaris Shipping") acquired Stellar Daisy having been operated as a VLCC by signing a charter party on 17 December 2007 in order to service her as a VLOC. On 21 December 2007, Stellar Daisy was registered in the Republic of Korea (ROK).

2.2.2 After completing conversion into an ore carrier, Stellar Daisy was owned by Stellar Ocean Shipping Limited and registered in the Republic of the Marshall Islands (RMI). Later, her ownership was again transferred to Daisy Maritime Ltd. on 22 January 2012 and then to V-14 Shipping Inc. on 27 July 2015.

2.2.3 Whenever her owner was changed in the documents, Polaris Shipping signed a bareboat charter with hire purchase (BBCHP)[3)] contract with the new owner and served as her practical owner. Polaris Shipping offered not just cargo booking, ship operations, including shipping to the port of loading and discharge, and safety management services, including ship surveys, repair, and ISM management, but also crew management, including recruitment and manning.

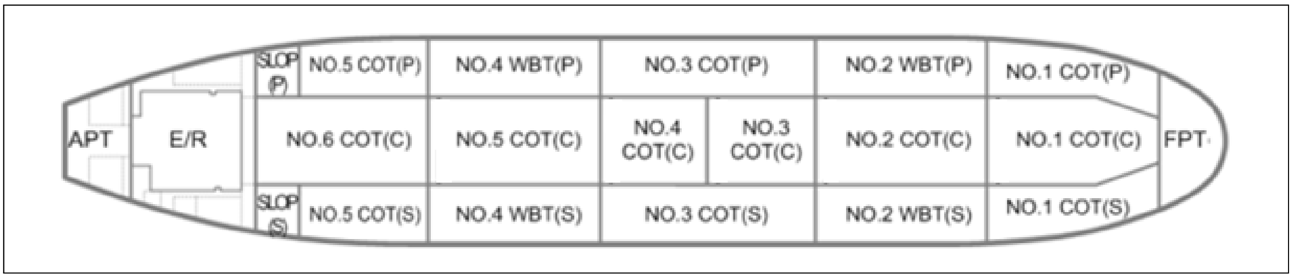
2) After conversion, Stellar Daisy's freeboard became 9.223 meters, satisfying the required minimum freeboard of 7.434 meters.

3) The term "bareboat charters with hire purchase" refers to an agreement by which the ships shall acquire the nationality of the ROK after expiry of the charter period and after full payment of chartering costs in Paragraph 18 of Article 2 of the Ship Safety Act of Korea.

2.3 Ship conversion

2.3.1 Ship structures before conversion

2.3.1.1 When built, Stellar Daisy was originally a single-hulled oil tanker, consisting of 6 cargo oil tanks (COTs) at the center, with 3 COTs and 2 water ballast tanks (WBTs) on both the port and starboard sides, built under the Rules and Guidance for the Survey and Construction of Steel Ships of the Japanese classification society, Nippon Kaiji Kyokai (ClassNK).



[Figure 3] Structure of Stellar Daisy when built

2.3.2 Application of the international conventions and regulations on conversion

2.3.2.1 Chapter II-1, Regulation 1.3 and Chapter II-2, Regulation 1.3 of the International Convention for the Safety of Life at Sea (SOLAS) stipulate that major repairs, alterations, and modifications shall meet the requirements applied to ships constructed on or after the date on which relevant regulations entered into force to the extent deemed reasonable and practicable by the Administration of the ship's flag state.

2.3.2.2 Stellar Daisy was classed by the Korean Register of Shipping (hereinafter "KR") on 19 December 2007, and she underwent conversion from a VLCC to a VLOC at COSCO Zhoushan Shipyard, China, from 22 July 2008 to 21 January 2009. While doing so, she gained a design approval under the 2007 Rules and Guidance for the Classification of Steel Ships published by KR. At that time, the Korean government, as a flag state, eased or exempted some parts of requirements specified in the international conventions[4], such as the Permanent Means of Access (PMA) and the Performance Standard for Protective Coatings (PSPC), which thereby were not applied[5] to the converted ore carrier.

4) Several requirements of the international conventions to be applied to newly built ships were relieved or exempted, as they were deemed infeasible or ineffective for old ship structures.

[Table 1] Requirements of the international conventions eased or exempted

Item	SOLAS Regulation	Date of Application	SOLAS Application	Date of Exemption
Permanent Means of Access (PMA)	II-1 Reg.3-6 (SOLAS 04Amend)	Ships built on or after 1 Jan. 2006	Exempted	2007/09/27
Performance Standard for Protective Coatings (PSPC)	II-1 Reg.3-2 (SOLAS 06Amend)	Ships built on or after 1 Jul. 2008	Exempted	2008/04/18
Enhancing the strength of lower parts of the towing and mooring equipment	II-1 Reg.3-8 (SOLAS 05Amend)	Ships built on or after 1 Jan. 2007	Applied to the parts replaced or newly built.	2008/04/18
Installing fuel oil service tanks and fittings to prevent the ingress of rainwater	II-1 Reg.26.11 (SOLAS 96Amend)	Ships built on or after 1 Jul. 1998	Installing service fuel tanks was exempted while installing fittings to prevent the ingress of rainwater was applied.	2008/04/18
Duplicating electrical power supply systems	II-1 Reg.41.4 (SOLAS 96Amend)	Ships built on or after 1 Jul. 1998	Exempted	2008/04/18
Prohibiting the use of halon extinguishing systems	II-2 Reg.10.4.1 (SOLAS 00Amend)	Ships built on or after 1 Jul. 2002	The use of halon extinguishing systems was permitted until their replacement.	2008/04/18
Installation of fixed local application firefighting systems in the engine room	II-2 Reg.10.5.6 (SOLAS 00Amend)	Ships built on or after 1 Jul. 2002	Exempted	2008/04/18
Voyage Data Recorders (VDR)	V Reg.20 (SOLAS 99/00Amend)	Ships built on or after 1 Jul. 2002	The existing simplified voyage data recorders (S-VDR) are accepted.	2008/04/18
Securing navigation bridge visibility	V Reg.22 (SOLAS 96Amend)	Ships built on or after 1 Jul. 1998	The existing ship conditions may be accepted if the ship had met the requirements when sailing on ballast before conversion.	2008/04/18

5) The Maritime Safety Committee (MSC) at its 89th session (11-20 May 2011) and the Marine Environment Protection Committee (MEPC) at its 62nd session (11-15 Jul. 2011) approved the unified interpretations on the application of SOLAS, MARPOL and Load Lines requirements, with the exception of PMA and PSPC, to conversions of single-hulled oil tankers to double-hulled oil tankers or bulk carriers occurring on or after 1 December 2011 (MSC-MEPC.2/Circ.10).

2.3.2.3 Also, SOLAS regulation XII/5[6] was newly applied to the ship as she had been converted from a crude oil carrier to an ore carrier. Therefore, C/H No. 1 underwent a review on whether it had sufficient strength to prevent the hold from being flooded, and the results showed that its longitudinal strength and double-bottom structural strength met the requirements.

2.3.3 Conversion and changes of the hull members

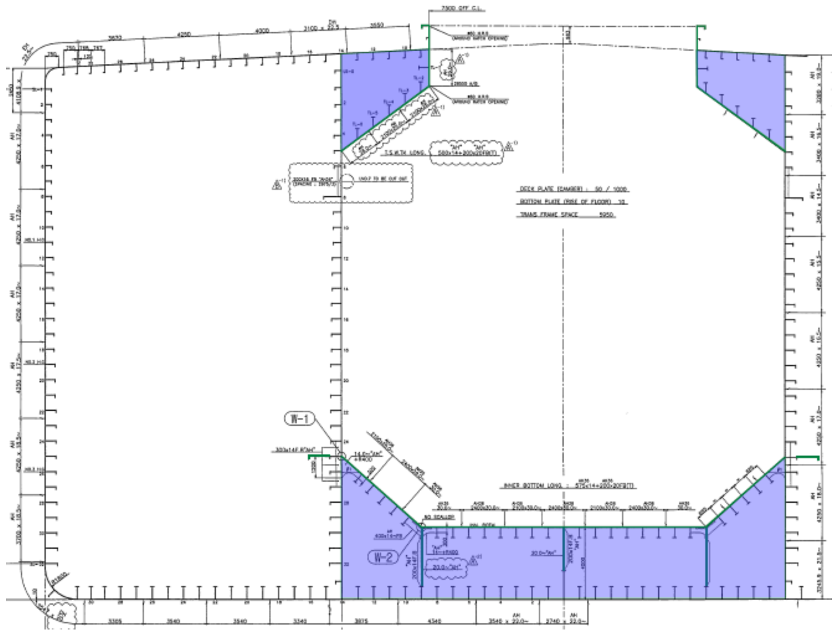
2.3.3.1 Stellar Daisy had undergone conversion to change and build major structures and hull members for conversion at COSCO Zhoushan Shipyard in China from 22 July 2008 to 21 January 2009.

2.3.3.2 Parts of hull structures and members to be changed were determined based on the analysis of cargo hold structure conducted by Joong Ang Ship Technology Ltd. In the analysis, design thickness(shown on the drawing), including corrosion additions, was used for the scantlings of the hull members. Based on the analysis, massive construction work commenced: installing inner bottoms and hopper structures; installing topside structures of cargo holds; installing support bulkheads to reinforce transverse strength; installing intermediate web frames in wing tanks; and reinforcing cross ties.

2.3.3.3 The inner bottoms and hoppers[7] were installed at the bottom of C/H Nos. 1-5 so that the holds could accommodate iron ore with a higher unit weight than crude oil. At the same time, hatch covers, coamings, and the topside structures were built on the upper side of the holds.

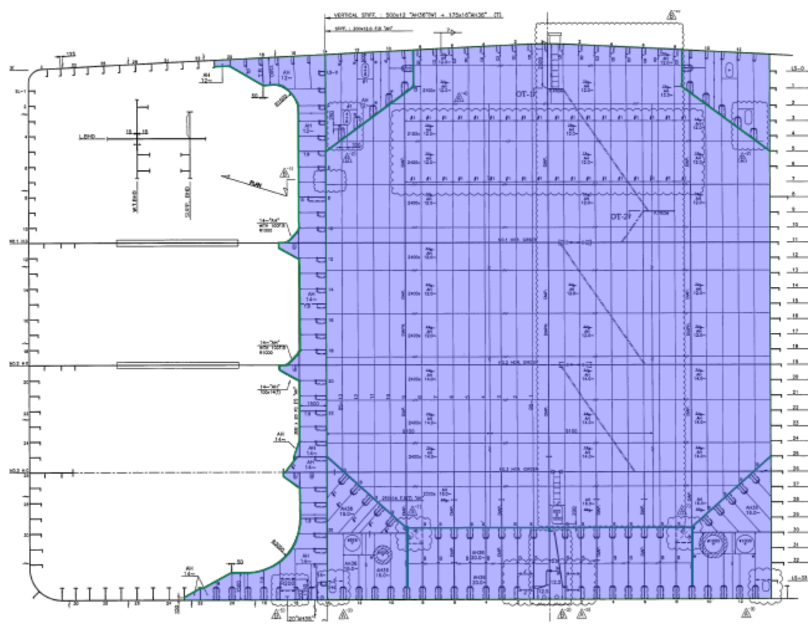
6) SOLAS XII/5 Structural strength of bulk carriers:
1. Bulk carriers of 150m in length and upwards of single-side skin construction, designed to carry solid bulk cargoes having a density of 1,000 kg/㎥ and above constructed on or after 1 July 1999, shall have sufficient strength to withstand flooding of any one cargo hold to the water level outside the ship in that flooded condition in all loading and ballast conditions.
2. Bulk carriers of 150 m in length and upwards of double-side skin construction, in which any part of longitudinal bulkhead is located within B/5 or 11.5 m, whichever is less, inboard from the ship's side at right angle to the centerline at the assigned summer load line, designed to carry bulk cargoes having a density of 1,000 kg/㎥ and above constructed on or after 1 July 2006, shall comply with the structural strength provisions of Paragraph 1.

7) The renewed or reinforced areas are shaded blue from [Figure 4] to [Figure 8].



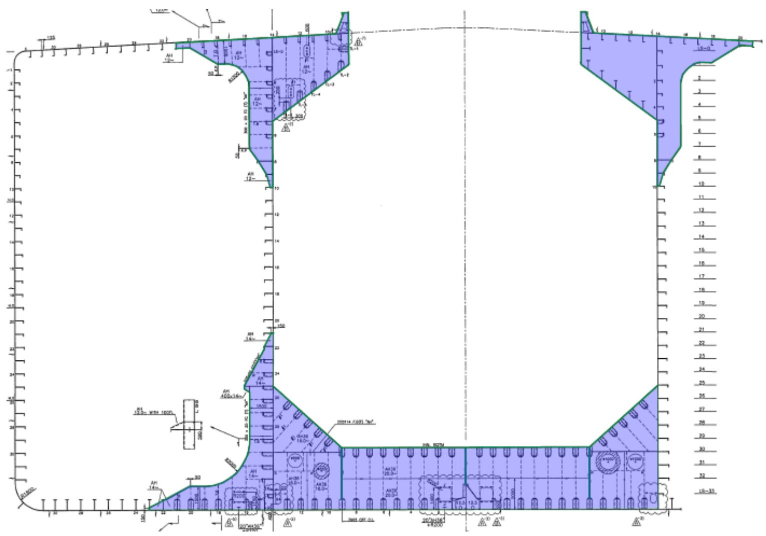
[Figure 4] C/H section after conversion, such as installation of inner bottoms

2.3.3.4 Support bulkheads were constructed to reinforce the transverse strength of frame Nos. 57.5 (between C/H Nos. 4 and 5), 65.5 (between C/H Nos. 3A and 4), 70.5 (between C/H Nos. 3F and 3A), 75.5 (between C/H Nos. 2 and 3F), and 83.5 (between C/H Nos. 1 and 2), located between C/H Nos. 1–5.



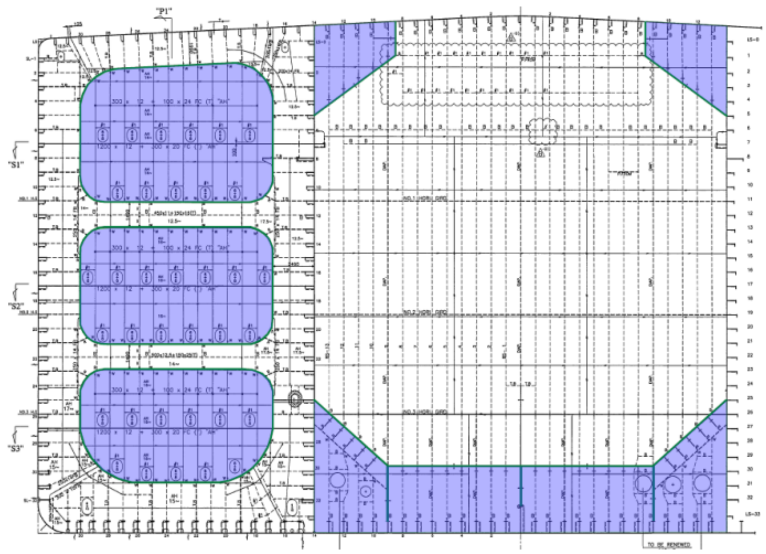
[Figure 5] Support bulkhead

2.3.3.5 The lower and upper intermediate web frames were newly installed on the existing wing tanks.



[Figure 6] Intermediate web frames

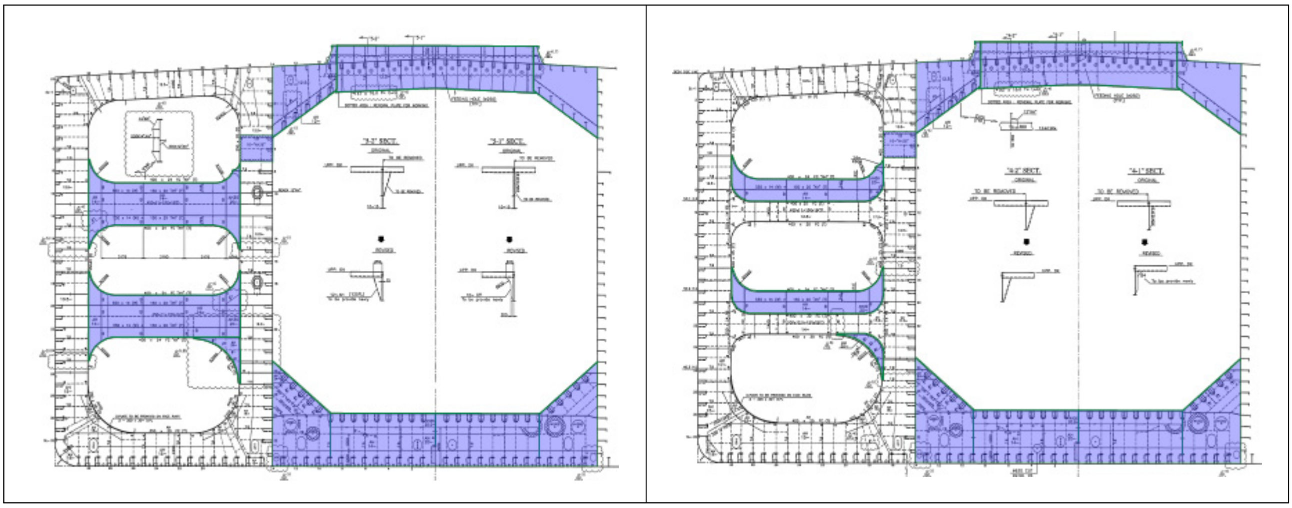
2.3.3.6 Wing tank Nos. 2, 3, and 4 needed more transverse strength, so swash bulkheads[8] were constructed at frame Nos. 61, 70, and 79 and partial swash bulkheads at frame Nos. 67 and 72.



[Figure 7] FR. 70 watertight bulkhead

8) It is a bulkhead installed in a ballast tank aboard a ship to control excessive movement of seawater inside.

2.3.3.7 Cross ties were either installed or reinforced across the web frames in the wing tanks. Therefore, entire web frames were reinforced with either cross ties, swash bulkheads or partial swash bulkheads.



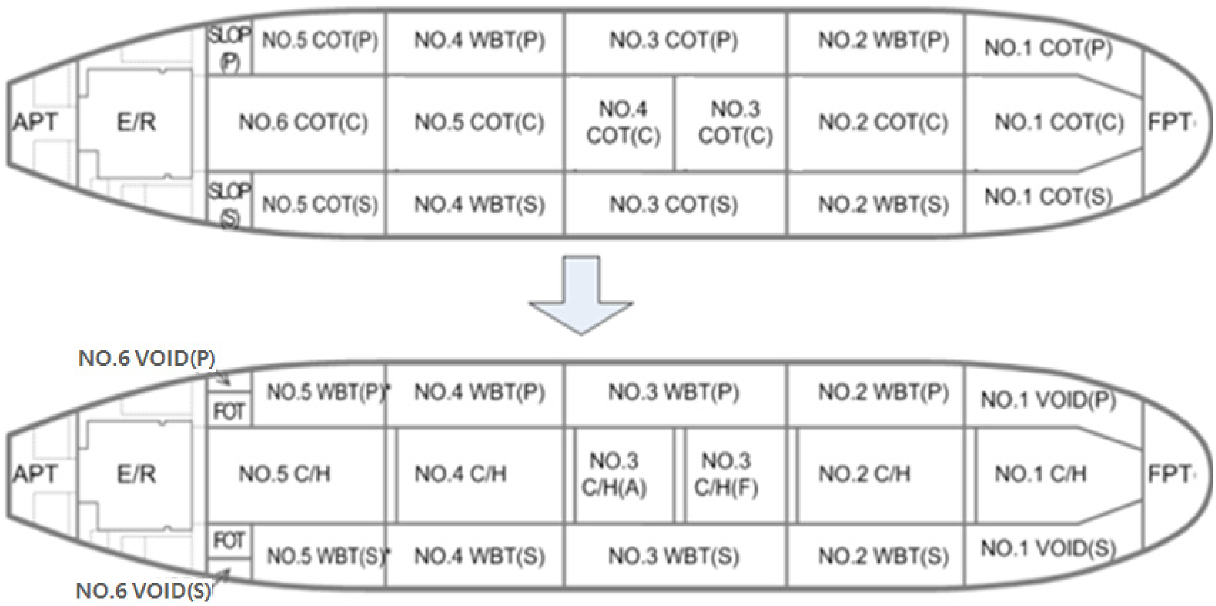
[Figure 8] Transverse section adjacent to oil-tight bulkhead

2.3.4 Major changes of the hull compartments

2.3.4.1 COT Nos. 1-6, located at the center, were reconfigured into C/H Nos. 1, 2, 3F (fore), 3A (aft), 4, and 5.

2.3.4.2 COT No. 1 (P/S) were converted into void tank (VT) No. 1 (P/S), while COT Nos. 3 and 5 (P/S) were each converted into WBT Nos. 3 and 5 (P/S). At the same time, the port and starboard slop tanks were changed into VT No. 6 (P/S) and fuel oil tanks (FOTs). WBT Nos. 2 and 4 (P/S) remained the same after conversion.

2.3.4.3 Converted C/H Nos. 1-5 and WBT Nos. 2-5 (P/S) were hard coated.



* WBT No. 5 (P/S) were converted into void tanks on 26 April 2011.
* Support bulkheads were installed in C/H Nos. 1-4 as described in Chapter 2.3.3.4.

[Figure 9] Conversion of hull compartments

2.3.4.4 The capacity of both the WBTs and cargo holds after the conversion are as shown in [Table 2]:

[Table 2] Capacity of WBTs and C/Hs after conversion

Item	Frame No.	Capacity (㎥)	Item	Frame No.	Capacity (㎥)
FPT (C)	91-FE	7,845.0	C/H No. 1	83½-91	25,104.4
WBT No. 2 (S)	75-83	23,493.9	C/H No. 2	75½-83	27,315.6
WBT No. 2 (P)	75-83	23,493.9	C/H No. 3F	70½-75	16,389.3
WBT No. 3 (S)	65-75	29,332.5	C/H No. 3A	65½-70	16,389.3
WBT No. 3 (P)	65-75	29,332.5	C/H No. 4	57½-65	27,315.8
WBT No. 4 (S)	57-65	23,150.3	C/H No. 5	49½-57	28,524.3
WBT No. 4 (P)	57-65	23,150.3	FWD FOT (S)	49-51	1,637.5
WBT No. 5 (S)	51-57	14,626.8	FWD FOT (P)	49-51	1,637.5
WBT No. 5 (P)	51-57	14,626.8	FOT (S)	34-49½	2,280.4
APT (C)	AE-14	3,194.2	FOT (P)	27-49½	2,528.4

2.4 Ship surveys

2.4.1 Stellar Daisy passed the first special survey after the conversion work was completed on 21 January 2009. The ship also passed subsequent special surveys, including annual and intermediate surveys conducted under the KR rules every year. Therefore, she was h2018 at the time of the accident.

2.4.2 Apart from periodical surveys, ships shall be subject to an occasional survey in any of the following cases: where the hull or the engine undergoes major damage, repairs or modifications on voyage; where details entered in a ship survey certificate are changed; or where the shipowner applies for occasional surveys. Stellar Daisy underwent a total of four occasional surveys after the conversion.

2.4.3 The first occasional survey was conducted when the flag state of Stellar Daisy was changed from the ROK to the RMI on 22 January 2009. The ship completed the second one at Gwangyang Port in Korea on 15 June 2012 and the third one at the Zhejiang Eastern Shipyard in Zhoushan, China on 5 July 2012, while repairing damaged areas after contacting a pier[9]. The last occasional survey was also conducted at the Zhejiang Eastern Shipyard, China on 25 August 2016 during repairs to the hull damages[10], which had been identified during the previous annual survey.

2.4.4 The following [Table 3] shows the history of surveys Stellar Daisy has received since she had been classed by KR.

9) When berthing at a pier for raw materials at Gwangyang Port in Korea on 11 June 2012, she contacted the pier, resulting in damage to the deck plating, deck, and deck store on the starboard bow.

10) Deformation of the aft bulkhead stiffener was identified inside WBT No. 3 (P/S).

[Table 3] Ship survey history

No.	Survey Type	Survey Date	No.	Survey Type	Survey Date
1	Classification Survey After Construction	2007/12/19	9	Occasional Survey	2012/06/18-2012/07/05
2	Alteration and Special Surveys	2008/05/20-2009/01/21	10	Annual Survey, Special Survey (commenced)	2012/06/16-2012/07/06
3	Occasional Survey	2009/01/22	11	Special Survey (completed)	2013/04/02-2013/04/04
4	Annual Survey	2009/07/02-2009/07/03	12	Annual Survey	2014/07/28-2014/07/29
5	Annual Survey	2010/07/19-2010/07/21	13	Intermediate Survey (commenced)	2015/05/09-2015/05/12
6	Intermediate Survey (commenced)	2011/06/28-2011/07/02	14	Intermediate Survey (completed)	2015/05/15-2015/05/24
7	Intermediate Survey (completed)	2011/07/04-2011/07/13	15	Annual Survey	2016/08/11-2016/08/12
8	Occasional Survey	2012/06/14-2012/06/15	16	Occasional Survey	2016/08/16-2016/08/25

2.5 Radio and safety equipment

2.5.1 Stellar Daisy had inside the bridge two VHF radios, one MF/HF radio, one NAVTEX receiver, one INMARSAT-C terminal, two search-and-rescue transponders (SARTs), and three 2-way VHF radio-telephones. In addition, one emergency position-indicating radio beacon (EPIRB) was installed outside the bridge, on the port side.

2.5.2 At the time of the accident, the vessels operated by Polaris Shipping were able to communicate wirelessly; each vessel was allotted 4 gigabytes (GB) of data capacity monthly through the FleetBroadband satellite network. The same data package had been provided to Stellar Daisy: the ship was able to communicate with her operator via computer network, mobile phone[11], or fax machine for business purposes within the monthly data limit of 4 GB. The crew was also allowed to use their personal mobile phones within this data limit.

11) When the accident occurred, Stellar Daisy was equipped with one business mobile phone through which the crew usually communicated with the operator by sending messages on Kakao Talk.

2.5.3 Stellar Daisy underwent a safety radio survey on 12 August 2016, holding a Safety Radio Certificate valid through 15 June 2018.

2.5.4 Lifesaving appliances[12] on board Stellar Daisy include one totally-enclosed, 30-person lifeboat as well as two inflatable 16-person liferafts with a hydrostatic release unit (HRU) each at the port and starboard stern on the upper deck of the crew quarters, while one inflatable 6-person liferaft which is not required to be fitted with an HRU was placed on the bow deck. In addition, 40 life jackets, 40 immersion suits[13], and 14 life buoys were available for the crew to use.

2.5.5 The Simplified Voyage Data Recorder (S-VDR)[14] was additionally installed on Stellar Daisy during the conversion work. The S-VDR is a JCY-1850 model manufactured by Japan Radio Company (JRC), which records the conversations on the bridge, VHF communications, images from the radar, and other information given by various sensors[15] in both the recording unit inside its main body on the bridge and the protective capsule[16] on the compass deck. The protective capsule was designed to withstand deep-sea pressures at up to 6,000 meters for 24 hours while the main body had no specific features[17] against high water pressure.

2.5.6 KR conducted a safety equipment survey covering the lifesaving appliances and VDR of the ship on 12 August 2016, issuing Stellar Daisy with a Safety Equipment Certificate valid till 15 June 2018.

12) Ships, other than passenger ships, of 500 gross tonnage and upwards engaged on international voyages shall be provided with enough lifeboats and liferafts on each side to accommodate the number of maximum passengers aboard. And, one more liferaft shall be placed forward if they are distanced more than 100m to the bow.

13) The same number of life jackets and immersion suits as the maximum passengers aboard shall be provided. And, considering watchkeeping or operation locations, additional portion shall be needed.

14) In accordance with SOLAS regulation V/20 and Article 108.7.3 of the Ship Appliance Standards (Public Notification of the Ministry of Oceans and Fisheries (MOF) of Korea), ships of 3,000 gross tonnage and upwards constructed before 1 July 2002 may be fitted with an S-VDR.

15) GPS, Speed Log, Gyro Compass, AIS, etc.

16) The protective capsule of JCY-1850 is an NDH-317 model, manufactured by L3Harris Technologies Inc.

17) SOLAS and the Ship Appliance Standards (Public Notification of the MOF) require deep-sea flooding tests for a protective capsule, but not for a main body.

2.6 Crew on board

2.6.1 Stellar Daisy may accommodate up to 30 persons on board under the ship survey certificate and a minimum of 16 persons under the safe manning certificate. At the time of the accident, 24 crewmembers were on board as specified by rank in [Table 4].

[Table 4] Crew composition

Rank	Min. No. of Manning	Crew on board	Rank	Min. No. of Manning	Crew on board
Master	1	1	Chief Engineer	1	1
Chief Officer	1	1	1st Engineer	1	1
2nd Officer	1	1	2nd Engineer	1	1
3rd Officer	1	1	3rd Engineer	1	2
Deck Ratings	5	5	Engine Ratings	3	6
Cook	-	2	Cadet	-	2

2.6.2 Among Stellar Daisy's 24 crewmembers, there were 8 Koreans, including the master, the chief officer (C/O), the second officer (2/O), the third officer (3/O), the first engineer (1/E), the second engineer (2/E), and one of the two third engineers (3/E); and 16 Filipinos, including the other 3/E, five deck ratings, 6 engine ratings, and two cadets. They communicated mainly in English on board.

2.6.3 The master of Stellar Daisy, who was on board the ship on 21 February 2017, was certified as a first class deck officer . Before joining Stellar Daisy, he had been working as the master for about six years and nine months, and he had worked on ore carriers as the C/O for about ten months.

2.6.4 Stellar Daisy C/O also held a first class deck officer certificate and joined Stellar Daisy on 1 November 2016. Prior to boarding this ship, he had served as the C/O for about five years and four months on other vessels, but this was his first time on an ore carrier.

2.7 Sailing after conversion

2.7.1 Polaris Shipping received its first registration certificate as a provider of overseas cargo transportation services from the Ministry of Oceans and Fisheries (MOF) of Korea on 15 December 2005.

2.7.2 After completing conversion of Stellar Daisy, Polaris Shipping signed a consecutive voyage charter (CVC) with the shipper, POSCO, under which the company had put the converted ship into the services carrying iron ore from Brazil, the Republic of South Africa, or Australia to Gwangyang and Pohang in Korea since 28 February 2009.

2.7.3 Later, the company signed another CVC with Vale S.A., a Brazilian iron ore producer, for a contract period from 28 February 2014 to 30 June 2023 and deployed Stellar Daisy to a route from Tubarao, Ponta Da Madeira (PDM), and Guaiba Island Terminal (GIT) in Brazil to China.

2.7.4 The following [Table 5] lists the 37 voyages, including 4 dry docking of Stellar Daisy post-conversion. In most voyages, the ship had one discharge port where all the cargo was offloaded. However, during eight voyages (voy. Nos 23, 25, 26, 30, 31, 33, 37, and 40), the ship was assigned with two discharge ports. In such cases, the ship offloaded part of the cargo at one port and the rest at a second port.

[Table 5] Voyages after conversion

No.	Loaded Cargo	Port of Loading	Duration	Port of Discharge	Duration
V.4	253,531 MT	Ponta Da Madeira	2009/02/28-2009/03/06	Gwangyang Port	2009/04/13-2009/04/17
V.5	253,618 MT	Ponta Da Madeira	2009/05/19-2009/05/23	Gwangyang Port	2009/06/29-2009/07/04
V.6	251,889 MT	Saldanha Bay	2009/08/02-2009/08/08	Gwangyang Port	2009/09/02-2009/09/08
V.7	253,249 MT	Ponta Da Madeira	2009/10/11-2009/10/22	Gwangyang Port	2009/11/28-2009/12/11
V.8	221,415 MT	Port Walcott	2009/12/20-2009/12/23	Gwangyang Port	2010/01/03-2010/01/07
V.9	252,637 MT	Ponta Da Madeira	2010/02/18-2010/02/23	Gwangyang Port	2010/04/02-2010/04/11

No.	Loaded Cargo	Port of Loading	Duration	Port of Discharge	Duration
V.10	256,514 MT	Ponta Da Madeira	2010/05/14-2010/05/31	Gwangyang Port	2010/07/08-2010/07/24
V.11	256,627 MT	Ponta Da Madeira	2010/08/30-2010/09/13	Gwangyang Port	2010/10/29-2010/11/08
V.12	258,772 MT	Ponta Da Madeira	2010/12/13-2010/12/24	Gwangyang Port	2011/02/02-2011/02/09
V.13	257,172 MT	Tubarao	2011/03/16-2011/04/07	Gwangyang Port	2011/05/17-2011/05/21
V.14	222,670 MT	Port Walcott	2011/06/02-2011/06/12	Gwangyang Port	2011/06/24-2011/06/29
V.15	Dry docking				
V.16	255,437 MT	Ponta Da Madeira	2011/08/18-2011/08/27	Gwangyang Port	2011/10/06-2011/10/15
V.17	252,365 MT	Tubarao	2011/11/19-2011/11/21	Gwangyang Port	2012/01/01-2012/01/09
V.18	250,641 MT	Tubarao	2012/02/14-2012/03/01	Gwangyang Port	2012/04/11-2012/04/14
V.19	252,317 MT	Saldanha Bay	2012/05/09-2012/05/13	Gwangyang Port	2012/06/10-2012/06/16
V.20	Dry docking				
V.21	251,283 MT	Saldanha Bay	2012/08/03-2012/08/14	Gwangyang Port	2012/09/11-2012/09/28
V.22	252,270 MT	Tubarao	2012/11/02-2012/11/06	Gwangyang Port	2012/12/15-2012/12/21
V.23	253,012 MT	Ponta Da Madeira	2013/01/28-2013/02/16	Gwangyang Port, Pohang Port	2013/03/31-2013/04/10
V.24	252,317 MT	Tubarao	2013/05/15-2013/05/26	Gwangyang Port	2013/07/04-2013/07/09
V.25	258,507 MT	Ponta Da Madeira	2013/08/16-2013/08/21	Gwangyang Port, Pohang Port	2013/10/04-2013/10/08
V.26	259,173 MT	Ponta Da Madeira	2013/11/18-2013/12/01	Gwangyang Port, Pohang Port	2014/01/13-2014/01/26
V.27	260,316 MT	Ponta Da Madeira	2014/03/04-2014/03/17	Gwangyang Port	2014/04/28-2014/05/04
V.28	226,611 MT	Tubarao	2014/06/09-2014/06/15	Pohang Port	2014/07/24-2014/07/30
V.29	227,417 MT	Ponta Da Madeira	2014/09/07-2014/09/09	Pohang Port	2014/10/25-2014/11/01
V.30	259,800 MT	Ponta Da Madeira	2014/12/09-2014/12/21	Majishan, Qingdao	2015/02/01-2015/02/08
V.31	260,027 MT	Tubarao	2015/03/18-2015/03/22	Majishan, Rizhao	2015/05/02-2015/05/11

No.	Loaded Cargo	Port of Loading	Duration	Port of Discharge	Duration
V.32	Dry docking				
V.33	259,916 MT	Ponta Da Madeira	2015/07/03-2015/07/10	Majishan, Lianyungang	2015/08/22-2015/08/31
V.34	260,057 MT	Ponta Da Madeira	2015/10/08-2015/10/14	Lianyungang	2015/11/27-2015/12/01
V.35	260,009 MT	Ponta Da Madeira	2016/01/07-2016/01/11	Lianyungang	2016/02/22-2016/03/02
V.36	260,000MT	Tubarao	2016/04/04-2016/04/11	Lumut	2016/05/08-2016/05/24
V.37	258,327 MT	Guaiba	2016/06/21-2016/06/27	Lianyungang, Rizhao	2016/08/05-2016/08/13
V.38	Dry docking				
V.39	260,009 MT	Ponta Da Madeira	2016/10/01-2016/10/08	Lumut	2016/11/11-2016/11/20
V.40	260,002 MT	Guaiba	2016/12/19-2016/12/25	Tianjin, Caofeidian	2017/02/05-2017/02/13
V.41	260,003 MT	Guaiba	2017/03/22-2017/03/26		

2.8 Safety management system (SMS)

2.8.1 Establishment and certification of SMS

2.8.1.1 In compliance with the International Safety Management (ISM) Code and SOLAS Chapter IX, ships engaged in international voyages and their operating companies shall establish and implement the safety management system (SMS).

2.8.1.2 Polaris Shipping set and implemented the SMS for a total of 28 ships, including Stellar Daisy. The ship passed the audit of KR, a recognized organization (RO), for a certificate renewal on 11 December 2013 and she received a document of compliance (DOC) valid until 3 February 2019.

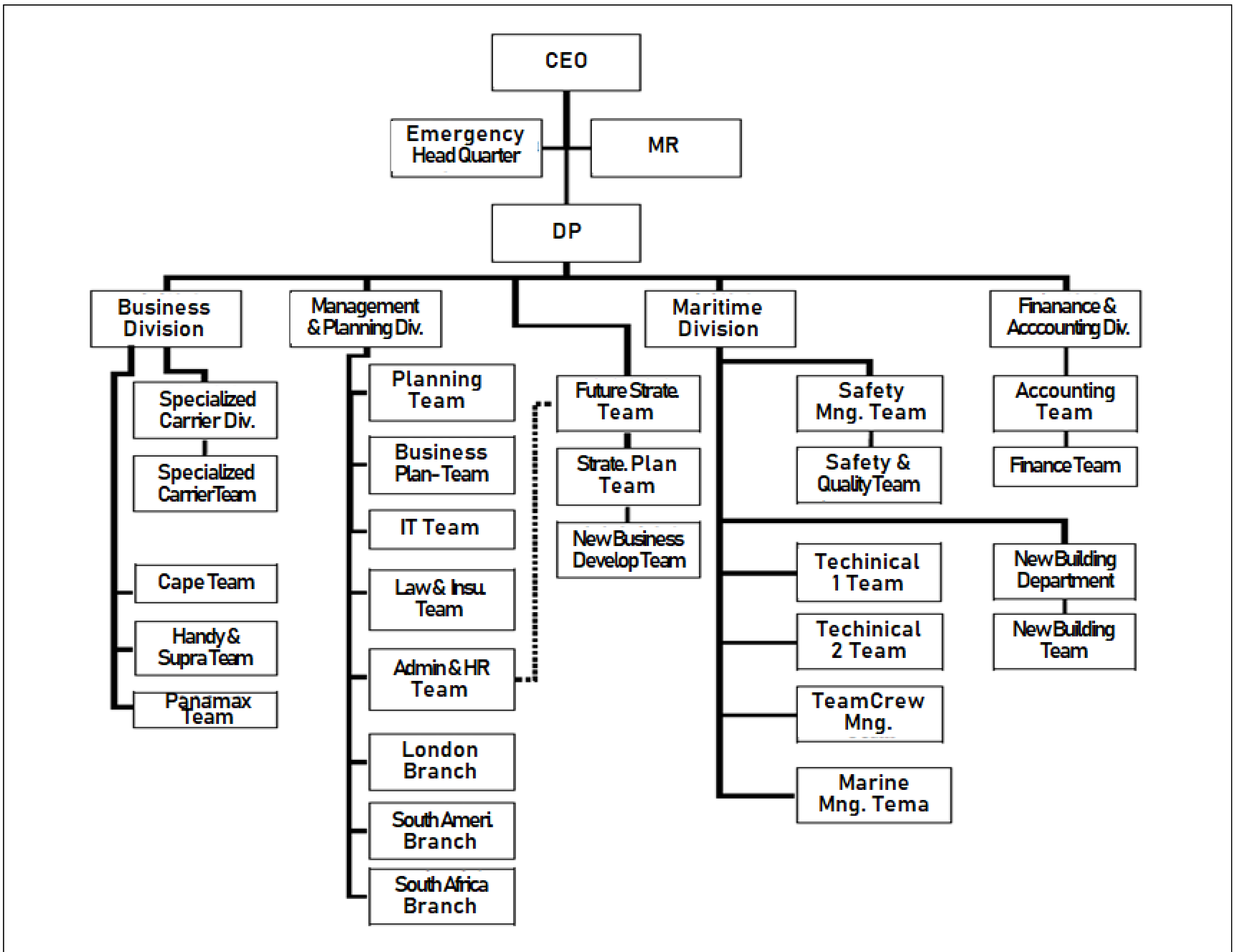
2.8.1.3 Stellar Daisy undertook an audit for interim certification on 22 January 2009 and passed the audit for initial certification on 1 July 2009 and for certification renewal on 30 April 2014, holding a safety management certificate (SMC) valid till 30 June 2019. [Table 6] lists SMS certification audits after conversion.

[Table 6] SMS certification audits

No.	Audit Type	Date of Audit	No.	Audit Type	Date of Audit
1	Interim	2009/01/22	4	Renewal	2014/04/30
2	Initial	2009/07/01	5	Intermediate	2017/02/07
3	Intermediate	2012/04/13			

2.8.2 Safety · Quality · Environment · Health Management System (SQEHM)

2.8.2.1 Polaris Shipping has located in Seoul and its branch office in Busan, Korea. The Seoul head office has the Business Division, the Management & Planning Division, the Future Strategy Office, and the Finance & Accounting Division, while the Maritime Division was located in Busan as of 2017.



[Figure 10] Organization chart of Polaris Shipping at the time of the accident

2.8.2.2 The company's designated person (DP) responsible for safe ship operation is authorized to directly submit regular and irregular reports to the chief executive officer (CEO) on business activities related to status of safety, environment, and quality issues, ensuring seamless communication between ship and shore offices or among departments and teams within the organization.

2.8.2.3 The master is authorized and responsible for managing ship operations, making the best decisions for the ship's safety and environmental protection on behalf of the company, and if necessary, asking shore personnel for support.

2.8.2.4 The Crew Management Team designs education and training procedures for all personnel onboard ships owned or managed by Polaris Shipping. The team conducts training on safe ship operation, cargo management, and emergency procedures by ship type.

2.8.2.5 Polaris Shipping directly manages recruitment, promotion, and manning of Korean crewmembers under its procedures for onboard personnel management. However, foreign nationals are on board under the crew management agreement between Polaris Shipping and crew management companies. When Polaris Shipping provides the crew management companies with information, including the name of a ship to be on board, ranks, and estimated date of boarding, the companies send Polaris Shipping the candidate list to be on board. After the Crew Management Team reviews their qualification, those who are qualified can be finally on board the ship.

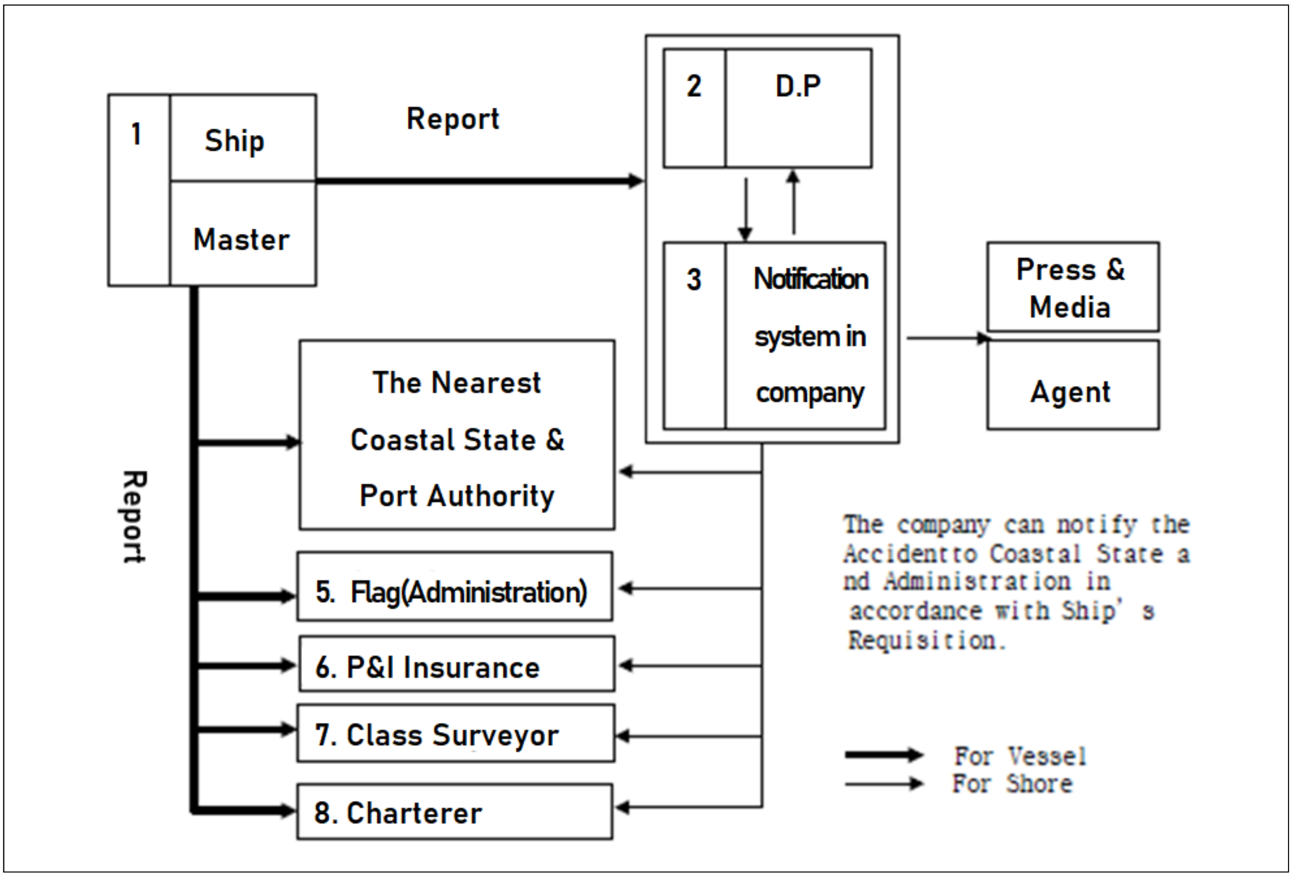
2.8.2.6 The Technical Team reviews the quarterly Master's Report and Hull Inspection Reports that were made on hull and engine conditions by a ship. If any ship cannot make the necessary repairs on its own, the team helps to get them repaired onshore.

2.8.2.7 To request on-shore repair, the ship must send an application form that is first reviewed by the C/E and then approved by the master to the technical superintendent at least 7 days before her port of entry. If urgent, the ship can consult with the technical superintendent and take steps forward.

2.8.2.8 The Business Division oversees cargo management, performing such tasks as providing appropriate cargo information for the ship and reviewing loading/offloading plans prepared by the ship so that the cargo can be handled and transported safely.

2.8.2.9 If strong wind such as Beaufort Wind Scale 8 or above threatens to damage a ship as well as her cargo. The master of the ship is to check the weather conditions and either alter the course, slow the ship down, or take deviation if necessary. The master is also required to notify it to the Safety Management Department and Business Division.

2.8.2.10 In an emergency, the master must inform the DP and the relevant agencies of the situation, and the DP has to report it to the head of the Maritime Division and the CEO so that the "Emergency Head Quarter" convenes. Each team of the company maintains a 24-hour response.



[Figure 11] Emergency reporting system of Polaris Shipping at the time of the accident

2.9 Major repairs and surveys after conversion

2.9.1 Intermediate survey: dry docking in July 2011

2.9.1.1 After conversion, Stellar Daisy received her first intermediate survey, including riding and floating surveys conducted from 28 June to 2 July 2011; and a dry dock survey conducted at the COSCO Zhoushan Shipyard in China from 4 to 13 July 2011. While in dry dock, the ship underwent a close-up examination and thickness measurements on all ballast tanks and cargo holds, VT Nos. 1 and 6 (P/S), and center VT Nos. 1-4. The surveys were conducted in accordance with the applicable rules of KR.

2.9.1.2 Neither the close-up survey nor the thickness measurements found defects that did not conform to the KR rules. The coating conditions of WBT No. 3 (P/S) were evaluated as "Poor[18]" while those of WBT Nos. 2 and 4 (P/S) as "Fair[19]."

2.9.1.3 [Table 7] lists major steel materials repaired during the dry dock survey.

[Table 7] Major steel materials repaired in dry dock in Jul. 2011

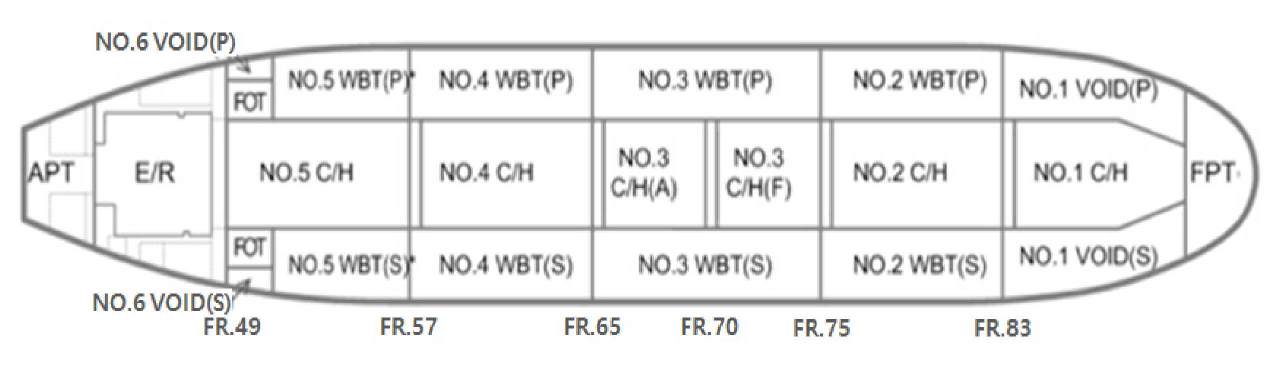
Area	Frame No.	Repaired Area	Remarks
WBT No. 2 (P)	FR. 75	• A double plate (D/P) around a slot hole on hori. girder No. 1 which vertical stiffener[20] No. 18 passes through • A D/P around a slot hole on hori. girder No. 2 which vertical stiffener No. 22 passes through	Renewed the deformed or cracked areas
	FR. 82	• A side web frame between side shell longi. Nos. 3-4 • A side web frame and a longi. between side shell longi. Nos. 7-8	
	FR. 82, 83	• Side shell longi. Nos. 3-4	

18) "Poor" means general film breakdown of 20% or more, or heavy rusting on 10% or more of the areas under consideration, which requires consistent observation at the next survey.

19) "Fair" means local film breakdown or light rusting on 20% or more of the areas under consideration, except in cases where the area is already evaluated as poor.

20) A vertical stiffener is a small or secondary beam-type member, such as a stiffener attached to a primary member.

Area	Frame No.	Repaired Area	Remarks
WBT No. 2 (S)	FR. 75	• A D/P around a slot hole on hori. girder No. 1 which vertical stiffener No. 22 passes through • A D/P around a slot hole on hori. girder No. 2 which vertical stiffener No. 21 passes through	Renewed the cracked areas
WBT No. 3 (P/S)	FR. 70	• Upper deck longi. Nos. 19-20	Renewed the cracked areas
WBT No. 4 (P)	FR. 57	• D/Ps around slot holes on hori. girder No. 1 which vertical stiffener Nos. 20, 21, and 26-28 pass through • Vertical stiffener Nos. 20-21	Renewed the deformed or cracked areas
	FR. 57, 58	• Longi. No. 8 of the longi. bulkhead (BHD)	
	FR. 60	• 1st cross tie from the upper deck	
	FR. 61	• A face plate at the left end of the 1st cross tie from the upper deck • Welding of the hori. tripping brackets supporting side shell longi. No. 12	
	FR. 62	• A cross tie plate at upper deck longi. No. 28	
WBT No. 4 (S)	FR. 57	• Hori. stiffeners for side shell longi. Nos. 10, 12, and 13 • A face plate of side shell longi. No. 8 at the longi. BHD • Hori. tripping brackets supporting longi. Nos. 14-17 of the longi. BHD • D/Ps around slot holes on hori. girder No. 2 which vertical stiffener Nos. 20, 21, 24, and 26 pass through	Renewed the deformed or cracked areas
	FR. 59	• A cross tie plate at upper deck longi. No. 20 • A stiffener at the end of the cross tie near longi. No. 13 of the longi. BHD	
	FR. 61	• Welding and stiffeners at the both ends of the 1st cross tie under the upper deck	
	FR. 63, 64	• Welding at the both ends of the 1st cross tie under the upper deck	



[Figure 12] Location of major frames

2.9.2 Special survey: dry docking in June 2012

2.9.2.1 The first special survey of Stellar Daisy after her conversion had been conducted from 16 June 2012 to 4 April 2013. The ship had undergone surveys, including a dry dock survey, at the COSCO Zhoushan Shipyard in China from 16 June to 6 July 2012. The special survey was completed from 2 to 4 April 2013. A close-up survey and thickness measurements were conducted for all cargo holds and ballast tanks, and VT Nos. 1, 5, and 6 (P/S) during the period.

2.9.2.2 The results showed that there were no areas of concern reported under the KR rules. Overall, the coatings of the cargo holds and WBTs were deemed to be in fair condition as the area inside WBT No. 3 (S) was hard coated again due to corrosion and the renewed steel materials of the WBT Nos. 2 and 4 (P/S) were hard coated. However, WBT No. 3 (P) was rated as poor.

2.9.2.3 Repairs were made during the dry dock survey to the damaged areas of Stellar Daisy, including the bulwark, the upper deck, and the deck store on the starboard bow, caused when the ship had contacted a pier at Gwangyang Port in Korea on 11 June 2012.

2.9.2.4 [Table 8] lists major steel materials repaired during the dry dock survey.

[Table 8] Major steel materials repaired in dry dock in Jun. 2012

Area	Frame No.	Repaired Area	Remarks
WBT No. 4 (P)	FR. 58	• Trans. web frames in way of upper deck longi. Nos. 15-17 and 29-31	Renewed the corroded areas
	FR. 59	• Trans. web frames in way of upper deck longi. Nos. 28-30	
	FR. 61	• Trans. web frames in way of upper deck longi. Nos. 17-19, 22-28, and 31	
	FR. 62	• Part of trans. web frames in way of upper deck longi. Nos. 19-26 and 28	
	FR. 63	• Part of trans. web frames in way of upper deck longi. Nos. 20-32	
	FR. 64, 65	• The face plate of upper deck longi. No. 19	
	FR. 58	• Face plates of upper deck longi. Nos. 30-32	
WBT No. 4 (S)	FR. 57	• The face plate of upper deck longi. No. 30	Renewed the corroded areas
	FR. 58	• Trans. web frames in way of upper deck longi. Nos. 17-28	
	FR. 59	• Trans. web frames in way of upper deck longi. Nos. 20-27	
	FR. 63	• Trans. web frames in way of upper deck longi. Nos. 20-27	
	FR. 64	• Trans. web frames in way of upper deck longi. Nos. 19-24	
	FR. 63-65	• The face plate of upper deck longi. No. 19	
	FR. 64, 65	• Face plates of upper deck longi. Nos. 30 and 32	

2.9.3 Intermediate survey: dry docking in May 2015

2.9.3.1 Stellar Daisy underwent a riding survey from 9 to 12 May 2015 and a dry dock survey from 15 to 24 May 2015 at the COSCO Dalian Shipyard as the second intermediate survey since conversion. A close-up survey and thick measurements were completed for all ballast tanks and cargo holds, and VT Nos. 1, 5, and 6 (P/S) during the periods.

2.9.3.2 As the result, no issues were identified based on the KR rules. The coatings on all ballast tanks and cargo holds were mostly in fair condition, but WBT No. 3 (P) was identified as "Poor."

2.9.3.3 [Table 9] lists major steel materials repaired during the dry dock survey.[21)]

[Table 9] Major steel materials repaired in dry dock in May 2015

Area	Frame No.	Repaired Area	Remarks
WBT No. 2 (P)	FR. 81	• Longi. BHD longi. Nos. 0-6	Renewed the corroded areas
WBT No. 2 (S)	FR. 75	• Longi. BHD longi. No. 0	Renewed the corroded areas
	FR. 78	• Longi. BHD longi. No. 2 • The face plate of side shell longi. No. 3	
	FR. 79	• The face plate of side shell longi. No. 2	
	FR. 80	• The face plate of longi. BHD longi. No. 1	
	FR. 75-77	• Face plates of side shell longi. Nos. 1 and 4	
	FR. 76-78	• Face plates of the deck trans. web frames between deck longi. Nos. 17-30	
	FR. 78, 79	• Longi. BHD longi. No. 0	
	FR. 78, 80	• Longi. BHD longi. No. 2	
	FR. 80, 81	• The face plate of side shell longi. No. 1	
	Unknown	• Face plates of the deck trans. web frames between deck longi. Nos. 28-29 • Face plates of the deck trans. web frames between deck longi. Nos. 26-30	
WBT No. 4 (P)	FR. 58	• The face plate of longi. BHD longi. No. 8	Renewed the corroded areas
	FR. 60, 63	• Longi. BHD longi. No. 5	
WBT No. 4 (S)	FR. 57	• The face plate of side shell longi. No. 1	Renewed the corroded areas
	FR. 60	• Longi. BHD longi. No. 4	
	FR. 63	• Longi. BHD longi. No. 6	
	FR. 64	• The face plate of longi. BHD longi. No. 5	
	FR. 59, 63	• Longi. BHD longi. No. 5	
	Unknown	• The face plate of hori. girder No. 1 of vertical stiffener Nos. 20-23 • The face plate of hori. girder No. 2 of vertical stiffener Nos. 20-22	

21) The steel work was not documented in the survey report. However, there is a note showing that the attending surveyor confirmed the steel work recorded in the shipyard's work done report.

2.9.4 Occasional survey: August 2016

2.9.4.1 While conducting an annual survey on Stellar Daisy at Rizhao Port in China from 11 to 12 August 2016, the surveyors identified the buckling[22] of the vertical stiffeners for the transverse bulkhead between WBT Nos. 3 and 4 on both port and starboard at frame No. 65.

2.9.4.2 The attending surveyor of KR stated that no damage was observed to the adjacent transverse bulkheads (frame Nos. 57 and 75), apart from the deformed areas. And he also added that he confirmed that Stellar Daisy had encountered winds as strong as Beaufort Wind Scale 7 to 8 underway, leading to a significant rolling in February 2016, and then, the damaged areas had been identified in March, according to the master's statement.

2.9.4.3 Therefore, KR surveyor who attended the survey reported to KR's head office in Busan the damage of the transverse bulkhead at frame No. 65. KR reviewed the structural analysis reports and other inspection records[23]. As the result, the agency determined that the damage was limited to the transverse bulkhead of frame No. 65 and repairs should be made only for the damaged area.

2.9.4.4 Stellar Daisy proceeded to the Zhejiang Eastern Shipyard in Zhoushan, China, accordingly. There, the ship renewed the damaged transverse bulkhead of frame No. 65 as described in [Figure 13] and received an occasional survey while berthing at the quay from 16 to 25 August 2016. The following describes major renewal works.

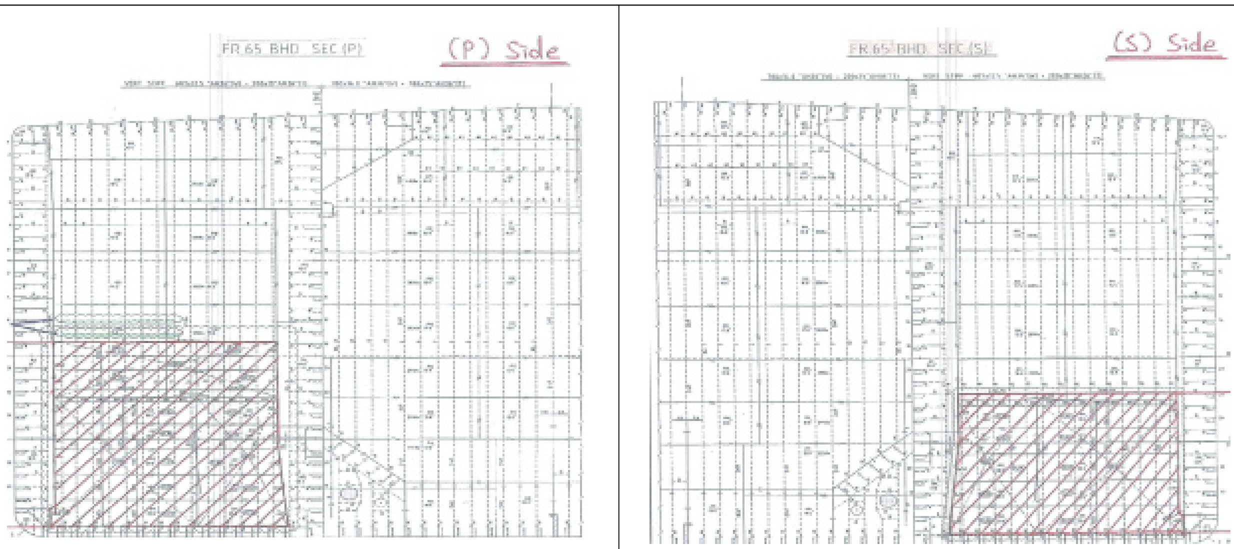
- A transverse bulkhead between WBT Nos. 3 and 4 (P): a 12.1 m[24] x 13.4 m face plate of the transverse bulkhead, and 14 vertical stiffeners and 14 brackets for the area were renewed.

22) Buckling refers to a situation when a structural member is loaded in compression and the load reaches the threshold, the member may be deformed or bend, ending up in an unstable state.

23) According to the report of the structural analysis on cargo holds which had been approved during conversion, the stress of the transverse bulkhead, calculated during the structural analysis, fell into the allowable level of KR (approx. 69% of KR's allowable level) and no damage was identified from adjacent bulkheads with a similar structure.

24) The width means the upper part of the renewed transverse bulkheads (The same applies to the starboard side).

- A transverse bulkhead between WBT Nos. 3 and 4 (S): a 12.1 m x 9.4 m face plate of the transverse bulkhead, and 14 vertical stiffeners and 14 brackets for that area were renewed.



Trans. BHD (P)	Trans. BHD (S)

[Figure 13] Repairs of FR. 65 BHD

2.10 Internal inspections by Polaris Shipping

2.10.1 In accordance with the SMS procedures of Polaris Shipping, masters shall conduct internal inspections on a quarterly basis on the overall hull structures, including cargo holds, tanks, and facilities of decks and engines, and report the results to Polaris Shipping (Technical Team).

2.10.2 Therefore, the master of Stellar Daisy had also submitted his master's reports and hull inspection reports to the company every quarter from 1Q2009 to 4Q2016 right before the accident. As for cargo holds and tanks, the crew went inside each cargo hold and tank and conducted inspections while the ship was underway in ballast. The results of such inspections were included in the reports.

2.10.3 The 1Q2009 inspection report, the first one written after conversion, pointed out a poor condition of the coatings and the buckling of the upper deck, including the cross deck, after loading cargo.

2.10.4 After the initial inspection report, the buckling of the overall upper deck was observed continuously. However, no record existed to suggest it had developed further after a certain period of time.

2.10.5 The poor coating condition of the ballast tanks or void tanks was consistently reported in internal inspections. Notably, the coating condition of WBT No. 3 (P) was reported as "Poor" in every inspection report (see [Figure 14]), while that of VT Nos. 1 and 5 (P/S) had been mostly rated as "Poor" from 2010 to 2Q2015. VT Nos. 1-5 (C) under the cargo holds had also been constantly reported as being in a "Poor" coating condition since 4Q2013 (see [Figure 15]).

[Figure 14] WBT No. 3 (P) (4Q2013 Hull Inspection Report)

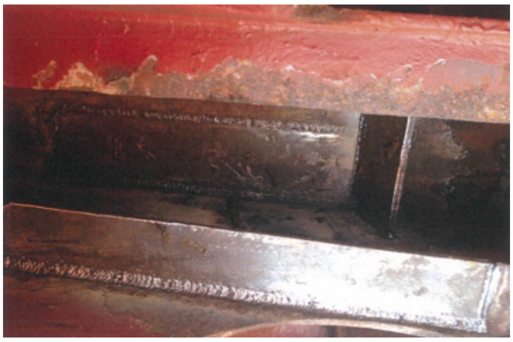
[Figure 15] VTs (c) under cargo holds (4Q2013 Hull Inspection Report)

2.10.6 Out of Stellar Daisy's WBT No. 3 (P/S) whose coatings had been constantly reported as being in a poorer condition than those of the other ballast tanks, WBT No. 3 (S) was recoated in June 2012 when the ship was dry docked in the shipyard for a special inspection while WBT No. 3 (P) was not[25).

2.10.7 In addition, the quarterly reports included the records of internal repairs made to several hull damage, including renewing the holed shell plate of the upper deck at the bow, doubling[26) the floor plate of the deck store at the bow, and fixing the cracked transverse web of WBT No. 4 (P). However, not every aspect of those repairs was reported to and reviewed by KR, her classification society.

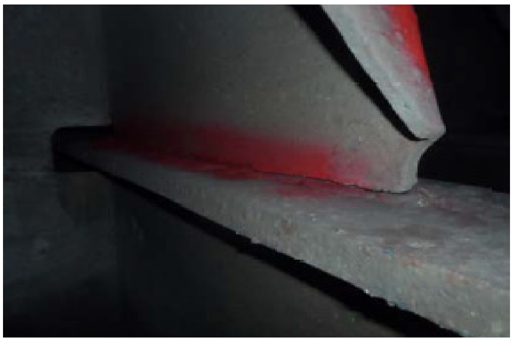
25) Polaris Shipping originally planned to recoat WBT No. 3 (P) when the ship would be dry docked in the shipyard for an intermediate survey around in May 2015. However, the plan was not implemented because that coating work would take more than a month to complete.

26) The 3Q2015 Hull Inspection Report specifies that the bottom of the deck store was doubled as it was holed and became thinner broadly.

 Before repair	 After repair

[Figure 16] Holes in the shell plate on the bow upper deck (3Q2015 Hull Inspection Report)

[Figure 17] Doubling the floor plate of the deck store on the bow (3Q2015 Hull Inspection Report)

 Before repair	 After repair

[Figure 18] Cracked trans. web frame of WBT No. 4 (P) (3Q2015 Hull Inspection Report)

2.10.8 Bilge wells inside the cargo holds of Stellar Daisy were fitted with a separate pipeline connected to the center void tanks under the cargo holds. Therefore, the moisture generated from cargo holds flows to the line and drains off to the center void tanks.[27] The inspection report analyzed that the water flowed into the void tanks and corroded their members while the bilge drained off through this line from the cargo holds to the center void tanks.

2.10.9 It is presumed that Polaris Shipping arbitrarily decided to install this kind of pipeline connecting the bilge well and the center void tanks without any approval from KR when modifying Stellar Daisy.

2.10.10 In addition to the poor coating conditions of several ballast tanks and void tanks, the 3Q2015 Hull Inspection Report written on 30 September 2015 reported the buckling of the vertical stiffeners for the transverse bulkheads between WBT Nos. 3 and 4 (P/S).

2.10.11 Such deformation of the vertical stiffeners was also reported in the 4Q2015 Inspection Report. And in particular, the next quarterly inspection reported that 28 vertical stiffeners at the transverse bulkhead, 14 each for the port and starboard sides, were significantly buckled due to a force applied to the transverse bulkhead in a direction from its back to the front, or from WBT No. 4 to WBT No. 3.

2.10.12 The technical superintendent of Polaris Shipping attended Stellar Daisy at Lumut Port in Malaysia around in May 2016, examined the buckling of the vertical stiffeners in way of the ballast tanks, and reported to the company that the ship would have to be repaired. The company determined to send a naval architecture expert to Stellar Daisy when she called out the outer port of Singapore in the same month.

2.10.13 The expert submitted to the company the results that repairs would be required after inspecting the buckling of the vertical stiffeners visually. However, the company neither reported this result to KR nor repaired the damage. Rather, it had Stellar Daisy embark on one more voyage.

2.10.14 Later, Stellar Daisy entered Rizhao Port in China and received the annual survey from 11 to 12 August 2016. And, the ship reported to the attending surveyor of KR the buckling of the vertical stiffeners and relevant repair was made as described in Chapter 2.9.4.4.

27) In the handover reports of Stellar Daisy, relieving C/Os recorded that the bilge was discharged from the cargo hold through the center void tank.

section

3

Development of Accident

3. Development of Accident

3.1 Voyage No. 041: Entry to GIT

3.1.1 Stellar Daisy discharged cargo and departed in ballast from Caofeidian Port in China on 13 February 2017. On 21 February when calling at Singapore, the ship changed the master and crew. Then, she set sail for Brazil.

3.1.2 While sailing for Brazil on 27 February 2017, Stellar Daisy was informed that the port of loading would be Guaiba Island Terminal (GIT) in Rio de Janeiro, Brazil, by the Business Team of Polaris Shipping. And on 6 March, the ship was given the voyage instruction, a detailed document, including the volume of cargo to be loaded.

1) LOADPORT: Guaiba Island, Brazil
2) CARGO: 260 kt +/- 10% SFHG
3) STOWAGE PLAN: Send Preliminary Stowage Plan
4) NOTICES AT LOADPORT: ETA Notice
5) DISCHARGE PORT: Chinese Ports

[Figure 19] Main items on the voyage instruction

3.1.3 The C/O of Stellar Daisy drafted a stowage plan based on a total cargo weight of 260,000 tons as described in the voyage instructions, reported it to the master, and sent it to the Business Team. The team and the charterer, Vale S.A., revised the draft plan, the weight of cargo and confirmed the final version of the stowage plan on 22 March in 2017 as in [Figure 20] with minor corrections of the departure draft. The final draft on departure was equally 20.22 meters fore, midships, and aft, no higher than her summer draft of 20.327 meters.

VALE

VALE STANDARD FORMAT - CARGO PLAN AND SEQUENCE

DOCUMENT	VSFPLAN
EDITION	04
ISSUE DATE	2014-09-15

VESSEL	STELLAR DAISY	PIER	GIT - SOUTH BERTH
AGENTS	GEM SHIPPING	OPERATION	LOAD

	11	10	9	8	7	6	5	4	3	2	1
SF		FULL	FULL	FULL	FULL	FULL	FULL	FULL	FULL	FULL	FULL
GRADE		SFHG	SFHG	SFHG	SFHG	SFHG	SFHG	SFHG	SFHG	SFHG	SFHG
QTTY		22,000	29,400	24,700	25,700	30,400	30,400	25,700	25,000	29,100	17,600

Load / unload rate agreed	8500	mt/hour
Ballast/deballast rate	7000	mt/hor
ballast/deballast time (incl. stripping)	30	hour
TPC	165.4	mt

TOTAL CARGO 260,000.00 mt

figure from cargo plan for comparision

LOADING / UNLOADING SEQUENCE PLAN						COMMENTS	CALCULATED VALUES							OBSERVED VALUES		
							DRAFT		MAXIMUM					DRAFT		
POUR	CARGO GRADE	HATCH	CARGO QUANTITY	BALLASTING OPERATIONS	TIME REQUIRED		FWD	AFT	BM	SF	AIR DRAFT	MID DRAFT	TRIM	FWD	AFT	MID
						BERTHING	11.00	13.80	48	81	18.95	12.40	2.80			
1	SFHG	5	15,000	PO WBT 3 -13000, APT -600	1.88		11.66	13.22	59	78	12.60	18.75	1.56			
2	SFHG	10	15,000	PO WBT 4 -13000, APT-600	1.88		10.29	12.63	40	67	19.89	11.46	2.34			
3	SFHG	1	6,000	PO WBT2 -5000, APT -600	0.75		11.19	14.00	30	48	18.76	12.60	2.81			
4	SFHG	6	15,000	PO WBT3 -13000, APT -600	1.88		11.05	14.00	20	50	18.83	12.53	2.95			
5	SFHG	9	15,000	PO WBT4 -13000, APT-600	1.88		10.26	15.51	35	41	18.47	12.89	5.25			
6	SFHG	2	15,000	PO WBT2 -13000	1.88		11.66	14.13	54	44	18.46	12.90	2.47			
7	SFHG	8	15,000	PO WBT4 -13000	1.88		11.38	14.73	60	56	18.30	13.06	3.35			
8	SFHG	3	15,000	PO WBT2 -13000	1.88		12.00	14.30	67	60	18.20	13.15	2.30			
9	SFHG	7	15,000	PO WBT2 -4000, WBT4 -8400	1.88		11.55	15.15	53	53	18.00	13.35	3.60			
10	SFHG	4	15,000	PO WBT2 -13200	1.88		11.61	15.34	43	32	17.88	13.48	3.73			
11	SFHG	5	15,400	PO FPT -2000, WBT 3 -2000	1.93		12.51	15.86	17	41	17.17	14.19	3.35			
12	SFHG	1	11,600	FPT -5500	1.45		13.98	15.06	29	39	16.83	14.52	1.08			
13	SFHG	10	7,000	STRIPPING	0.88		13.28	16.77	40	43	16.33	15.03	3.49			
14	SFHG	6	15,400	STRIPPING	1.93		14.23	17.74	13	43	15.37	15.99	3.51			
15	SFHG	4	10,700	STRIPPING	1.34		15.82	17.41	25	51	14.74	16.62	1.59			
16	SFHG	9	11,300	STRIPPING	1.41		15.23	19.48	22	44	14.00	17.36	4.25			
17	SFHG	7	10,700	STRIPPING	1.34		15.49	20.52	37	71	13.35	18.01	5.03			
18	SFHG	3	10,000	STRIPPING	1.25		17.31	19.89	33	59	12.75	18.60	2.58			
19	SFHG	8	9,700	STRIPPING	1.21		17.23	21.15	41	82	12.16	19.19	3.92			
20	SFHG	2	11,200	STRIPPING	1.40		19.67	20.04	28	72	11.50	19.86	0.37			
						CHECK DRAFT FOR TRIMMING										
21	SFHG	9	3,000		0.38		19.54	20.53	33	77	11.32	20.04	0.99			
22	SFHG	2	3,000		0.38		20.22	20.22	55	85	11.13	20.22				
					32.50											

TOTAL = 260,000 MT

REMARKS :
1- FOR ONE TYPE/GRADE OF CARGO, FILL UP ONLY HOLD / HATCH / QUANTITY
2- PLEASE COUNT NUMBERS OF HATCHES IN SEQUENTIAL MODE WITHOUT ANY LETTERS (EXAMPLE: 1, 2, 3, 4, 5, 6, 7, ETC.) (IT IS NECESSARY FOR REFERENCE OF SHIPLOADER'S OPERATORS)
3 - BENDING MOMENTS (BM) AND SHEAR FORCES (SF) ARE TO BE EXPRESSED AS A PERCETAGE OF MAXIMUM PERMITTED IN-PORT VALUES FOR INTERMEDIATE STAGES, AND OF MAXIMUM PERMITTED AT-SEA VALUES FOR THE FINAL STAGE.
EVERY STEP IN THE LOADING / UNLOADING PLAN MUST REMAIN WITHIN THE ALLOWABLE LIMITS.

CARGO PLAN AND SEQUENCE AGREED:

VALE DD/MM/YYYY HH:MM

ON BEHALF OF VESSEL

ON BEHALF OF TERMINAL

[Figure 20] Stowage Plan

3.1.4 On 22 March, Stellar Daisy arrived at the outer port of GIT at around 05:30 (LT) and anchored. At that time, the ship was laden with a total ballast water of 106,100 tons: 24,100 tons each in WBT No. 2 (P/S); 23,700 tons each in WBT No. 4 (P/S); 3,000 tons in the APT; and 7,500 tons in the FPT.

3.1.5 On the same day, the ship lifted anchor from the outer port of GIT and transited to the inner port at around 18:24 (LT). Upon arriving at the inner port, she dropped anchor again at around 20:30 (LT).

[Figure 21] Guaiba Island Terminal

3.1.6 GIT has one berth each on the south and north where a ship can be moored. The north berth can accommodate ships up to 19 m in air draft, 295 m in length, 47 m at the beam, and 185,000 deadweight tons, while ships with a 19 m air draft as long as 340 m length, as wide as a 62 m beam, and as heavy as 350,000 deadweight tons may use the south berth.

3.1.7 Stellar Daisy was scheduled to dock at the south berth. Therefore, she put 14,000 tons of additional ballast water each into her WBT No. 3 (P/S)[28] to meet the berth's allowable air draft level of 19 meters.

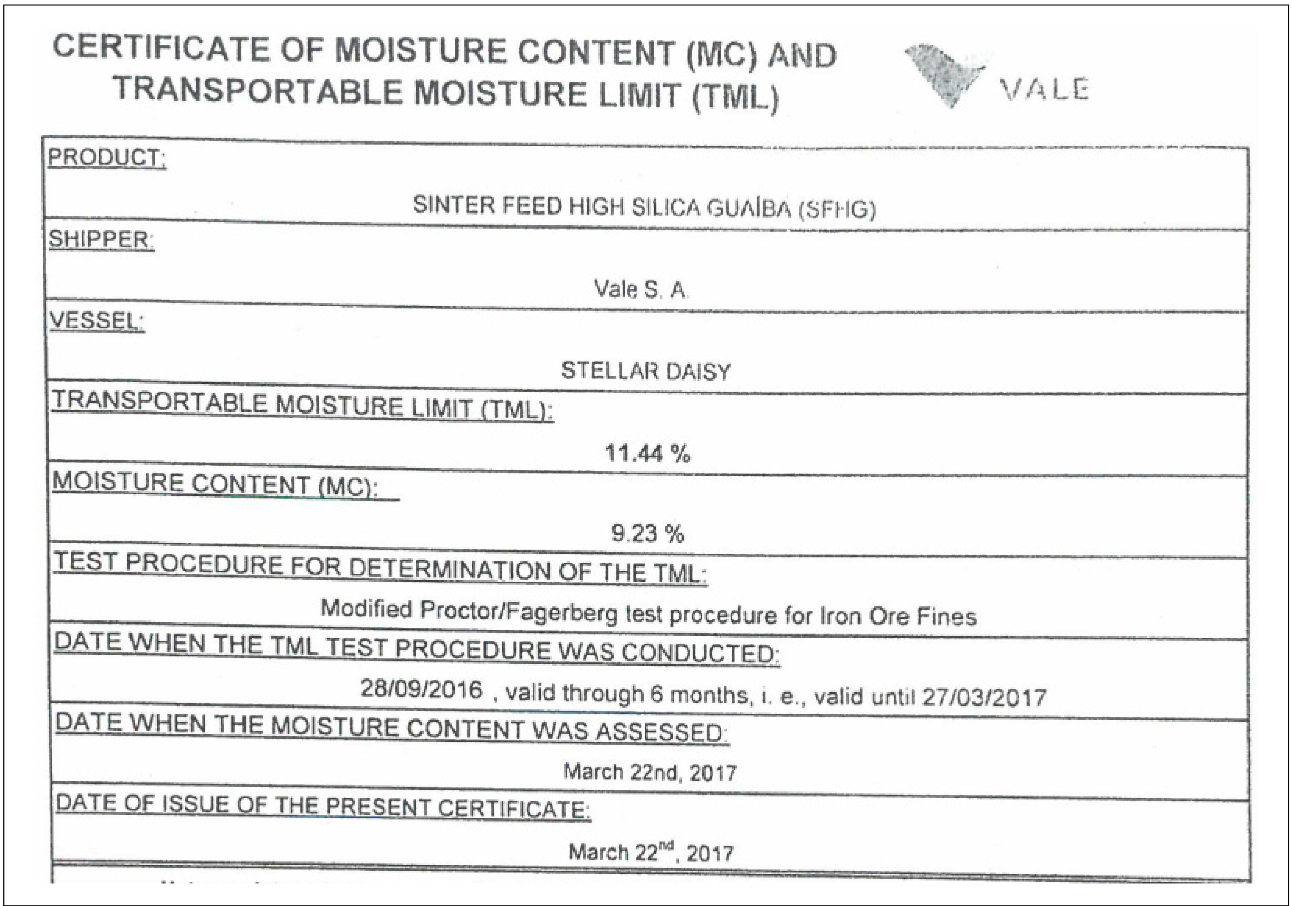
3.1.8 Later, on the same day, Stellar Daisy heaved up anchor at the inner port at around 23:00 (LT) and docked at the south berth at around 01:50 (LT) on the next day.

3.2 Cargo loading

3.2.1 According to the cargo manifest of Stellar Daisy received from the shipper, Vale S.A., the loaded cargo has a trade name, Sinter Feed High Silica Guaiba, and its type is iron ore fines, classified into Group A under the International Maritime Solid Bulk Cargoes Code (IMSBC Code).[29]

28) According to Polaris Shipping, WBT No. 3 (P/S) were not used at ordinary times but only for reducing the air draft so that the ship could load cargo at the port.

3.2.2 Also, Vale S.A. provided the ship with a Certificate of Moisture Content and Transportable Moisture Limit of cargo[30]. The certificate states the transportable moisture limit (TML) of 11.44% and the moisture content (MC) of 9.23%. [Figure 22] outlines the certificate.



CERTIFICATE OF MOISTURE CONTENT (MC) AND TRANSPORTABLE MOISTURE LIMIT (TML)

VALE

PRODUCT:	SINTER FEED HIGH SILICA GUAÍBA (SFHG)
SHIPPER:	Vale S. A.
VESSEL:	STELLAR DAISY
TRANSPORTABLE MOISTURE LIMIT (TML):	11.44 %
MOISTURE CONTENT (MC):	9.23 %
TEST PROCEDURE FOR DETERMINATION OF THE TML:	Modified Proctor/Fagerberg test procedure for Iron Ore Fines
DATE WHEN THE TML TEST PROCEDURE WAS CONDUCTED:	28/09/2016 , valid through 6 months, i. e., valid until 27/03/2017
DATE WHEN THE MOISTURE CONTENT WAS ASSESSED:	March 22nd, 2017
DATE OF ISSUE OF THE PRESENT CERTIFICATE:	March 22nd, 2017

[Figure 22] Certificate of Moisture Content and Transportable Moisture Limit

3.2.3 Stellar Daisy docked at the south berth of GIT and began loading operations based on the stowage plan at around 08:25 (LT) on 23 March 2017. The ship loaded iron ore onboard at a rate of about 8,500 tons per hour through the on-shore conveyor belt system, and the ship was able to deballast about 7,000 tons of ballast water per hour accordingly.

29) Under the IMSBC Code section 7.5., a Code A cargo is defined as the one likely to liquefy if shipped at a moisture content (MC) exceeding its transportable moisture limit (TML).

30) The TML and MC of cargo were measured at GIT, which was approved by the government of Brazil.

[Figure 23] Cargo loading of the sister ship owned by Polaris Shipping

3.2.4 While loading at around 19:48 (LT) on 25 March 2017, the crew checked the ship's drafts and conducted trimming once. Cargo loading resumed at 20:11 (LT) and was completed at around 21:24 (LT) on 25 March. In the meantime, the loading operation was stopped several times at the request of the shore office.

3.2.5 [Table 10] shows the timetable of cargo loading.

[Table 10] Cargo loading timetable

DATE	TERMINAL TIME		OTHER PERIODS		NOTE
	START	END	START	END	
2017/03/23	08:25	24:00	-	-	Commenced loading/ Loading in progress
2017/03/24	00:00	24:00	-	-	Loading and stoppages by terminal account
2017/03/25	00:00	19:48	-	-	Loading and stoppages by terminal account
2017/03/25	-	-	19:48	20:11	Draft check for trimming -vessel´s account
2017/03/25	20:11	21:24	-	-	Loading and stoppages by terminal account
2017/03/25	-	21:24	-	-	Loading completed
2017/03/25	-	-	21:24	21:28	Final draft survey

3.2.6 [Table 11] outlines the results of the draft survey conducted after loading.

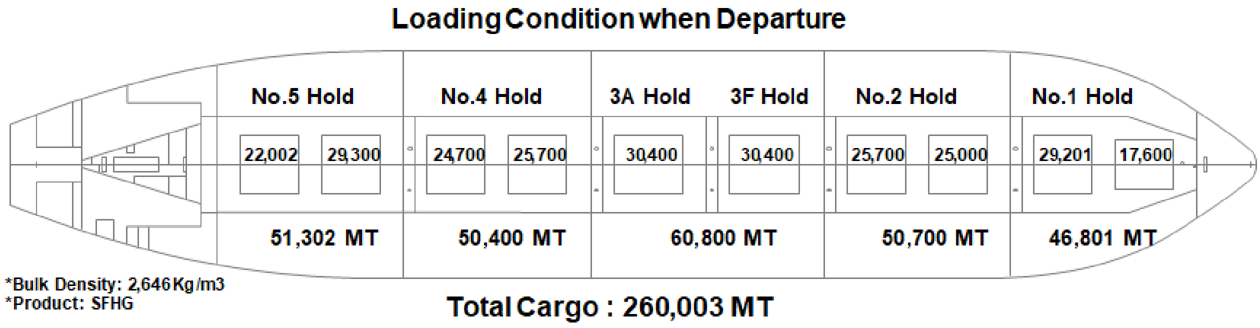
[Table 11] Draft Survey Report

DRAFT SURVEY REPORT — VALE

TERMINAL: TIG			
Vessel:	STELLAR DAISY	BERTH	SOUTH
Port Reg:	MAJURO		LBP: 310 m
Port Discharge:	MAIN CHINESE PORTS		DWT: 266140.5 MT
Light Ship: 38188.715	G. Tons: 148131	Const declared:	575.00 MT
Port of Survey:	TIG SOUTH	Const Found.	575.00 MT

DESCRITION	INITIAL SURVEY	FINAL SURVEY	
Date	March 23rd, 2017	March, 25th, 2017	
Fr. Draft on Mark	10.60000	20.22000	
Correction to pp	-0.00815	0.00000	
Cor. frd. Draft	**10.59185**	**20.22000**	
After Draft	13.62000	20.22000	
Correction to pp	0.12808	0.00000	
Corrected After Draft	**13.74808**	**20.22000**	
MEAN DRAFT	**12.16997**	**20.22000**	
Midship Draft Port	0.00000	20.22000	
Midship Draft Star	12.50000	20.22000	
Mean Midship Draft	12.50000	20.22000	
Correction to Midship	0.00000	0.00000	
Cor. Midship Draft	12.50000	20.22000	
QUARTER MEAN	12.41749	20.22000	
Corresp. DISPLACEMENT	**178456.50**	**302558.06**	
True TRIM	3.15623	0.00000	
L.C.F.	-10.168	0.360	
TPC/TPI	152.72	165.32	
MTC + 0,5m/MTI + 6	2832.50	3545.40	
MTC - 0,5m/MTI - 6"	2771.30	3484.00	
Trim Correction	-1482.74	0.00	
Displac. Corrected	**176973.77**	**302558.06**	
Sea Water Density	1.0240	1.0250	
Displac. Corrected	**176801.11**	**302558.06**	原本對照畢
CONSUMABLES	138037.40	3791.50	
Fuel Oil	3229.47	3229.50	
Diesel Oil	187.80	162.00	
Lub Oil	0.00	0.00	
Fresh Water	342.00	300.00	
Ballast	134278.13	100.00	
Others	0.00	0.00	
NET DISPLACEMENT.	**38763.72**	**298766.56**	
TOTAL CARGO LOADED IN WET METRIC TONS		**260003**	

3.2.7 Consequently, Stellar Daisy was loaded with 260,003 tons of cargo, 100 tons of ballast water, and 3,229 tons of fuel oil. [Figure 24] and [Table 12] show the loading condition including each cargo hold.



◆ Specification of Cargo:

1) Product ······ Sinter Feed High Silica Guaiba (SFHG)
2) Stowage factor ······ 0.38 ㎥/t
3) Bulk density ······ 2.646 kg/㎥
4) Angle of repose ······ 38 to 40 degrees
5) IMSBC Code ······ Group A

◆ Cargo Moisture Condition:

1) Transportable Moisture Limit (TML) ······ 11.44 %
2) Moisture Contents (MC) ······ 9.23 %

[Figure 24] Loading condition of cargo

[Table 12] Loading condition of ballast water, fuel oil, etc.

Tank	Weight (MT)	Volume (%)	Tank	Weight (MT)	Volume (%)
F.P WBT (C)	0	0	FWD F.O TANK (P/S)	0	0
WBT No. 2 (P)	30	0.12	F.O TANK (P)	2000	82.40
WBT No. 2 (S)	30	0.12	F.O TANK (S)	1107	50.59
WBT No. 3 (P)	10	0.03	F.O SETT. T (P)	85	95.79
WBT No. 3 (S)	10	0.03	F.O SERV. T (P)	37	87.37
WBT No. 4 (P)	10	0.04	D.O TANK (S)	150	45.47
WBT No. 4 (S)	10	0.04	D.O SERV. T (S)	12	74.21
A.P WBT (C)	0	0	DRINK WATER T (P)	150	57.89
WBT TOTAL	100	0.06	FRESH WATER T (S)	150	57.89

3.2.8 The Weather Company (https://weather.com), a weather information provider, reported it had not rained from 21 March 2017, one day before the ship entered GIT in Brazil, to 25 March 2017 when she departed.

3.3 Departure from GIT and sailing

3.3.1 After loading 260,003 tons of iron ore fines, Stellar Daisy departed from GIT in Brazil for Qingdao in China at around 22:54 (LT) on 25 March 2017. At that time, 24 crewmembers were on board, including 8 Koreans and 16 Filipinos.

3.3.2 The ship's drafts on departure were 20.22 meters fore, midships, and aft.

[Figure 25] Simplified planned route and accident location

3.3.3 The Noon Report, which Stellar Daisy submitted to the shipping company from 26 to 31 March 2017 after departing from GIT in Brazil, stated that the ship was underway at 64 rpm of the main engine and a speed of 11 to 12 knots as in [Table 13]. She was sailing across the South Atlantic Ocean towards the southern end of Africa, on a course of 110˚ to 120˚.

[Table 13] Noon Report of Stellar Daisy from 26 to 31 Mar. 2017

Date	Position		RPM	Speed	Course	Wind Direction	Wind Force
	LAT.	LONG.					
26 Mar.	24-13S	041-52W	63.4	11.74	116	W	4
27 Mar.	26-33S	037-07W	64.0	12.29	120	W	5
28 Mar.	28-54S	032-15W	63.9	11.67	120	SE	7
29 Mar.	30-54S	028-15W	64.3	11.13	115	SE	7
30 Mar.	32-27S	023-24W	64.2	11.08	115	SE	7
31 Mar.	34-18S	018-47W	63.7	11.09	110	SE	7

3.3.4 On 26 and 27 March 2017, wind was at Beaufort Wind Scale 4 to 5. However, from 28 March to the date of the accident, it was reported as Beaufort Wind Scale 7 in the Noon Report.

3.3.5 Stellar Daisy ran the 24/7 navigational watch system as follows: the officers (C/O, 2/O, and 3/O) took turns keeping watch in 4-hour shifts along with one helmsman. After the shift was over, the officer and the helmsman on duty would rest for 8 hours before going back on watch. When sailing at night, the helmsman was on watch but supporting routine maintenance on the deck in the daytime.

3.3.6 The engine room also had the same watchkeeping system where the 2/E, 3/E A and 3/E B kept watch for 4 hours in rotation. The 1/E and ratings took full responsibility for routine engine maintenance, and sometimes they would offer to take a watch shift as necessary.

3.4 Accident occurrence

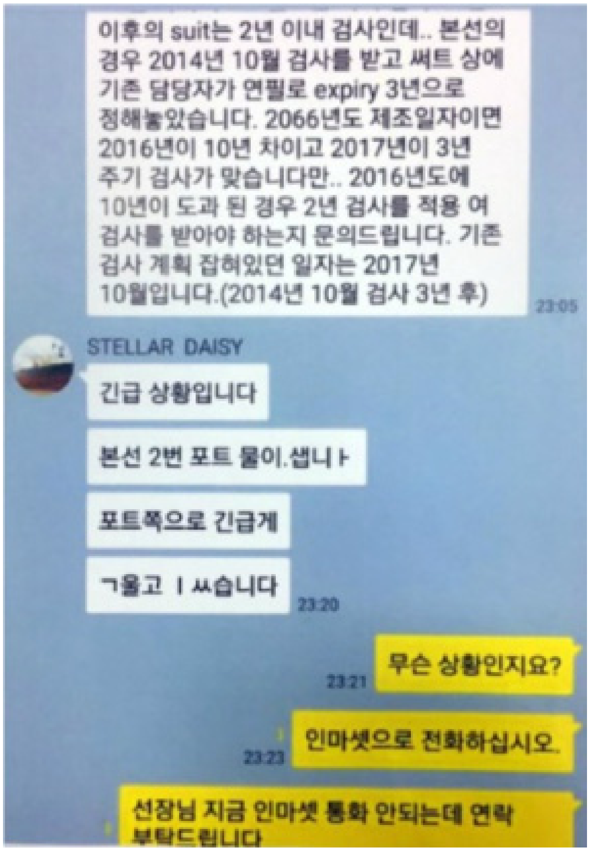
3.4.1 On 31 March 2017, the 2/O took over the watch from the 3/O and started watchkeeping on the bridge at around 11:45 (LT).

3.4.2 The Noon Report, written at 12:00 on 31 March, was sent to the company through the computer system at around 13:03 (LT) on the same day, and the ship was reported to be sailing on a course of about 110° at about 11.09 knots.

3.4.3 At around 13:00 (LT) on the same day, deck ratings started painting within the ship's accommodation area after having lunch. The engine ratings began cleaning and repairing pipes in the engine room while the 2/E was on watch.

3.4.4 The 2/O who was on watch sent a message to the superintendent via Kakao Talk, a social media widely used in Korea, with his business mobile and asked about the inspections of the ship's immersion suits at around 13:05 (LT) on the same day.

3.4.5 At around 13:20 (LT), about 15 minutes later, the ship sent a message to the superintendent saying, "Emergency. The ship's No. 2 Port is leaking. The ship is rapidly inclining to port." At around 13:21 (LT), one minute after, the JRCC Honolulu[31] received a distress signal sent from Stellar Daisy via INMARSAT-C DSC.



[Figure 26] Mobile screen with the Kakao Talk message[32]

31) Joint Rescue Coordination Center (JRCC) Honolulu.

32) It is the screenshot the superintendent took on his mobile phone, and the time displayed in the message was the Korea time.

3.4.6 The superintendent who checked the message immediately replied and requested him to check the situation on board. At around 13:23 (LT), about two minutes later, he again asked the ship to call him back by INMARSAT-C. However, no reply had come from the ship.

3.4.7 Two crewmembers survived from the accident. One of them, AB A, stated that he had heard a crashing sound and felt the ship inclining to the port side along with a strong vibration when he had been painting inside the ship's accommodations. He also said that he went to the cabin to put on a lifejacket, got his immersion suit, and went to the muster station on the port side out of the accommodation area. However, no one was there when he arrived. Then, he heard the master's announcement, saying "All crew go to bridge," and he went onto the bridge using the outside ladders of the accommodation area.

3.4.8 AB A, who arrived at the bridge, saw that the master, C/E, 2/O, 3/O, deck cadet, chief cook, 2nd cook, and ratings of the deck and engine department, and that the 3/O was shouting "Mayday" on the radio communication equipment. He saw the clinometer on the bridge indicating a 40° list to port.

3.4.9 When water was about to flood on the bridge as the ship heeled to port further, AB A jumped into the water from the port bridge wing.

3.4.10 The other survivor, No. 1 oiler, said that he had felt the main engine's rpm decreasing with a strong vibration while he was repairing machines on the 3rd deck of the engine room. He added that he later moved to get out of the engine room after hearing the master's announcement.

3.4.11 The No. 1 oiler saw the 2/E operating a generator on the 3rd deck of the engine room and the 1/E making a gesture on the 2nd deck to tell him to leave the engine room immediately. And, Stellar Daisy started listing to port.

3.4.12 After the No. 1 oiler escaped from the engine room and went out onto the upper deck, the increasing port list prevented him from going up to the bridge. Therefore, he held onto the handrails at the muster station on the starboard side of the crew quarters.

3.4.13 Behind him, the bosun was also holding onto the handrails, while the C/O, 1/E, wiper, and engine cadet were seen holding onto the handrails along the door walkway on the starboard side of the crew quarters area on the upper deck. The No. 1 oiler and the bosun attempted to launch liftrafts on the starboard side. However, the increasing port list made their efforts futile, and left them holding onto the handrails on the starboard side of the upper deck.

3.4.14 The No. 1 oiler saw the water and oil soaring near the upper deck of WBT No. 5 (S). Later, the ship continuously heeled to port, and in the end, he was washed overboard by a huge wave.

3.4.15 Then, the ship quickly heeled to port and suddenly sank into the water. The No. 1 oiler and AB A were sunk down before being floated back to the surface.

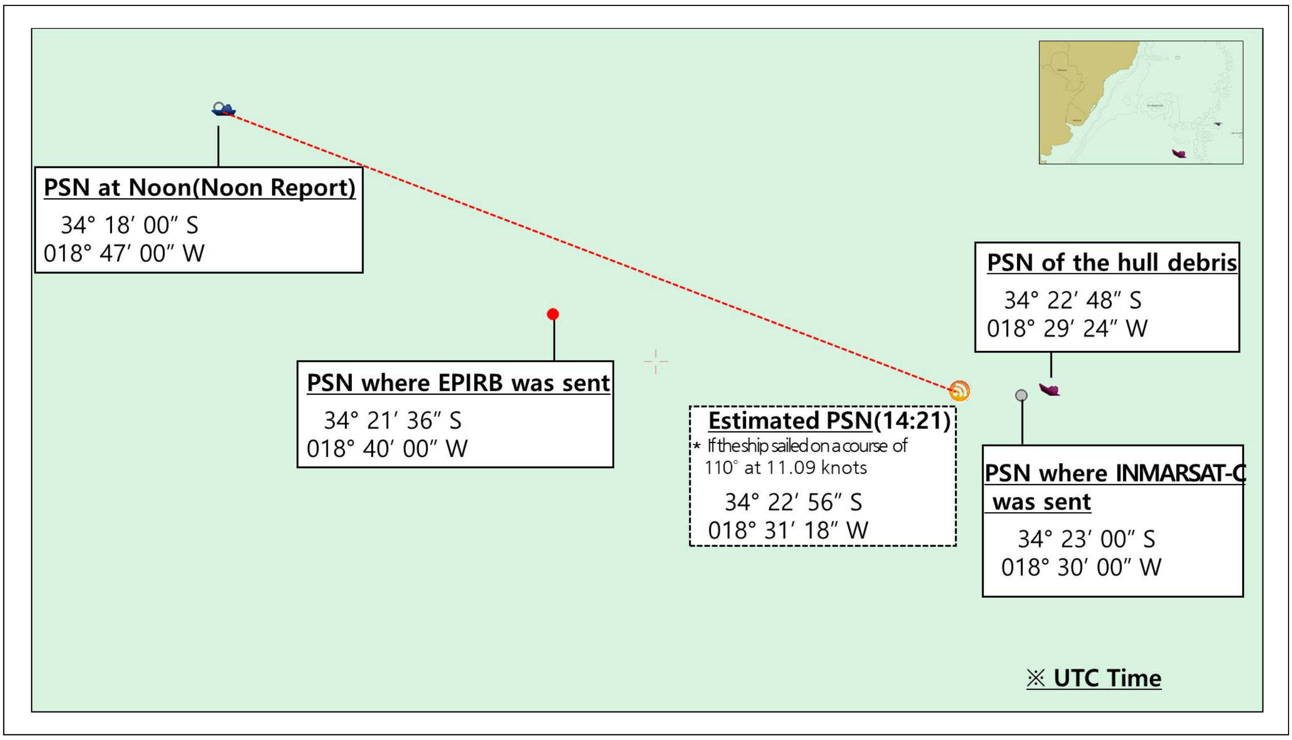
3.4.16 After surfacing, AB A spotted a liferaft floating about 300 m away; he swam to it and climbed onto it. The No. 1 oiler swam about 300 meters to join him on the liferaft.

3.4.17 Stellar Daisy's EPIRB was activated at sea about 1,550 miles southwest of Santos in Brazil, and its message reached the JRCC Honolulu at around 13:25 (LT) on the same day.

3.5 Accident location

3.5.1 The distress location sent via INMARSAT-C DSC at around 13:21 (LT) was 34°23'S, 18°30'W. The distress signal sent via the EPIRB was also received at around 13:25 (LT) and the location was indicated as 34°21.6'S, 18°40.0'W, approximately 8.5 miles at 280° away from the INMARSAT-C DSC position.

3.5.2 According to the Noon Report written on the day of the accident, Stellar Daisy was sailing on a course of about 110° at about 11.09 knots at a location of 34°18'S, 018°47'W at 12:00 (LT). It is calculated that the ship sailed at 11.48 knots on the same course from the position at noon to the one sent by INMARSAT-C DSC.



[Figure 27] Location of the accident

3.5.3 Given the ship's position at noon, the time when the ship sent out the social media message, and distress signals, including when and where the signals were sent, the accident was presumed to have occurred at sea at 34˚23'S, 18˚30'W[33], approximately 1,550 miles southeast of Santos, in Brazil, at around 14:21 (LT) on 31 March 2017, right after the distress signal had been sent out by INMARSAT-C DSC.

3.6 Search and rescue

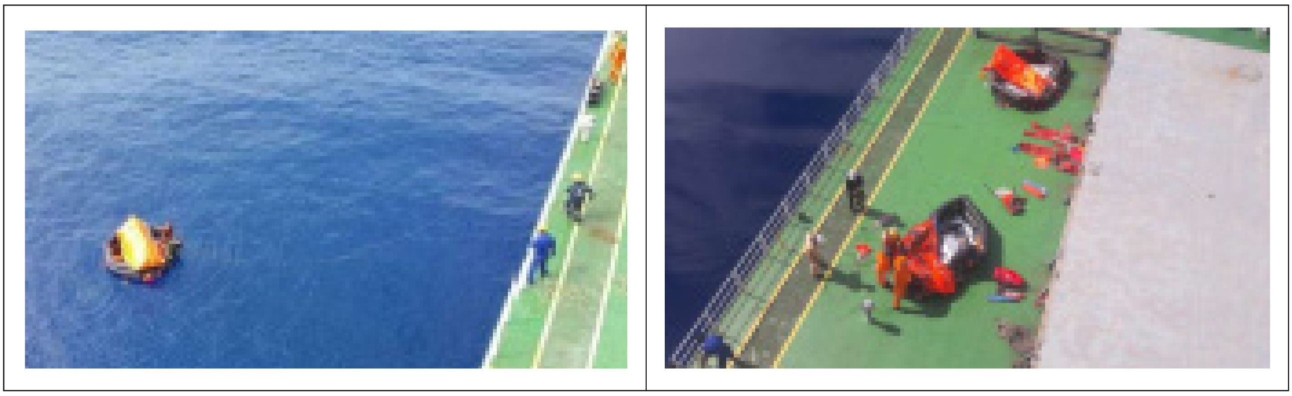
3.6.1 The JRCC Honolulu received a distress call via EPIRB from Stellar Daisy at around 14:25 (LT) on 31 March 2017, and provided the information for her flag state, RMI.

3.6.2 After being informed that the JRCC Honolulu had received the distress call from Stellar Daisy, the RMI official notified this fact to the DP of Polaris Shipping on the phone at around 14:43 (UTC) and via email at around 14:25 (UTC) on the same day.

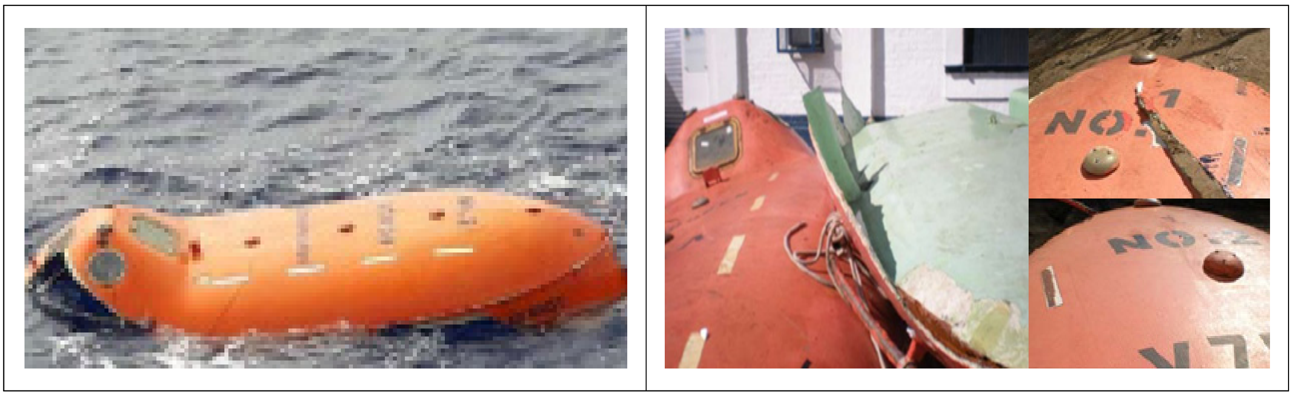
33) The deep-sea search, conducted in February 2019, discovered the hull debris of Stellar Daisy on the seabed approx. 3,400 m deep and approx. 1 km away from the position (an 1 km x 0.8 km area, located at 34˚22.8'S, 018˚29.4'W) indicated by INMARSAT-C DSC.

3.6.3 Later, the MRCC Uruguay, who was in charge of the area where the accident occurred, requested vessels nearby to assist in search and rescue operations. On 1 April 2017, M/V Spitha (Cyprus) first arrived in the area and witnessed an oil slick at around 02:40 (UTC). Then, M/V CKNG (ROK), M/V Eternal (Panama), and M/V Elpida (Malta) arrived and joined the operations on the same day.

3.6.4 At around 12:50 (UTC), M/V Elpida sighted two liferafts and rescued AB A and the No. 1 oiler from one of them.[34] M/V CKNG also found another liferaft and two lift boats, all of which were damaged. However, no survivors were in them.



[Figure 28] Liferafts sighted during the search and rescue operations



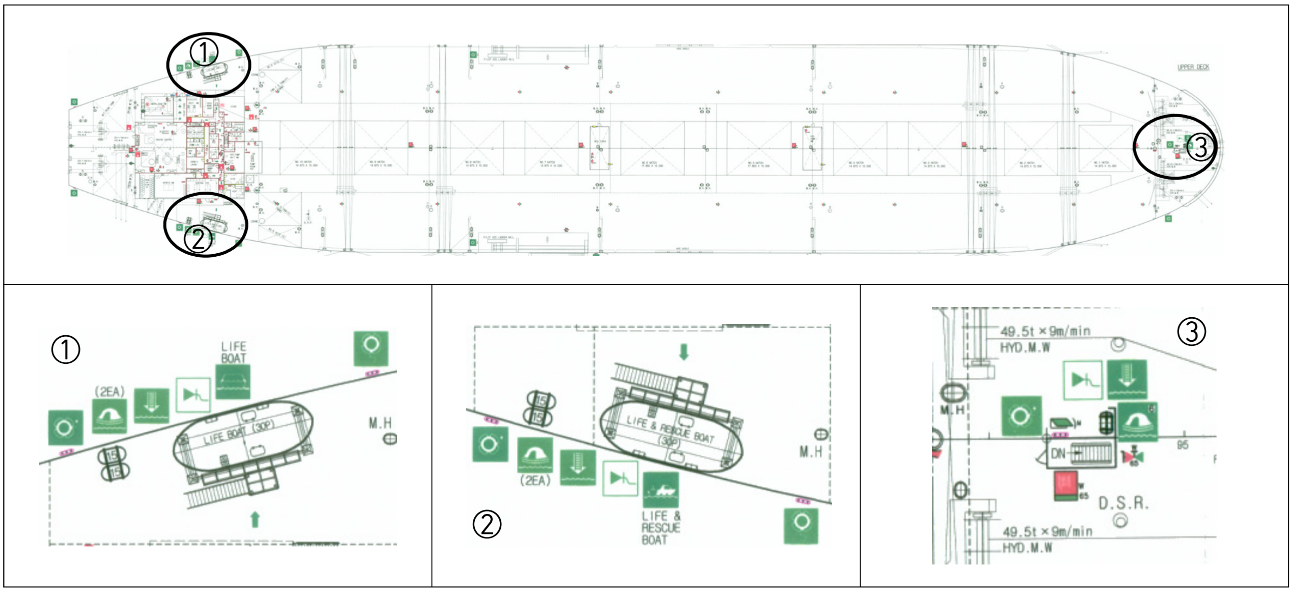
[Figure 29] Lifeboats sighted during the search and rescue operations

3.6.5 The two rescued crewmembers disembarked from M/V Elpida in Cape Town, the Republic of South Africa, on 13 April 2017.

34) Two Filipino crewmembers were rescued at 32˚03.48S, 018˚33.04W, about 35 km away from the position indicated by EPIRB.

3.6.6 The MRCC Uruguay led an intensive search operation with mobilizing enormous resources such as three warships (from 6 to 16 Apr. 2017), aircrafts (8 times by Brazil and 5 times by the U.S. from 2 to 13 Apr. 2017), and 30 private vessels, for 40 days after the accident had occurred. However, nothing else were found.

3.6.7 Stellar Daisy was equipped with the following lifesaving appliances: one totally-enclosed, 30-person lifeboat and two 16-person inflatable liferafts with an HRU[35] each on the port and starboard side of the quarters area on the upper deck at the stern; and one 6-person inflatable liferaft without an HRU[36] at the bow. Among these, one 16-person inflatable liferaft and one 6-person inflatable liferaft were never found.[37]



[Figure 30] Installed location of the lifeboats and liferafts on Stellar Daisy

35) When a ship sinks below 4 meters, the hydrostatic release unit (HRU) which secures a liferaft is automatically released, and then the liferaft is detached from the ship. As the detached liferaft is automatically inflated by compressed gas inside, it floats free to the surface.

36) In general, the liferaft without an HRU is secured onto the deck with a rope so that it cannot be washed overboard by waves. In an emergency, the liferaft can be inflated only when its rope is pulled manually.

37) They were not identified in the deep-sea search image as well.

section

4 Analysis

4. Analysis

4.1 Ship's voyage condition

4.1.1 Sea states

4.1.1.1 The following data were reviewed to ascertain sea states at the time of the accident: the Noon Report prepared by the ship; weather information received by Stellar Daisy from the meteorological service provider, StormGeo; and the data from the National Oceanic and Atmospheric Administration (NOAA)[38] that were obtained after the accident.

4.1.1.2 The Noon Report described the directions and strength of wind and waves as of 12:00 local time (noon), and StormGeo provides forecast data on wind and waves twice in a day (at 00:00 and 12:00). Last, every 30 minutes the NOAA summarizes global wind and wave patterns for the previous three hours. Therefore, the KMST referred to the NOAA's data for analyzing states at sea from the time Stellar Daisy had left GIT in Brazil on 25 March 2017. The data are not a forecast but a hindcas t[39], which is revised with the subsequent measurements.

4.1.1.3 The following [Tables 14] and [Table 15] list the sea states on Stellar Daisy's route in accordance with the NOAA data.

38) The data include information on the coastlines and ocean depths around the world provided by the National Center for Environmental Information (NCEI, https://www.ncei.noaa.gov) and information on the world's winds and waves by the National Weather Service Environmental Modeling Center (NWS EMC, https://polar.ncep.noaa.gov).

39) The data on oceanographic conditions are divided into the following three categories: forecasts, which cover weather predictions for the next 6 hours; nowcasts, which is a very short-range forecasting, generally less than six hours; and hindcasts, which offer revised oceanographic data based on measurements calculated later.

[Table 14] Waves on the voyage route of Stellar Daisy (Reconstructed NOAA data)

Date and Time				Location				Combined Wave[40]			Wind Wave			Swell		
Date	Time Local	Time Zone	UTC	Lat. S	Long. W	Lat. Decimal	Long. Decimal	Sig. height meter	Dir.[41]	Mean periods	Sig. height meter	Dir.	Mean periods	Sig. height meter	Dir.	Mean periods
26 Mar.	13:00	-3	16:00	24°13.00′	041°52.00′	-24.28	-41.87	1.34	132.34	7.55	0.56	255.21	3.58	1.05	133.77	9.96
			18:00			-24.4774	-41.457	1.31	136.69	7.34	0.60	251.37	3.66	0.98	135.47	9.83
			00:00			-25.0696	-40.2178	1.36	139.50	6.86	0.71	252.55	3.85	1.10	122.14	9.11
			06:00			-25.6617	-38.9787	1.32	122.48	7.00	0.57	274.55	4.02	1.11	118.34	8.72
			12:00			-26.2539	-37.7396	1.23	96.54	6.84	0.48	296.58	4.10	0.67	95.42	6.58
27 Mar.	13:00	-2	15:00	26°33.00′	037°07.00′	-26.55	-37.12	1.23	91.87	6.91	1.01	0.75	5.81	0.70	140.83	8.01
			18:00			-26.8438	-36.5525	1.38	110.92	6.64	0.89	149.25	7.56	0.71	19.16	5.67
			00:00			-27.4313	-35.4175	2.11	144.18	6.25	1.85	151.09	6.59	0.79	19.34	6.17
			06:00			-28.0188	-34.2825	2.67	151.76	6.57	2.48	156.40	6.99	0.83	21.28	6.75
			12:00			-28.6063	-33.1475	2.77	155.28	6.73	2.60	159.68	7.26	0.89	10.42	6.96
28 Mar.	13:00	-2	15:00	28°54.00′	032°35.00′	-28.9	-32.58	3.1	150.43	6.91	2.97	153.51	7.51	0.81	9.76	7.13
			18:00			-29.15	-32.0388	3.04	152.69	7.04	2.91	155.54	7.66	0.80	6.29	7.13
			00:00			-29.65	-30.9563	3.03	156.86	7.22	2.92	158.43	8.07	0.69	3.00	7.41
			06:00			-30.15	-29.8738	2.75	150.84	7.17	2.61	153.08	7.83	0.61	359.52	7.59
			12:00			-30.65	-28.7913	2.63	142.58	7.08	2.50	143.58	7.47	0.53	356.60	7.59
29 Mar.	13:00	-2	15:00	30°54.00′	028°15.00′	-30.9	-28.25	2.82	141.35	7.20	2.73	143.42	7.52	0.49	353.80	7.64
			18:00			-31.0938	-27.6438	2.86	142.50	7.23	2.77	144.46	7.55	0.50	352.07	7.64
			00:00			-31.4813	-26.4313	2.99	140.62	7.46	2.20	110.02	6.90	1.90	182.21	8.50
			06:00			-31.8688	-25.2188	3.17	143.00	7.59	2.60	121.46	7.47	1.68	192.11	9.49
			12:00			-32.2563	-24.0063	3.2	140.54	7.54	2.66	119.34	7.36	1.62	193.33	9.48
30 Mar.	13:00	-2	15:00	32°27.00′	023°24.00′	-32.45	-23.4	3.15	138.35	7.66	2.61	116.33	7.35	1.61	191.88	9.55
			18:00			-32.6913	-22.7974	3.15	133.19	7.68	2.64	111.17	7.35	1.53	192.27	9.58
			00:00			-33.1739	-21.5922	2.81	138.37	8.00	2.20	101.93	6.71	1.06	179.58	9.44
			06:00			-33.6565	-20.387	3.21	171.72	10.03	1.70	87.40	6.39	2.45	186.30	12.83
			12:00			-34.1391	-19.1817	3.61	183.56	11.20	1.35	65.22	7.15	3.28	190.64	13.23
31 Mar.	**13:00**	**-1**	**14:00**	**34°18.00′**	**018°47.00′**	**-34.3**	**-18.78**	**3.7**	**189.33**	**12.18**	**1.41**	**3.25**	**9.46**	**3.42**	**192.30**	**14.90**
31 Mar.	13:25	-1	14:25	34°21.36′	018°40.00′	-34.356	-18.667	3.72	189.98	12.18	1.13	62.90	7.49	3.48	193.47	15.11
			18:00			-34.3107	-18.6494	3.73	189.84	12.14	1.20	3.25	9.47	3.53	193.73	14.81
			00:00			-34.2349	-18.6199	3.56	187.18	11.55	1.34	3.15	8.72	3.30	193.83	14.38
			06:00			-34.1591	-18.5903	3.15	191.15	11.15	1.13	3.26	8.74	2.94	195.61	13.56
			12:00			-34.0833	-18.5608	2.75	195.43	10.80	1.36	3.43	8.65	2.39	194.10	12.95
1 Apr.	13:00	-1	14:00	34°03.48′	018°33.04′	-34.058	-18.551	2.59	197.44	10.68	1.30	3.48	8.55	2.24	195.55	12.81

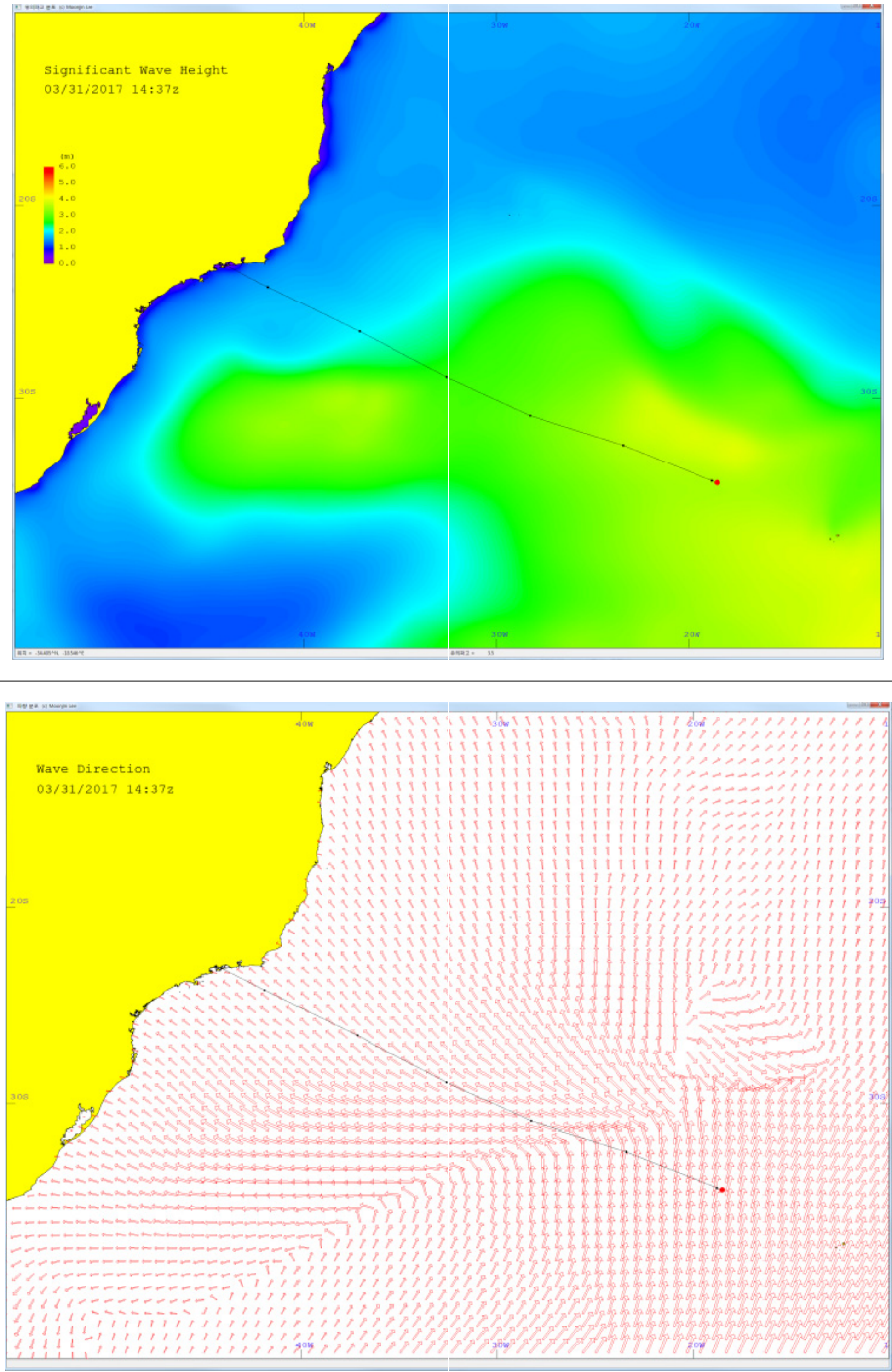
40) Waves are generally categorized as either wind waves, generated when winds strengthen, or swells, generated away from their area of origin when winds are calmer. The waves referred in the forecast are the combination of these two types, marked as "combined wave" in the table.

41) Wave direction means the direction which the wave is coming from, the same as the way the waves are generally reported.

[Table 15] Winds and currents on the voyage route of Stellar Daisy (Reconstructed NOAA data)

Date and Time				Location				Wind			Current		Air	
Date	Time Local	Time Zone	UTC	Lat. S	Long. W	Lat. Decimal	Long. Decimal	BF No.	Speed m/s	Dir.	Eward m/s	Nward m/s	Temp. ℃	Press. Pa
26 Mar.	13:00	-3	16:00	24°13.00′	041°52.00′	-24.28	-41.87	4	5.79	245.38	-0.24	0.09	25.65	101316.4
			18:00			-24.4774	-41.457	4	6.36	227.68	-0.32	0.19	26.25	101110.9
			00:00			-25.0696	-40.2178	4	7.04	223.96	-0.08	-0.01	25.65	101168.9
			06:00			-25.6617	-38.9787	4	5.54	249.6	0.12	0.13	25.35	100985.5
			12:00			-26.2539	-37.7396	3	4.90	231.96	-0.18	0.10	25.55	101070.9
27 Mar.	13:00	-2	15:00	26°33.00′	037°07.00′	-26.55	-37.12	3	4.04	207.58	-0.18	0.04	25.15	100913.3
			18:00			-26.8438	-36.5525	4	6.76	168.74	0.01	0.09	25.25	100907.4
			00:00			-27.4313	-35.4175	6	11.49	153.55	0.28	0.18	24.25	101036.4
			06:00			-28.0188	-34.2825	6	12.85	155.21	0.05	0.10	23.55	101018.7
			12:00			-28.6063	-33.1475	6	12.85	144.44	0.08	0.02	23.65	101152.7
28 Mar.	13:00	-2	15:00	28°54.00′	032°35.00′	-28.9	-32.58	7	14.34	143.51	0.02	0	23.25	100926.3
			18:00			-29.15	-32.0388	6	13.25	144.99	-0.08	0.05	22.95	101247.8
			00:00			-29.65	-30.9563	6	12.32	143.95	0.15	0	21.45	101513.6
			06:00			-30.15	-29.8738	6	10.82	131.74	-0.22	-0.14	20.95	101495.5
			12:00			-30.65	-28.7913	6	11.16	121.18	-0.08	0.17	20.75	101624.3
29 Mar.	13:00	-2	15:00	30°54.00′	028°15.00′	-30.9	-28.25	6	12.08	114.87	-0.08	0.06	20.25	101542.4
			18:00			-31.0938	-27.6438	6	12.24	116.40	-0.11	0	20.15	101627.0
			00:00			-31.4813	-26.4313	6	12.08	115.23	-0.12	0	20.05	101800.2
			06:00			-31.8688	-25.2188	6	12.69	122.45	-0.13	-0.17	19.35	101757.8
			12:00			-32.2563	-24.0063	6	13.72	121.99	0	-0.24	18.55	101994.2
30 Mar.	13:00	-2	15:00	32°27.00′	023°24.00′	-32.45	-23.4	6	11.86	122.36	-0.13	-0.26	19.05	101822.1
			18:00			-32.6913	-22.7974	6	12.80	117.25	-0.43	-0.34	18.35	101778.5
			00:00			-33.1739	-21.5922	6	11.70	112.99	-0.14	-0.15	19.05	101666.0
			06:00			-33.6565	-20.387	5	9.24	122.18	-0.20	-0.08	18.15	101639.2
			12:00			-34.1391	-19.1817	5	9.66	127.64	0	0.05	17.95	101783.5
31 Mar.	**13:00**	**-1**	**14:00**	**34°18.00′**	**018°47.00′**	**-34.3**	**-18.78**	**4**	**6.64**	**123.76**	**0.29**	**0.08**	**17.65**	**101717.1**
31 Mar.	13:25	-1	14:25	34°21.36′	018°40.00′	-34.356	-18.667	4	7.40	120.45	0.19	-0.04	17.45	101702.9
			18:00			-34.3107	-18.6494	4	7.12	158.41	0.19	-0.04	18.25	101754.3
			00:00			-34.2349	-18.6199	4	6.83	161.03	0.13	0.21	18.65	101865.9
			06:00			-34.1591	-18.5903	4	6.58	178.17	0.13	0.21	18.75	101805.2
			12:00			-34.0833	-18.5608	3	5.25	178.58	0.13	0.21	19.05	102014.3
1 Apr.	13:00	-1	14:00	34°03.48′	018°33.04′	-34.058	-18.551	3	5.48	188.81	0.13	0.21	18.75	101805.2

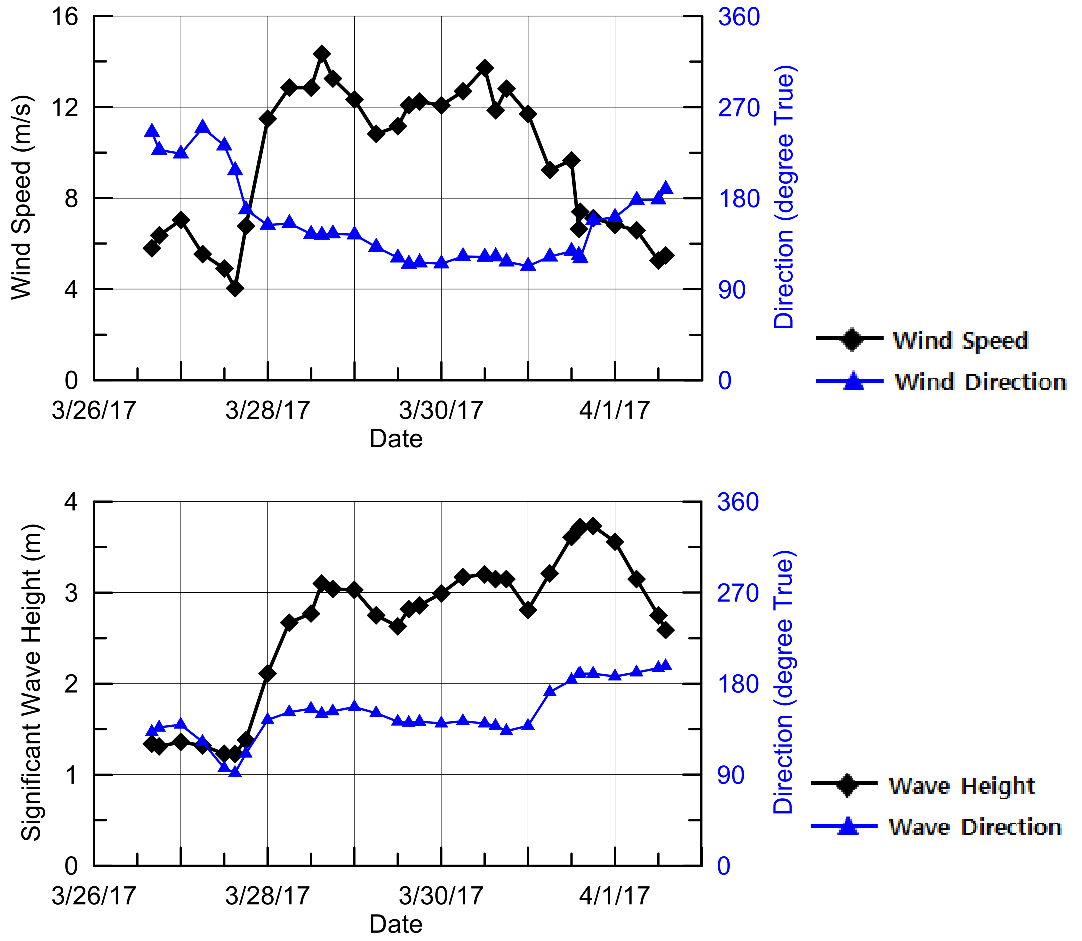
4.1.1.4 The significant wave height (Hs) and wave direction distribution at the time of the accident are visualized in [Figure 31].



[Figure 31] Distribution of Hs and wave directions at the time of the accident

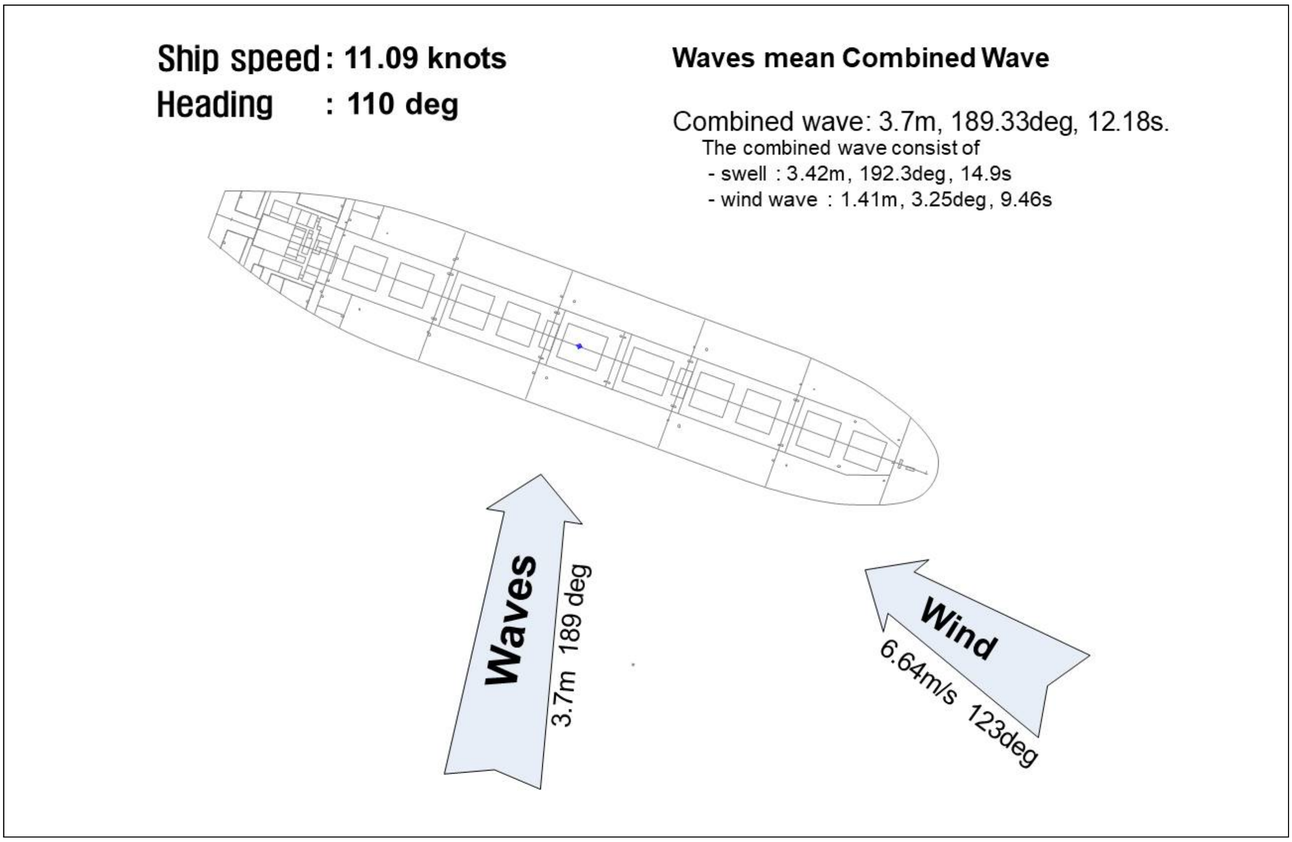
4.1.1.5 According to the Noon Report of Stellar Daisy, the ship sailed at about 12 knots for two days after departing from GIT in Brazil on 25 March. She maintained her main engine speed at 64 rpm. However, as the wind and waves increasingly got stronger, the speed dropped to 11.67 knots on 28 March, reaching 11.08 knots on average by noon on 30 March. At noon on the next day, with continuing impacts from strong winds and waves, the ship was operating at an average speed of 11.09 knots.

4.1.1.6 Analysis also shows that Stellar Daisy sailed at 11.5 knots on average for about 129 hours from the time her departure on 25 March 2017 to the moment of the accident. Meanwhile, she encountered winds mainly coming from the southeast at a speed of 6-14 m/sec and waves with Hs of 1.2-3.7 meters, but the waves direction shifted from the east to the south, as demonstrated on the graphs in [Figure 32].



[Figure 32] Sea states of the accident voyage by time

4.1.1.7 At the moment of the accident, the wind was coming from the starboard bow of Stellar Daisy at about 6.6 m/sec, while a 3.7-meter-high wave was coming from the ship's starboard beam.



[Figure 33] Wind and wave at the time of the accident

4.1.1.8 The ship's motions, including heave, roll, and pitch, were estimated[42] to figure out the influence that such conditions had made on this accident.

42) The motions were estimated by the Korea Research Institute of Ships and Ocean Engineering (KRISO).

[Table 16] Estimated motions of Stellar Daisy at the time of the accident

Standard Spectrum (Wave spectrum combining wind-generated waves and swells) (Reference: ITTC Standard Spectrum)		
Hs: 3.7 m		
Wave Heading: 100° Port		
Motion	Significant Values	Maximum Values
Heave (m)	0.60	1.20
Roll (deg.)	0.54	1.08
Pitch (deg.)	0.44	0.88
Swell Spectrum (mostly consisting of swell-dominated waves) (Ref.: ISO15016 Swell Spectrum)		
Hs: 3.42 m, Period: 14.90s		
Wave Heading: 100° Port		
Motion	Significant Values	Maximum Values
Heave (m)	1.30	2.60
Roll (deg.)	1.06	2.12
Pitch (deg.)	0.20	0.40

* When the wave heading is 0°, the wave proceeds in the same direction as the ship while 180° means it is proceeding in the opposite direction.
* The maximum value refers to the largest among thousands of motions, which is generally double the significant value.
* In order to figure out when the motion gets higher, the following two spectra were considered: standard wave spectrum and swell spectrum.

4.1.1.9 It is estimated that the motion of Stellar Daisy affected by the sea state at the time of the accident would increase as the waves in the form of swells came from the starboard beam. In this case, the values of heave, roll, and pitch were calculated at 1.3 m, 1.06°, and 0.20°, respectively. Despite high waves, given the ship's size, such motions are considered a relatively low or an average level.

4.1.1.10 Therefore, it is determined that such sea states, including waves at the time of the accident, are less likely to have increased the ship's motion excessively and caused significant damage to the hull or capsized the ship.

4.1.2 Intact stability

4.1.2.1 The intact stability of Stellar Daisy was calculated in [Table 17] based on the weight of cargo, ballast water, and fuel loaded on board when the ship had departed from GIT in Brazil on 25 March 2017.

[Table 17] Intact stability calculation on departure[43]

Name		Weight	CGX	CGY	CGZ
		Ton	m	m	m
CARGO HOLD	RHO=2.646				
NO.5 CARGO		51302.30	70.90	0.00	13.60
NO.4 CARGO		50400.00	119.27	0.00	13.53
NO.3A CARGO		30400.20	157.94	0.00	13.58
NO.3F CARGO		30400.20	187.69	0.00	13.58
NO.2 CARGO		50700.30	226.37	0.00	13.58
NO.1 CARGO		46800.90	272.06	0.00	13.92
SUBTOTAL		260003.90	170.63	0.00	13.64
HFO	RHO=0.960				
		3229.50	44.98	-0.88	17.70
BWT	RHO=1.025				
		100.00	9.13	0.00	12.77
FWT	RHO=1.000				
		300.00	12.02	3.39	22.08
DOT	RHO=0.900				
		162.00	26.82	18.15	20.94

	Weight	CGX	CGY	CGZ
Deadweight	263795.60	168.77	0.00	13.70
Lightweight	38188.70	145.34	0.00	14.98
Displacement	301984.30	165.80	0.00	13.86

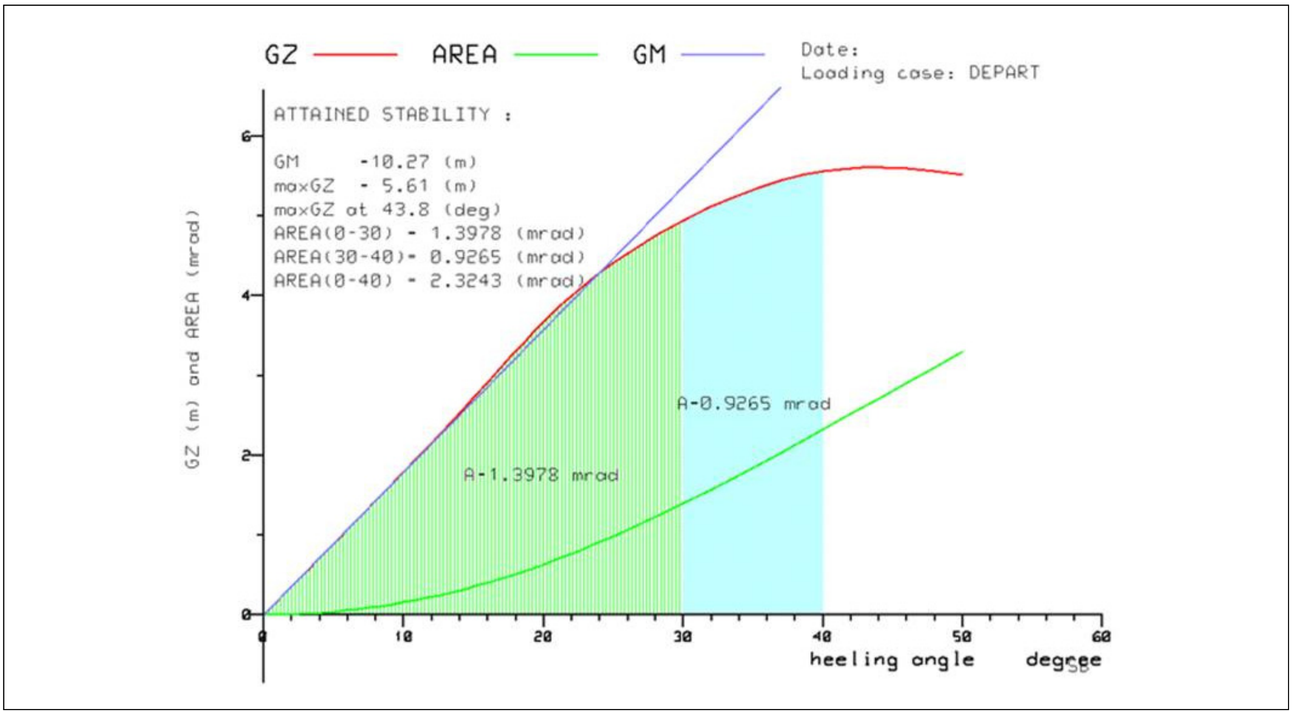
FLOATING POSITION

Draught moulded	**20.23**	m	**KM**	**24.14**	m
Trim[44]	**0.07**	m	**KG**	**13.86**	m
Heel, SB=+	**0.00**	deg			
TA	**20.20**	m	**GM**	**10.27**	m
TF	**20.27**	m	**GMCORR**	**0.00**	m
Trimming moment	**25915.00**	ton-m	**GoM**	**10.27**	m

43) Factors, such as ballast water (0.03% of the then displacement) and fuel oil (1.07% of the then displacement), determined not to have a significant influence on the ship's stability, are calculated based on the total weight loaded, not the individual weight of each tank.

44) It is slightly different from the drafts (fore 20.22 m and aft 20.22 m) in the ship's draft survey report written upon departure. The ones in the report are the drafts read during the draft survey. On the other hand, some weights in this intact stability calculation used design ones since their exact weights were unknown. In that case, these weight differences presumably led to a slight difference in drafts.

4.1.2.2 The righting lever curve of Stellar Daisy resulting from the stability calculation is demonstrated in [Figure 34].



[Figure 34] Righting lever curve

4.1.2.3 Stellar Daisy satisfied the required intact stability criteria[45], such as the initial metacentric height and maximum righting lever, at the time of her departure as shown in [Table 18].

[Table 18] Results of the intact stability criteria on departure

IMO's Intact Stability Criteria	Requirements	Calculated Values	Result
Initial metacentric height (GoM)	≥0.15 m	10.27 m	Satisfied
Maximum righting lever (GZmax)	≥0.2 m at heel angle≥30°	5.61 m at 43.8°	Satisfied
Area under the righting lever curve (m-rad)	AREA (0°-30°) > 0.055	1.3978	Satisfied
	AREA (30°-40°) > 0.030	0.9265	Satisfied
	AREA (0°-40°) > 0.090	2.3243	Satisfied

45) IMO Resolution A.749 (18) Chapter 3.1 specifies the safety criteria of intact stability, i.e., the general criteria of the magnitude of restoring force which makes a ship float upright or return to her original position on her own when the ship's hull is not damaged.

4.1.2.4 When loading grain in a bulk carrier, the effect of the angle of repose[46] must be considered to secure the ship's stability. Thus, the grain stability is to be reviewed in accordance with the International Code for Safe Carriage of Grain in Bulk of IMO[47]. Although Stellar Daisy is not subject to the grain stability requirement since she was not loaded with grain, the KMST calculated her grain stability by applying the same load cases as the ones applied to the intact stability calculation to determine the effect of cargo shift. The result showed that the ship satisfied the grain stability criteria as well.

[Table 19] Results of the grain stability criteria

IMO Grain Stability Criteria	Requirements	Calculated Values	Result
Heel angle	≤12°	6.3°	Satisfied
Initial metacentric height (GoM)	≥0.3 m	10.335 m	Satisfied
Area under the righting lever curve (m-rad)	AREA (0°-40°) > 0.075	1.687	Satisfied

4.1.3 Damage stability

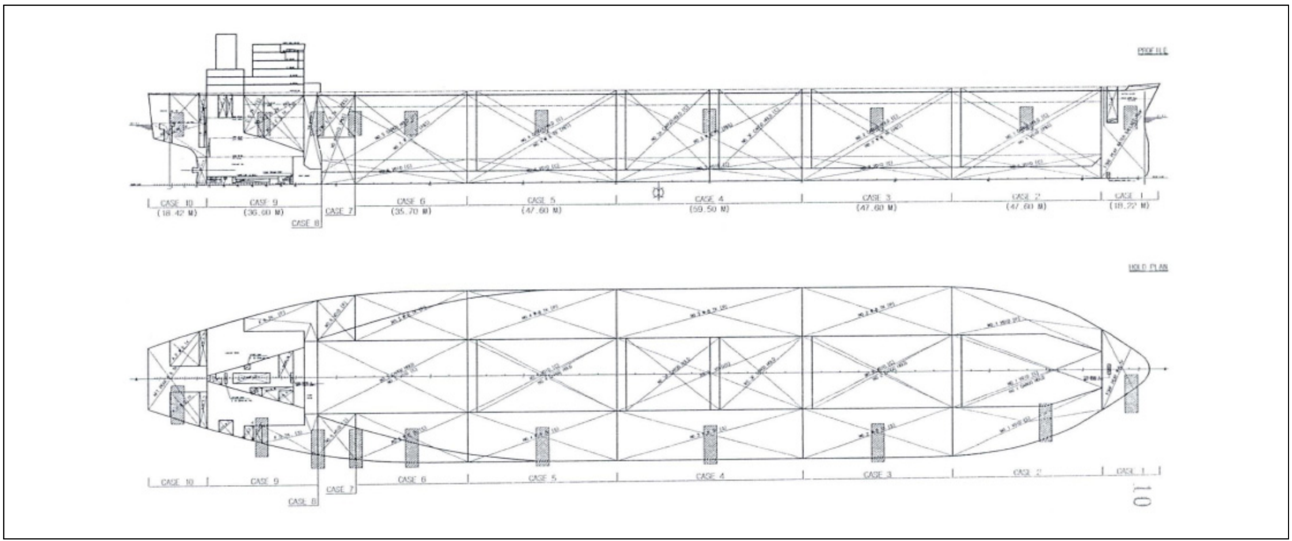
4.1.3.1 KR reviewed the damage stability of Stellar Daisy to assign the ship with a freeboard pursuant to the requirements in Regulation 27 (Freeboard) (8) (d) of Annex B (revision) of the Protocol of 1988 Relating to the International Convention on Load Lines, 1966 (hereinafter as "ICLL 1988").

4.1.3.2 According to the damage stability book approved by KR on 19 June 2009, it was reviewed whether she reached equilibrium in the damage conditions defined in Regulation 27 (12) of Annex B of the ICLL 1988, or where a portion of watertight compartments are damaged and flooded under the condition that cargo is evenly loaded to the level of the summer load line. And, the results showed that the ship satisfied the damage stability criteria.

46) When a ship inclines over a certain angle, the surface of the loaded cargo inclines, shifting the cargo. As a result, the ship's stability would decline, which is called the effect of the angle of repose.

47) The International Code for Safe Carriage of Grain in Bulk adopted at IMO Resolution MSC.23 (59)

4.1.3.3 The ship's damage stability book reviewed a total of 10 damage cases. The stability calculations of each case are presented in [Figure 35] and [Table 20].



[Figure 35] Damage cases

[Table 20] Results of damage stability calculation

Damage Case	Damaged Compartments	Heel Angle[48]	GM minimum (A)	GM actual (B)	GM excess (B-A)
CASE No. 1	BOSUN STORE (C) CHAIN LOCKER (P/S) F.P.W.B TANK (C)	0.00	0.004	7.021	7.017
CASE No. 2	CARGO HOLD No. 1 (C) VOID No. 1 (S) VOID No. 1 (C)	9.82	6.258	7.021	0.763
CASE No. 3	WBT No. 2 (S)	10.12	4.790	7.021	2.231
CASE No. 4	WBT No. 3 (S)	12.29	5.799	7.021	1.222
CASE No. 5	WBT No. 4 (S)	9.44	4.384	7.021	2.638
CASE No. 6	WBT No. 5 (S)	5.26	2.585	7.021	4.436
CASE No. 7	WBT No. 5 (S) VOID No. 6 (S) FWD F.O.TANK (S) F.O.TANK (S)	6.29	3.184	7.021	3.837
CASE No. 8	FWD F.O.TANK (S) VOID No. 6 (S) F.O.TANK (S)	0.32	0.668	7.021	6.353
CASE No. 9	ENGINE RM F.O.TANK (S) D.O.TANK (S) STEERING G. RM (C)	0.18	0.755	7.021	6.266
CASE No. 10	ENGINE RM APT TANK (C) STEERING G. RM (C)	0.00	0.383	7.021	6.638

4.1.3.4 Among the ten damage cases, seven (Case Nos. 2–8) are related to the flooding of the wing tanks inside adjacent to the cargo hold. Moreover, the damage stability criteria required in SOLAS Regulation XII 4.2 (Damage stability requirements applicable to bulk carriers) are applicable for case No. 2 where cargo hold No. 1 is damaged. In that case, calculations showed that the heel angle was 9.82°, which is less than the threshold of 15°, while the GM was 7.021 m, which is 0.763 m higher than the threshold of 6.258 m. Such results indicate that the damage stability of Stellar Daisy met the requirements specified in Regulation XII/4[49].

4.1.3.5 The actual loading condition of Stellar Daisy at the time of the accident was not the same as the loading condition specified in the damage stability booklet, meaning that the damage stability in the loading condition at the time of the accident needs to be reviewed. [Table 21] compares the loading condition in the damage stability booklet for the damage stability calculation with the condition at the time of the accident[50]. The latter had a relatively better stability than the former since its GM value was about 3 m higher and its draft was about 0.1 m less than those of the former.

[Table 21] Damage stability comparison:
damage stability book vs. actual loading condition at the time of the accident

Item	Loading Condition in Damage Stability Booklet	Actual Loading Condition (Accident)	Remarks
Specific Gravity of Cargo	1.92298724	2.646	
Displacement	304329.25 MT	301984.3 MT	
GoM	6.96 m	10.27 m	3.3 m increase
Mean Draft	20.33 m	20.22 m	0.107 m decrease

48) In accordance with Regulation 27 (13) (c) of Annex B of the ICLL 1988, the angle of heel shall be no greater than 15°, and if no part of the deck is immersed, the heel angle of up to 17° may be accepted.

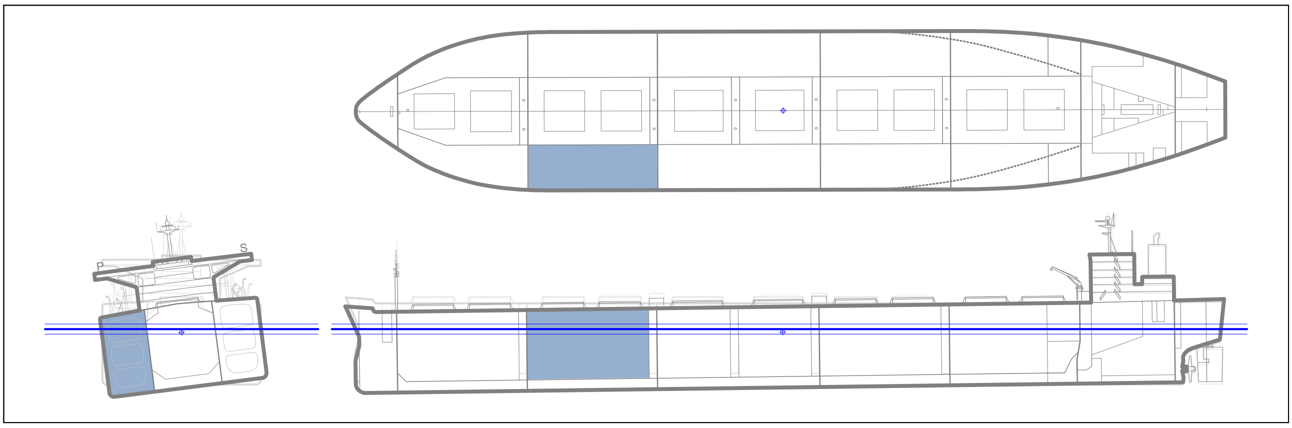
49) In accordance with SOLAS Regulation XII/4/2, it is the vicinity of the cargo hold No. 1 where any part of longitudinal bulkhead is located within B/5 or 11.5 m, whichever is less, inboard from the ship's side. Therefore, the results showed that Stellar Daisy in case No. 2, where the cargo hold No. 1 was included, was able to remain afloat in a condition of equilibrium even after being flooded, which satisfies regulations specified in Paragraph 4.

50) The damage stability in the actual loading condition at the time of the accident was calculated by KRISO.

4.1.3.6 Stellar Daisy had better damage stability at the time of the accident than the one written in the damage stability booklet. Therefore, the actual heel angle would have been smaller than the one calculated in each damage case, meaning that it is less possible that the upper deck or the deck opening was flooded.

4.1.3.7 Stellar Daisy sent a message, reporting that "The ship's No. 2 Port is leaking" at the time of the accident, and here, "No. 2 Port" is presumed to mean WBT No. 2 (P). In this accident, the situation corresponds to damage case No. 3 in the damage stability booklet, and an angle of heel is calculated at 10.12° in case WBT No. 2 (P or S) is damaged.

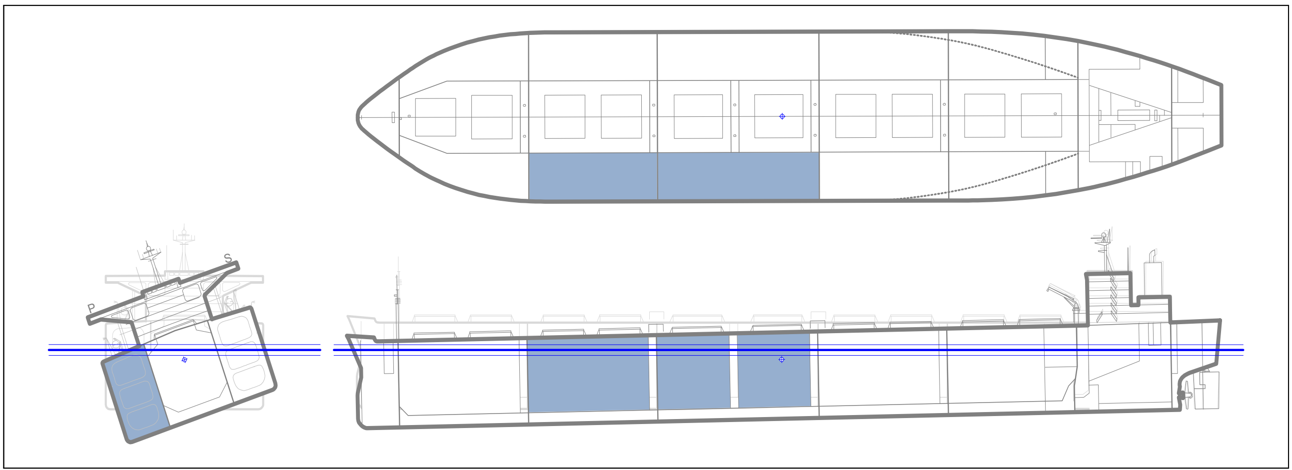
4.1.3.8 The calculations also showed that if WBT No. 2 (P) were damaged under the actual loading condition at the time of the accident, the ship would heel over about 7° and submerge about 1.2 m further as demonstrated in [Figure 36].



[Figure 36] The hull's immersion and posture if WBT No. 2 (P) were damaged[51)]

4.1.3.9 In addition, the calculations showed that when both WBT Nos. 2 and 3 (P) were simultaneously flooded under the loading condition at the time of the accident, which is not the required criteria of the damage stability caculation, the heel angle would be about 19°, the ship would go under about 3.3 m, and thereby the upper deck of the ship would start submerging. Despite the significant wave height at the time of the accident, the hatch covers of the cargo holds were estimated to remain afloat as in [Figure 37].

51) When it was assumed that damage was made to an area of 1 m x 4 m on the lower shell plate of WBT No. 2 below the waterline, the results showed that it took about 500 seconds to reach 90% of the ship's final state since the flooding had begun. (Here, the blue line indicates changing waterlines at an Hs of 3.7 m.)



[Figure 37] The hull's immersion and posture if WBT Nos. 2 & 3 (P) were damaged[52)]

4.1.3.10 In conclusion, the loading conditions of Stellar Daisy had satisfied the damage stability criteria required in the international conventions at the time of the accident. Even if WBT Nos. 2 and 3 (P) were both damaged, it seemed difficult to determine that such stability had caused the ship to sink in the sea.

4.1.4 Longitudinal strength under cargo loading

4.1.4.1 The KMST reviewed the bending moment (BM)[53)] and the shearing force (SF)[54)] of Stellar Daisy depending on the cargo loading conditions upon departure from the GIT in Brazil by referring to the ship's loading computer approved by KR.

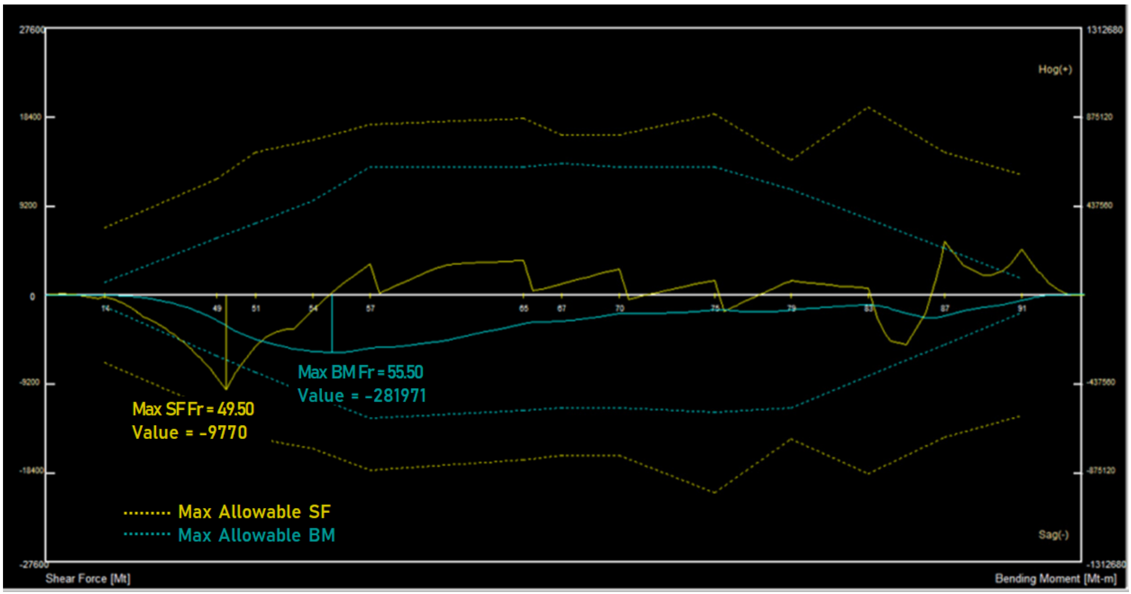
4.1.4.2 While Stellar Daisy was putting on cargo at GIT in Brazil from 23 to 25 March 2017 (when berthing), the maximum values of both the BM and the SF were within their allowable limits: the BM was 68% of its allowable limit at the frame No. 65.50; and the SF was 60% at the frame No. 61.00.

52) In a scenario where damage was made to an 1 m x 4 m area on the lower shell plate of both WBT Nos. 2 and 3 (P) under their waterlines, it took about 700 seconds to reach 90% of the ship's final state.

53) The bending moment (BM) is the integral of the shearing force (SF), which is generated due to a difference between the buoyancy and the gravity acting in the longitudinal direction of the ship. The BM is zero at the ends of the hull while reaching a maximum value around the midship.

54) The shearing force (SF) refers to the force to a certain transverse section due to a difference between the buoyancy and the weight force acting in the longitudinal direction of the ship.

4.1.4.3 The at-sea values of the BM and the SF when cargo loading had been completed were calculated in [Figure 38]. The maximum value of the BM was 53% at the frame No. 55.00, and that of the SF was 77% at the frame No. 49.50, meaning that both remained within their allowable limits as well.



[Figure 38] Longitudinal strength calculation after completion of loading

4.1.4.4 Stellar Daisy was able to deballast at about 7,000 MT per hour while the loading rate of on-shore conveyor system was about 8,500 MT per hour, leaving a gap of 1,500 MT per hour. If such capacity difference hampers deballasting operations during loading operations, it may temporarily affect the hull's strength at a certain structure. Therefore, the loading operations must be slowed or halted in line with the deballasting rate of the ship in order to prevent such problems. However, given that no records showed the operations had been halted due to a delay in deballasting, it seemed that there were no deballasting issues, and thereby, no impact on hull strength as well.

4.1.5 Cargo liquefaction

4.1.5.1 The cargo loaded on Stellar Daisy at GIT in Brazil is iron ore fines, classified into Group A under the IMSBC Code. When such a cargo contains moisture above a certain content level, it can be liquefied.

4.1.5.2 Before loading, the shipper, Vale S.A, provided the ship with the Certificate of Moisture Content and Transportable Moisture Limit, which showed that the MC of the loaded cargo was 9.23%, which is lower than the TML of 11.44%.

4.1.5.3 According to the local weather information, it did not rain during the period when the ship checked the cargo MC before loading and completed the loading operations. The statements by the surviving crewmembers also confirmed that it had not rained during the loading operations nor her sailing until the date of the accident.

4.1.5.4 Also, the ship measured and discharged bilge water from the cargo holds twice a day (at 08:00 and 16:00) when sailing and reported the results to the shipping company every three days. The records showed that the height of bilge water measured from each cargo hold from 27 to 29 March 2017 had been between 0.19 and 0.30 m (the height of the bilge well is 0.9 m), indicating bilge water had not surged significantly in the cargo holds.

4.1.5.5 Although Stellar Daisy loaded a liquefiable cargo of iron ore fines, the MC of the cargo was less than its TML when being loaded. Moreover, it did not rain during loading, and no significant amount of bilge water was in the cargo holds while the ship was underway. Therefore, the cargo was deemed unlikely to have liquefied during the voyage.

4.1.6 Sub-conclusion

4.1.6.1 The KMST analyzed the following factors in order to review general accident causes likely to occur during VLOC voyages: the sea states at the time of the accident; the ship's intact stability and damage stability; longitudinal strength on loading; and probability of liquefaction. However, none of these causes were found to have possibly contributed to this accident.

4.2 Ship conversion and structural condition

4.2.1 Ship conversion

4.2.1.1 KR reviewed whether the longitudinal and transverse strength of Stellar Daisy satisfied the level required in the KR rules based on the results from the structural analysis to check the structural adequacy of the hull design at the time of the ship's conversion. For the midship, the RO assessed direct strength[55] as well.

4.2.1.2 As for longitudinal strength, the longitudinal BM and SF of Stellar Daisy met the required levels in the KR rules while the ship satisfied the required level of transverse strength as well by increasing scantlings of frames or adding web frames.

4.2.1.3 For direct strength, KR conducted the structural analysis of three cargo holds[56] in way of the midship of Stellar Daisy as the analysis scope. The RO applied a total of nine load cases to the analysis by dividing loads into external loads, including still water pressures and wave-induced loads, and internal loads, which reflected cargo and ballast loads.

4.2.1.4 In the Guidance Relating to the Rules for the Classification of Steel Ships of KR (Part 3, Annex 3-2 Guidelines for the Direct Strength Assessment, Table 8), the allowable value of the buckling criterion was defined as 1.2 at the time of conversion. Also, the Guidance stated an exceptional clause[57] that "the buckling strength can be examined by other analytical procedure instead of the guidance when deemed appropriate by the Society." KR considered that the ship could have greater strength than the allowable value of the buckling criterion defined by the International Association of Classification Societies (IACS) even when changing its allowable value of the buckling criterion to 1.0. Thus, KR applied an allowable value of 1.0 based on the exceptional clause when reviewing the buckling strength.

55) Various empirical equations are used for designing a ship's hull structures. However, such equations are not sufficient to guarantee structural integrity. The direct strength assessment is intended to evaluate the hull's structural integrity by directly applying the observed wave information, and observing how the hull responds to it.

56) A full of C/H No. 3 (Nos. 3F and 3A) and half of C/H Nos. 2 and 4

57) The Guidance Relating to the Rules for the Classification of Steel Ships of KR, Part 3 Hull Structure, Annex 3-2 Guidelines for the Direct Strength Assessment III.2 (1) (C).

4.2.1.5 The results of the direct strength calculation showed that the ship's renewed structural members had a stress[58] level within their allowable limits[59] and also satisfied the allowable buckling criterion of 1.0 or above[60] except for certain members such as web frames. Therefore, after being modified (reinforced), those structural members with a low buckling strength[61] were reassessed and the results showed that they satisfied the allowable limits.

4.2.1.6 When calculating the allowable stress in the direct strength analysis, KR used design thickness, which included corrosion additions (thickness on the drawings), for the scantlings of the hull members. This decision may have complied with the KR rules, but the design thickness may not reflect precisely how much the corrosion had progressed up to the time of the conversion, compared to the actual measured thickness.

4.2.1.7 At the time of conversion, the ship did not carry out a fatigue strength assessmen t[62], as it was not required in the KR rules. Thus, no review was made at the time of the conversion on how much fatigue had accumulated in the hull of the crude oil tanker before the conversion and whether the resultant structural vulnerability was acceptable.

4.2.1.8 In addition, when newly built members for longitudinal strength, including the inner bottoms, hopper, and topside structures inside the cargo holds, were welded with the existing members, a fillet weld[63] with a leg length[64] of 5 mm was used for several members. The same weld was used for the face plate of the side transverse web frame in way of the bilge when reinforcing it with doubler plates for transverse strength.

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58) Stress refers to the force per unit area generated inside a hull structure to resist the load applied to it.

59) It means the reference stress which should always be no less than working stress generated while a structure is being loaded.

60) When the ship encountered the wave crest in ballast condition, the bottom plate had the largest compression force (the buckling criterion of 1.294). The largest compression force (1.276) was applied to longitudinal bulkhead plates when the ship was in the ballast and hydraulic test conditions. The side shell plate had the largest compression force (1.164) when the ship was loaded with high-density cargo (3.0) under crest wave conditions.

61) Web Frame, W.T.BHD, Support BHD

62) Fatigue failure is where a structure suffers a crack when repeatedly facing the level of stress less than its yield stress. And, fatigue strength refers to the strength of the fatigue failure that a structure can withstand.

63) When welding two members at right angles, such as plates and stiffeners, one is to be welded onto the corner of the joint.

64) The leg length refers to the distance from the corner of the joint to the weld toe.

4.2.1.9 When new members are installed for longitudinal strength, it is typical that a full or partial joint penetration weld[65], rather than a fillet weld, is applied to the area cut by the existing transverse bulkhead so that the continuity of longitudinal strength can remain the same.

4.2.1.10 When a fillet weld is applied, the weld can be corroded or even cracked as material property deteriorates. Therefore, careful inspection and management are required for the welds when fillet welding is applied to major members, which reinforce the hull strength.

4.2.1.11 No cracks are presumed to have resulted from the fillet welding, as no record showed that damage or repairs were made to the welds of the newly installed members in the inspection reports carried out after the conversion of Stellar Daisy.

4.2.2 Alternate offloading

4.2.2.1 With respect to cargo loading, the "Final Trim, Stability & Longitudinal Strength Booklet" of Stellar Daisy approved by KR defined the loading condition as the cases where the ship departs from or arrives at port with fully loaded cargo evenly distributed in each cargo hold. Based on this condition, the hull strength was calculated and the booklet was approved. No mention is made about a situation where the cargo is unequally distributed among the holds.

4.2.2.2 The second paragraph of the "Guidance for Masters" on page five of this booklet tells that the load computer can supplement calculation of stability and strength for loading conditions not mentioned in this booklet.[66] The fifth paragraph on the same page adds, Masters shall take special care when loading cargo in a way not included in this booklet.[67] However, the booklet does not specify what the special care is and how masters are to practice it.

65) In metallic welding, one is joined by penetrating the weld metal fully or partly into the joint, which is called a full or partial joint penetration weld.

66) As a complement to this booklet the loading computer provided on board may also be used to perform the trim, stability and strength calculation for any loading conditions not included in this booklet.

67) It should be noted that, however, this booklet can not cover unusual condition or and the master of the ship shall take special care when loading the ship different loading cases.

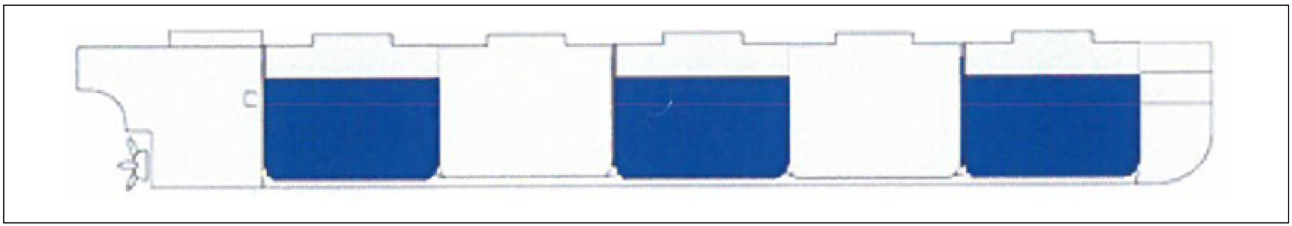
4.2.2.3 The SOLAS Regulation XII/14 (Restrictions from sailing with any hold empty) regulates that bulk carriers of 150 m in length and upwards of single-side skin construction, carrying cargoes having a density of 1,780 kg/m³ and above, shall not sail with any hold loaded to less than 10% of the hold's maximum allowable cargo weight when in the full-load condition. However, Stellar Daisy, which obtained a double-side skin construction after the conversion, does not apply to this regulation.

4.2.2.4 It was during eight voyages, described in [Table 22], when the vessel offloaded cargo at two discharging ports among 33 voyages with a full load after the conversion. Among those, the ship offloaded the same amount of cargo from each hold at the first port of discharge and moved to the second discharge port during the four voyages. However, the ship was operated in an "alternate loading condition," meaning that the ship offloaded all of the cargo from alternate holds at the first port of discharge and then emptied out the other holds at the second discharge port over the remaining four voyages as illustrated in [Figure 39].

[Table 22] History of multi-port discharge after conversion

No.	Loaded Cargo	Port of Loading	Duration	Port of Discharge	Duration	Note
V.23	253,012 MT	Ponta Da Madeira	2013/01/28 - 02/16	Gwangyang Port, Pohang Port	2013/03/31 - 04/05 2013/04/05 - 04/10	HOM
V.25	258,507 MT	Ponta Da Madeira	2013/08/16 - 08/21	Gwangyang Port, Pohang Port	2013/10/04 - 10/05 2013/10/06 - 10/08	HOM
V.26	259,173 MT	Ponta Da Madeira	2013/11/18 - 12/01	Gwangyang Port, Pohang Port	2014/01/13 - 01/15 2014/01/16 - 01/26	HOM
V.30	259,800 MT	Ponta Da Madeira	2014/12/09 - 12/21	Majishan, Qingdao	2015/02/01 - 02/04 2015/02/05 - 02/08	HOM
V.31	260,027 MT	Tubarao	2015/03/18 - 03/22	Majishan, Rizhao	2015/05/02 - 05/07 2015/05/08 - 05/11	**ALT**
V.33	259,916 MT	Ponta Da Madeira	2015/07/03 - 07/10	Majishan, Lianyungang	2015/08/22 - 08/28 2015/08/30 - 08/31	**ALT**
V.37	258,327 MT	Guaiba	2016/06/21 - 06/27	Lianyungang, Rizhao	2016/08/05 - 08/08 2016/08/08 - 08/13	**ALT**
V.40	260,002 MT	Guaiba	2016/12/19 - 12/25	Tianjin, Caofeidian	2017/02/05 - 02/08 2017/02/08 - 02/13	**ALT**

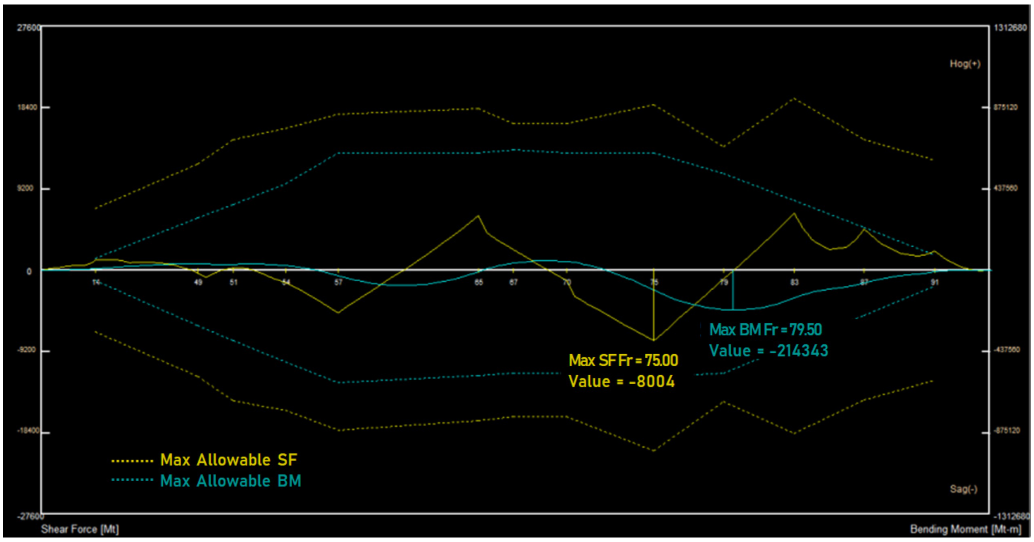
4.2.2.5 Even with voyage No. 40, the one just before the accident, Stellar Daisy discharged all of cargo from only cargo hold Nos. 2 and 4 and left cargo in cargo hold Nos. 1, 3, and 5 at the port of Tianjin in China and proceeded to Caofedian in China in the alternate loading condition.



[Figure 39] Example of alternate offloading (discharging cargo from alternate holds)

4.2.2.6 For the ship in the alternate loading condition during voyage No. 40, the loading computer calculated the hull strength and showed that both BM and SF were within the allowable levels as frame No. 75.90 had the maximum BM, amounting to 40% of the allowable level, and frame No. 75.00 had the maximum SF, or 93% of the allowable level as in [Figure 40].

4.2.2.7 However, the computer could not be used to check the ship's local stress[68] which might be generated when cargo was not evenly loaded or offloaded. That is because the computer could offer only the BM and the SF for hull strength.



[Figure 40] Longitudinal strength calculation of the loading computer

68) When high-density cargo is not evenly loaded, local areas of the hull would experience local stress concentration due to excessive loads, and such local stress could cause cracks and buckling.

4.2.2.8 If the decision is made to discharge cargo from alternate holds, in other words, the ship attempts to apply a loading condition not included in the booklet, the ship's RO should review in advance whether the ship's hull can be subject to local stress from unevenly loaded or offloaded cargo in accordance with the applicable rules. Accordingly, the ship may be required to reinforce the hull structures or be subject to restrictions on the voyage conditions, if necessary. However, neither the master of the ship nor the shipping company requested the RO to review the ship's specific loading condition.

4.2.2.9 In this case, Stellar Daisy had a double-side skin construction and was in the alternate hold cargo condition, not a fully loaded condition, meaning that she was not subject to SOLAS Regulation XII/14. Moreover, it was a short coastal navigation less than two days when the ship operated under the alternate loading condition. Therefore, it is determined that the resulting local stress would have been less likely to cause severe damage to the hull of Stellar Daisy.

4.2.2.10 However, the possibility cannot be completely ruled out that local stress may have been put on the hull when a ship was sailing with high-density cargo that was not evenly distributed in the holds, even though it was a short period of time. Moreover, repeated application of local stress to the hull could have any impact onto the overall hull strength. Therefore, if the ship was scheduled to sail in an alternate hold cargo condition, it is considered appropriate for the ship to have been reviewed by the RO prior to her voyages.

4.2.3 Repair on voyage

4.2.3.1 When Stellar Daisy was converted, the PSPC was not applied to the ship. Instead, she was hard coated. Poor coating condition in several WBTs, including WBT No. 3 (P)[69], and void tanks[70] were consistently noted in the inspection reports made by KR and the internal inspection reports written by the master on board.

69) According to Polaris Shipping, WBT No. 3 was in use only when the ship's air draft needs to be lowered at the ports of loading, but not in daily use.

70) According to the 3Q2015 Hull Inspection Report written by the master, a pipeline connected to the bilge well inside cargo holds was newly installed, and bilge water was discharged from cargo holds to void tanks through the pipeline, causing corrosion of the void tanks.

4.2.3.2 Of course, a poor coating condition of the hull does not mean that the poorly coated area must be newly coated or replaced with new materials. However, it is widely known that if the steel is in a poor coating condition, it may become corroded more easily and rapidly and its strength can be compromised as well.

4.2.3.3 Also, the 3Q2015 Hull Inspection Report pointed out a buckling of the vertical stiffeners in the transverse bulkhead at frame No. 65 between WBT Nos. 3 and 4 (P/S).

4.2.3.4 In May 2016, Polaris Shipping received a report from a naval architect who had attended and inspected the ship that repairs should be made. However, the company deployed the ship on one more voyage. Later, an attending surveyor of KR checked the buckling of the vertical stiffeners in the transverse bulkhead at frame No. 65 while conducting the annual survey on board Stellar Daisy around in August 2016.

4.2.3.5 KR's surveyor reported the damage to KR headquarters after determining that the damaged area of the vertical stiffeners was relatively large. KR reviewed the hold structural analysis report issued at the time of the conversion and confirmed that the stress level of the transverse bulkhead sufficiently satisfied its required allowable value. KR also noted that no other records existed of damage made to the adjacent bulkheads with the similar structure in the ship, and no other cases of similar damage were found among the other converted ships registered in the RO. Based on the facts, KR determined that the damage was limited to the transverse bulkhead at frame No. 65 of Stellar Daisy and advised permanent repair only for the damaged area.

4.2.3.6 The master of Stellar Daisy submitted his statement that such damage had been made when the ship had sailed under the inclement weather conditions (Beaufort Wind Scale 7 to 8). However, neither the company nor KR conducted a separate analysis to figure out whether the damage was caused due to a bad weather or some other factors.

4.2.3.7 Therefore, permanent repair was made to the damaged area in August 2016. Since then, in the ship's periodic inspection surveys, no reports were made that the repaired area or any of its adjacent areas had been damaged again up until voyage No. 41, meaning it is difficult to conclude this damage caused the accident.

4.2.3.8 Apart from that, the following facts were identified during the investigation: some of the repairs made in dry dock were not specifically written in the survey reports[71] or presumed to be written in error; and no actions were made to a buckled upper deck even after it was reported in internal inspection reports. However, nothing was found to be directly related to the accident.

4.2.4 Sub-conclusion

4.2.4.1 In this investigation, the KMST analyzed Stellar Daisy's survey records and the management records documented by the company while the ship traveled from the moment of being converted from a single-hulled oil tanker to an ore carrier till the time of the accident. As the result, the following cases were found: several WBTs and void tanks had been constantly corroded; repairs to the hull's major members had been delayed; efforts to identify causes of the damage had been insufficient; and the ship had operated in the alternate offloading condition without getting any safety review in advance.

4.2.4.2 Still, it is considered inappropriate to conclude that such factors caused sufficient hull damage to sink Stellar Daisy. If such factors are intertwined with other factors, they could serve as a potential cause to accelerate damage to the ship's hull.

4.3 Estimation of hull damage scope and sinking

4.3.1 Estimation of hull damage scope

4.3.1.1 The sinking of Stellar Daisy means she lost her buoyancy. In this report, therefore, analysis was conducted on the size and scope of the flooding which could lead to the loss of buoyancy and sinking of Stellar Daisy.

4.3.1.2 Stellar Daisy was sailing in a fully-loaded condition prior to the accident. Given the statements of the surviving crewmembers, the following situation of the sinking may be assumed:

71) Repairs made to major steel materials during the intermediate survey in May 2015 were not written in the survey report.

1) The waves were high.

2) There was virtually no pitching but some rolling.

3) A thundering "crash" was heard, and the hull shook furiously, and thereafter WBT No. 2 (P) was leaking and the ship began to heel to port.

4) The ship inclined 10˚ to 15˚ within one to two minutes after the loud sound and vibration. Two to three minutes later, the heeling angle reached almost 40˚.

5) The crewmember, AB A, jumped into the sea from the port wing of the bridge at a heel angle of 40˚ to 50˚.

6) No. 1 oiler who was on the starboard upper deck was washed overboard by rushing waves when the ship inclined about 50˚ to port.

7) There was no information about trim.

In sum, it took as short as five minutes for Stellar Daisy to sink after the great "crash" sound was heard and the great vibration of the hull was felt. While the ship was heeling to port, its heeling speed suddenly accelerated just before sinking, and then the ship went underwater.

4.3.1.3 The displacement of Stellar Daisy under the upper deck amounted to about 470,000 tons. Aside from about a 300,000-ton displacement at the time of the accident, the reserve buoyancy would be about 170,000 tons. And, the ship would sink under the condition of losing all of the buoyancy. Therefore, seawater as many as 170,000 tons of her reserve buoyancy should enter the hull.

4.3.1.4 In addition, since the ship sank only within five minutes, an amount of 170,000 tons of seawater would have had to enter the ship at a rate of at least 566 tons/sec during the same brief period. If it is assumed that the damaged area was 10 m below the sea level and the seawater entered the ship with the corresponding pressure, the opening size in the hull should be at least 40 ㎡.

4.3.1.5 However, a 170,000-ton seawater could not flow into the ship if only one compartment was flooded. The area below the upper deck plate was divided into several compartments with a unit size of 20,000 to 30,000 tons. Even when WBT No. 3, which is the largest compartment among the ballast or void tanks, was flooded, a mere 30,000-ton water would flow into the ship, meaning that multiple compartments had to be flooded simultaneously to sink the ship.

4.3.1.6 As in [Table 23], the KMST reviewed the amount of the water ingress depending on the damaged compartments, and the resulting probability of losing buoyancy (sinking). Even if every tank on the port side (WBTs and VTs) was flooded, the ingress of water would amount to a mere 110,000 tons, and the remaining 60,000 tons would enter into other compartments, such as cargo holds or tanks on the starboard side, so as for the ship to lose buoyancy.

[Table 23] Damage cases to determine probability of sinking

	Volume (㎥)	Port Flooding (ton)	Port+DB Flooding (ton)	Port+STBD Flooding (ton)	Port+DB+STBD Flooding with C/H Damage[72] (ton)
Light Weight		38188	38188	38188	38188
Miscellaneous Weight*		3691	3691	3691	3691
Cargo Hold	141038	260003	260003	260003	144564
Port WBT, VOID	109531	112269	112269	112269	112269
STBD WBT, VOID	109531	0	0	112269	112269
Double Bottom	32110	0	32913	0	32913
Miscellaneous Space**	35280	0	0	0	36162
Sum		414151	447064	526420	480056
Displacement Under Main Deck	459700	471192	471192	471192	471192
		Floating	Floating	**Sinking**	**Sinking**

* Miscellaneous Weight: Fuel Oil (3229 t) + Fresh Water (300 t) + Diesel Oil (162 t)
** Miscellaneous Spaces: APT + FPT + Engine Room + Engine Casing

4.3.1.7 It has also been calculated that the tanks on starboard would have to be damaged in addition to every tank on port in order for Stellar Daisy to incline at such a large angle to port and sink so rapidly. Otherwise, along with all tanks on port, the double-bottom tanks and cargo holds would have to be damaged successively, and a huge weight of water needed to flow into the ship.

72) It is assumed that cargo holds were damaged, leaking all of the cargo (iron ore) into the sea and filling up these empty space with the seawater instead.

4.3.1.8 The ship can suddenly incline to port and sink fast as stated by the surviving crewmembers, instead of sinking slowly, only when the flooding water exceeds her reserve buoyancy. Therefore, it is considered reasonable to estimate that tens of thousands of tons of water beyond the calculated reserve buoyancy of 170,000 tons would have had to flow into the ship.

4.3.1.9 It can be assumed that all cargo holds were damaged, leaking all of the cargo (iron ore) into the sea. In this case, however, the ship would not end up in sinking because the hull's buoyancy would be maintained as the seawater, which has a lower specific gravity than iron ore, would fill those empty cargo holds while several ballast tanks and void spaces remained intact.

4.3.1.10 Therefore, the possibility may be ruled out that much of the cargo spilled into the sea due to severe damage to the cargo holds. Still, there is a possibility that as the flooding of WBTs continued, causing cracks into the hull, several holds were cracked as well. Therefore, a portion of the cargo presumably spilled slowly into the sea through those cracks.

4.3.1.11 Meanwhile, the KMST looked into the probability of sinking when the area below the upper deck plate was cut. To do that, the agency analyzed a scenario in which the compartments where cargo hold No. 2 and WBT No. 2 were located were cut or almost cut and roughly connected with several members, such as the upper deck plate.

4.3.1.12 In this case, the ship would lose all 50,700 tons of the cargo in hold No. 2 through the broken area and have the adjacent WBT No. 2 (P/S) and double-bottom tanks filled with seawater instead. The weight of influx seawater was calculated at 54,786 tons based on the ship's draft at that time of the accident, which means the 50,700 tons of iron ore in cargo hold No. 2 would be replaced with 54,786 tons of seawater.

4.3.1.13 Therefore, a discrepancy of 4,086 tons in weight would exist between before and after the flooding, and the ship would lose an equivalent amount of her buoyancy only. Even if the broken compartments was flooded, the ship would maintain a significant buoyancy, and thereby she would stay floating at sea with the area below the upper deck plate submerged.

4.3.1.14 Overall, the above analyses lead to the conclusion that the ship would sink if she faced major damage to the hull. And, such damage should be made simultaneously to several compartments of the hull, including the ballast tanks on port, and the ship should not lose much iron ore, which is the heavy weight cargo.

4.3.1.15 In other words, it is presumed that if several wing tanks on port and the ballast tanks and void tanks on starboard were damaged and flooded almost at the same time, the situation would arise where the ship inclined to port fast and sank rapidly, just as the surviving crewmembers described in their statements.

4.3.2 Sinking simulation

4.3.2.1 In this investigation, the KMST commissioned KRISO to conduct a simulation with the scenarios of the accident which include the stated facts: the flooding of WBT No. 2 (P), a sudden port inclination, and sinking within 5 minutes.

4.3.2.2 The simulation was performed with three categorized cases broadly as following: first, no damage was made to the cargo holds; second, the cargo holds were flooding, and thereby, the iron ore inside was mixed with seawater and spilled into the sea; third, the cargo holds were flooding, but the difference in specific gravity between the cargo and seawater prevented it from mixing with seawater, and thus, only seawater entered into the holds and no iron ore was spilled. And then, the flooded compartments in these cases were changed depending on the situation while the simulation was conducted. The prerequisite for these cases was that the flooding of WBT No. 2 (P), mentioned in the social media messenger, was true.

4.3.2.3 In the simulation of the first case group (15 scenarios) where no damage was made to the cargo holds, the ship would incline about 7° and be 1.2 m lower into the water if WBT No. 2 (P) were damaged. If WBT Nos. 2-3 (P) were damaged, the heel angle would increase to about 19° with an immersion of 3.3 m. More cases of damaging ballast tanks on port were added to the simulation. However, the results showed that the hull stayed afloat for a significant period of time in all cases. In other words, unless the engine room was flooded, flooding of the portside tanks only was not sufficient to cause the sinking of the ship.

4.3.2.4 Also, where only two ballast tanks on port were presumably damaged, the ship did not sink, even when all double-bottom tanks were damaged, too. Therefore, the simulation confirmed that the ship could sink only when at least three ballast tanks on port were damaged[73)] and such damage led to flooding of the double-bottom tanks and tanks on the starboard side. Also, the size of the damage would have to be significant for the ship to go underwater within only five minutes.

4.3.2.5 The simulation of the second case (14 scenarios) assumed the cargo holds were flooded, iron ore mixed with seawater, and it spilled into the sea. Most calculations led to the conclusion that the hull floated on the surface. If iron ore spilled into the sea, the ship would only sink after almost all compartments were damaged.

4.3.2.6 The simulation of the third case (5 scenarios) where only seawater entered the ship and no iron ore was spilled showed that more areas of the hull were under water, while the heel angle decreased since the hull was filled with seawater from the bottom.

4.3.2.7 Among these 34 scenarios, the ones resulting in the situation consistent with the factual information, given by the surviving crewmembers and a message sent via a social media messenger, are listed in [Table 24].

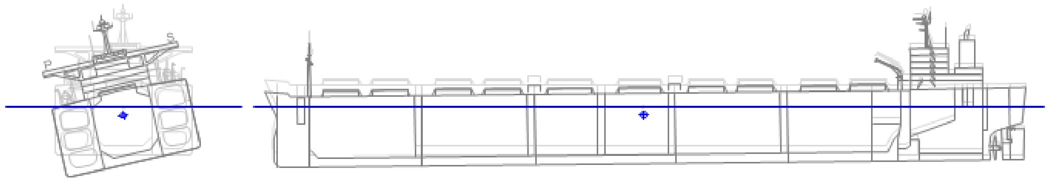
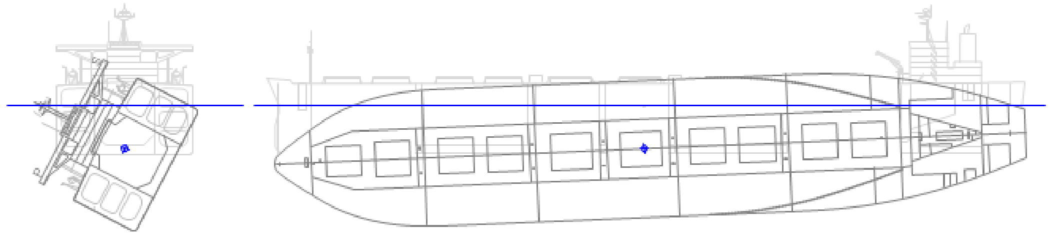
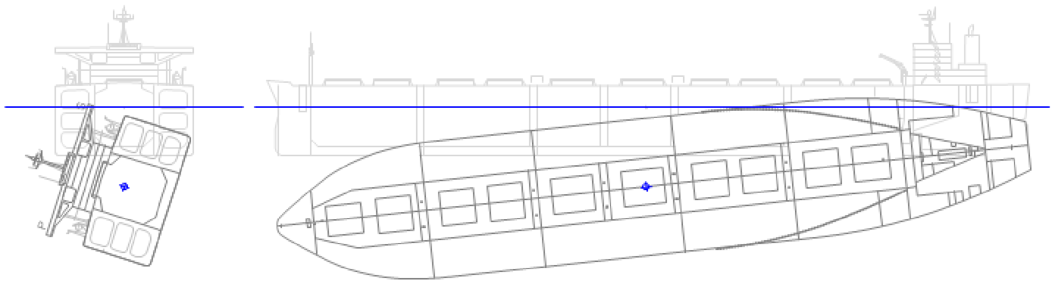
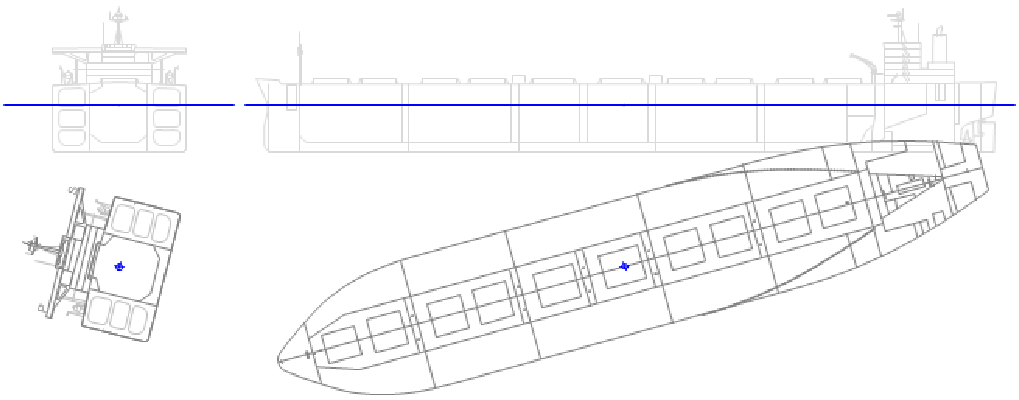
[Table 24] Probable scenarios

Scenario	Location of Damage			Note
	Shell plate damage	Internal damage	Other	
Scenario No. 1	WBT No. 2 (P) WBT No. 3 (P) WBT No. 4 (P) VT No. 5 (P)	Double-bottom tank Nos. 2-3 (P/S)	Upper side of C/H No. 2 Upper side of C/H No. 4 Forward area of Engine Room	
Scenario No. 2	WBT No. 2 (P) WBT No. 3 (P) WBT No. 4 (P) VT No. 5 (P)	Double-bottom tank Nos. 2-3 (P/S)	Upper side of C/H No. 2 Upper side of C/H No. 4 Upper side of C/H No. 5 Upper side of VT No. 5 (S) Forward area of Engine Room	

73) More than four ballast tanks on port would need to be flooded in order to satisfy the conditions, such as reaching a 40° heel angle after two to three minutes, described in the statement of the crewmembers.

4.3.2.8 In the scenario No. 1, the ship heeled more than 40˚ in less than three minutes after the water entered the ship. The bow area was immersed first. However, no record exists to specify whether the bow or stern went underwater first.

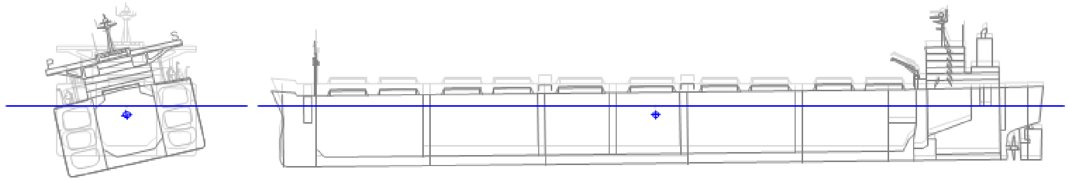
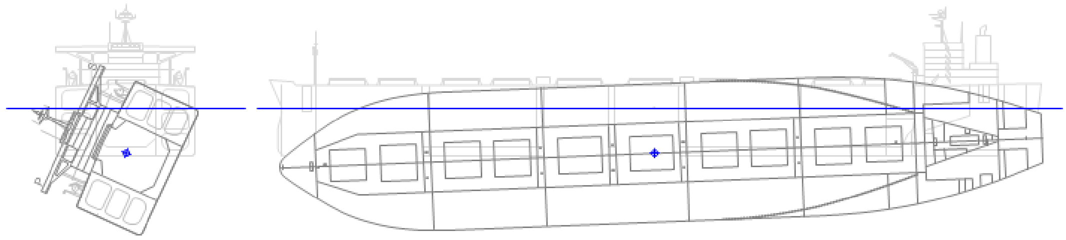
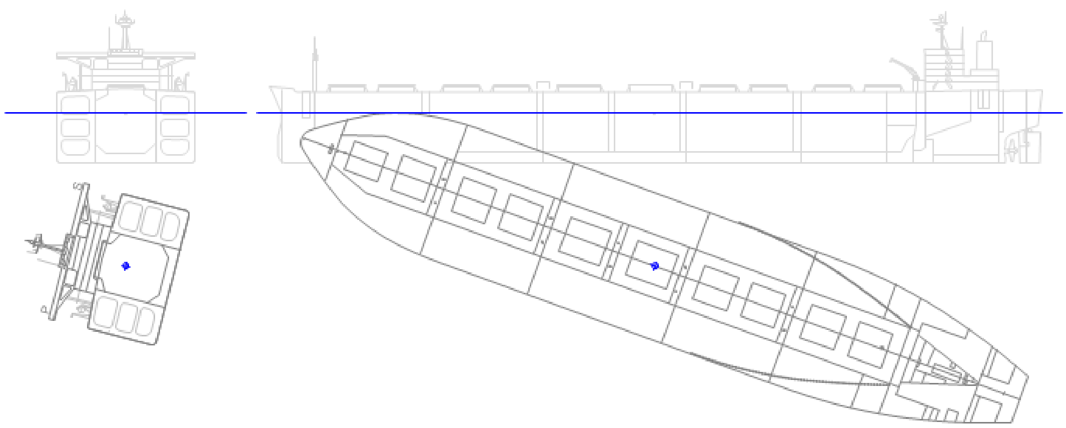
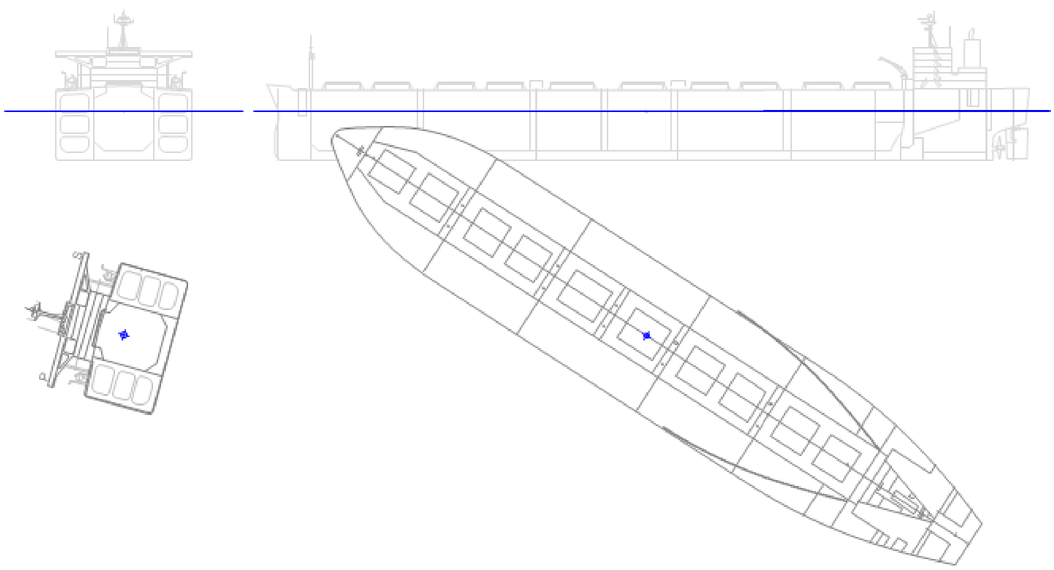
[Table 25] Scenario No. 1

Time (sec.)	Immersion and Posture of Hull[74]
100	
200	
300	
333	

4.3.2.9 The scenario No. 2 is also consistent with the situation described by the survivors. In this case which added cargo hold No. 5 and VT No. 5 (S) to the scenario No. 1, the aft body of the ship sank first, unlike the scenario No. 1.

74) In this table, the transverse section is viewed from the stern while the longitudinal section is from the port side.

[Table 26] Scenario No. 2

Time (sec.)	Immersion and Posture of Hull
100	
200	
300	
310	

4.3.3 Sub-conclusion

4.3.3.1 The estimated scope of damage and the results of its simulation led to the conclusion that at least three tanks on port, including WBT No. 2 (P), would have had to be flooded in order for Stellar Daisy to sink within about five minutes.

4.3.3.2 In addition, the ship needs more than 170,000 tons of water flowing into the hull to lose her buoyancy. The ballast and void tanks on port are not large enough alone to store 170,000 tons of seawater, leading to a presumption[75)] that the double-bottom tanks were also damaged and the ballast tanks on starboard were also flooded, accordingly. Also, the cargo is presumed not to have spilled at all or just slightly.

4.4 Post-casualty structural analyses to figure out causes of damage

4.4.1 Objectives

4.4.1.1 It is presumed that Stellar Daisy experienced flooding of WBT No. 2 (P) along with a thundering "crash" and vibration, suddenly inclined to port, and sank within about five minutes. There had been no signs of potential hull damage or flooding reported prior to the accident.

4.4.1.2 To reveal causes of the sinking, the KMST reviewed dangerous situations that could occur in the process of conversions, ship surveys, safety management, and ship operations, and their relevant critical factors. However, those findings were insufficient to explain the causes of the accident.

4.4.1.3 Still, it is considered reasonable to assume the following information as truth based on the statement of the surviving crewmembers, the social media message, and the analysis results of Chapter 4.3: the ship's shell plate must have been

75) The number and location of the ballast tanks presumed to be flooded were estimated based on the reserve buoyancy, capacity of the tanks, the time of the sinking, and the heel angle of the ship at the time of the accident, which did not consider whether those tanks actually had any damage factors.

damaged, given the fact that the ship was flooded; the ship must have had significantly large openings in the hull in order to sink; several compartments had to be flooded, given the assumption that the amount of ingress water would be greater than buoyancy; and multiple ballast tanks on port had to be damaged since the ship heeled to port so fast.

4.4.1.4 Therefore, post-casualty structural analyses were conducted to find grounds to support such presumptions with naval architecture methodologies. The analyses particularly focused on figuring out the structural vulnerability that first triggered the flooding and the critical areas.

4.4.1.5 In the analyses, both KR's standards and those of other classification societies, including Lloyd´s Register (LR), were applied so that structural strength could be assessed from different perspectives. Along with the ship's strength, the KMST reviewed fatigue strength as well as ultimate strength[76], which had not been applied to Stellar Daisy at the time of her conversion.

4.4.1.6 In addition, this report includes a fracture analysis to review whether there was any probability that the ship's structural materials were fractured by excessive stress or strain.[77]

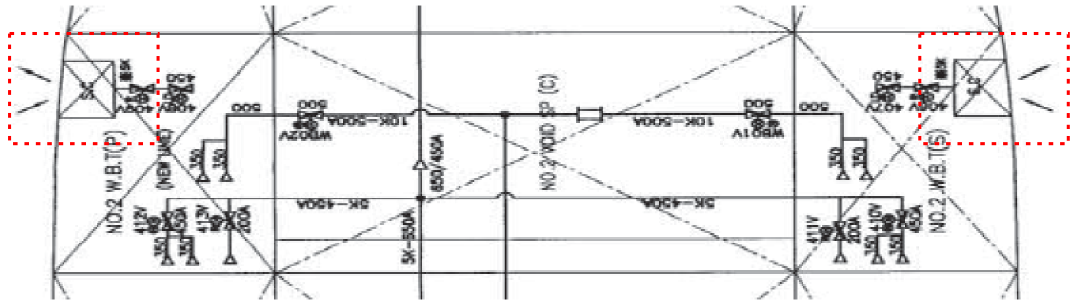
4.4.2 Structural strength analysis if WBT No. 2 (P) were flooded

4.4.2.1 After the sinking of Stellar Daisy, KR reviewed strength of the ship's structures under the assumption that about 80% of WBT No. 2 (P) was flooded when the hull was intact. This analysis was intended to identify structural damage, or how the flooding of WBT No. 2 (P) affected the ship's structural safety, and its relevancy to the sinking, given the fact that Stellar Daisy sank even though she had complied with structural strength regulations as reviewed during the conversion.

76) Ultimate strength refers to the stress at a moment when a hull finally collapses after facing deformation, such as a buckling. It is the maximum load stress that the hull can withstand. In this report, it means the ultimate longitudinal strength.

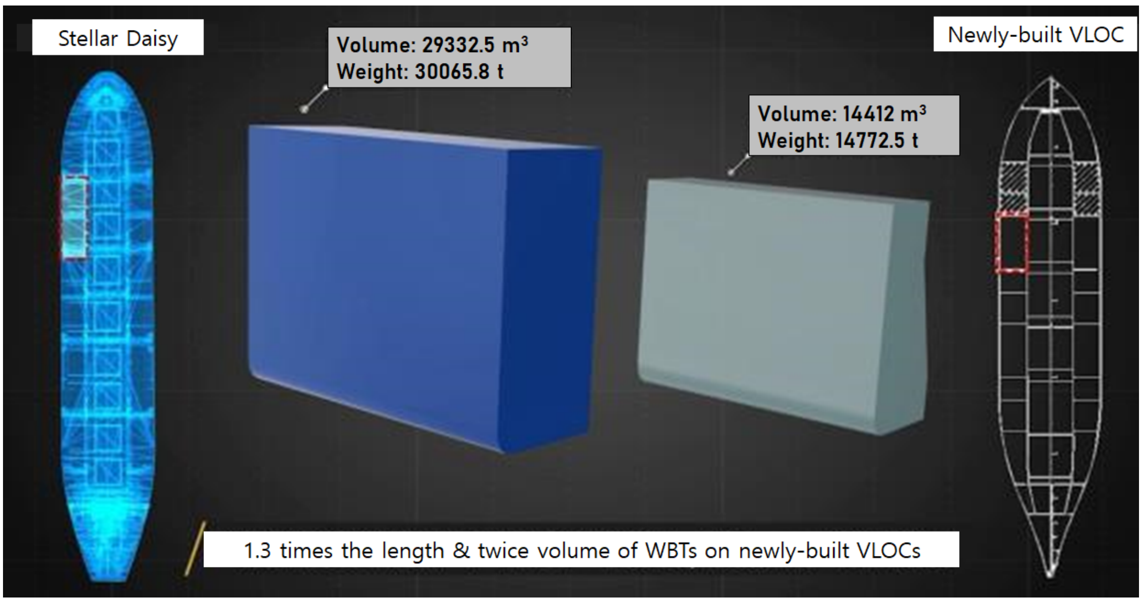
77) If an external force is applied to an object, the shape and size of the object may change. Strain is the ratio of the original size to the changed one.

4.4.2.2 KR focused on the sea chest valve for reasons behind the flooding of WBT No. 2 (P). WBT No. 2 (P/S) were fitted with a separate pipeline[78] directly connected to sea chest valves on the floor. Seawater could be poured in or discharged from these tanks by gravitation through this pipeline. Therefore, even when the hull is not damaged and the valve of WBT No. 2 (P) is open, seawater could enter the tank.



[Figure 41] Diagram of sea chest valves and pipeline of WBT No. 2

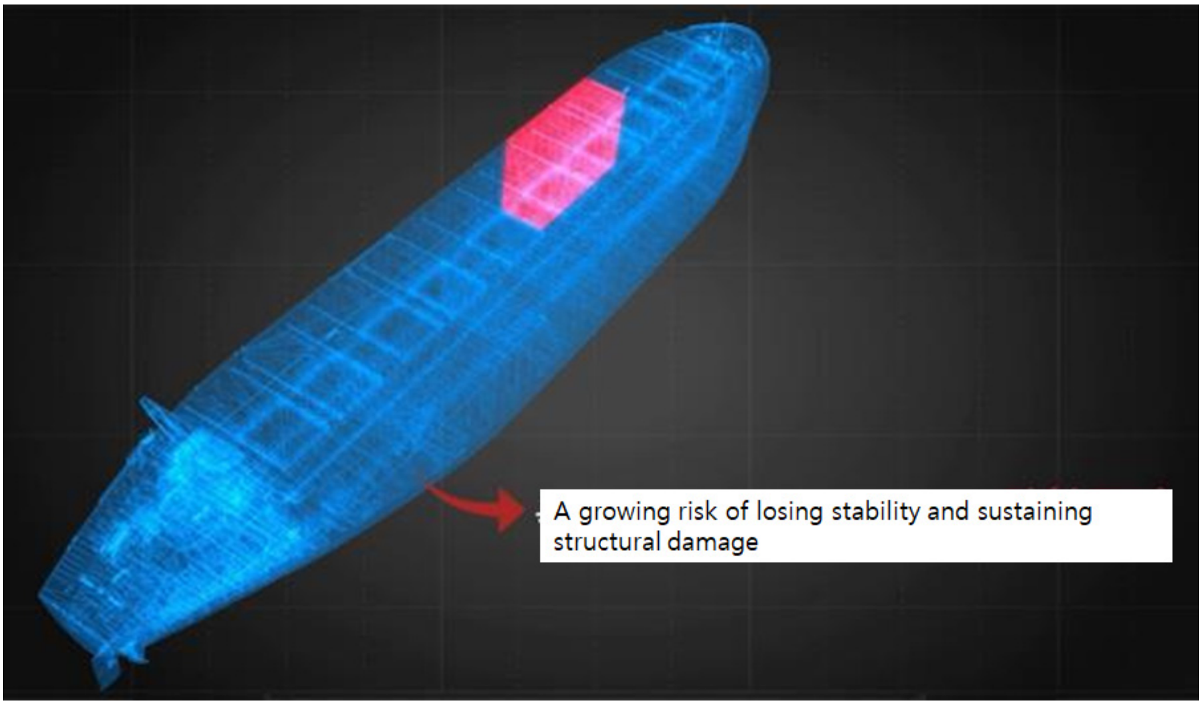
4.4.2.3 Also, as an ore carrier converted from a single-hulled oil tanker, Stellar Daisy has ballast tanks on both sides that are 1.3 times the length and twice the volume of those on the recently-built ore carriers.



[Figure 42] Size comparison of Stellar Daisy's WBT to that of new VLOCs

78) The pipeline connected to sea chest valves of WBT No. 2 is 450 mm in diameter and has two sea chest valves in the middle. They are butterfly-type valves, hydraulically operated: the outboard one is operated from the cargo control room, while the inboard one is run from the upper deck.

4.4.2.4 According to the analysis conducted by her RO, the flooding of WBT No. 2 (P) would lead to the following results: the ship's BM would increase about 30%; the torsional moment would occur together with a heeling event resulting from asymmetric loads; the ship would experience roll motion and acceleration depending on asymmetric distribution of weight; the ship's shell plate would face higher wave pressure; and the cargo would have greater inertia.



[Figure 43] Risk if WBT No. 2 (P) were flooded

4.4.2.5 The analysis found that such an increase in the torsional moment and the cargo inertia would put excessive stress on the area around the cargo hatchway; web frames under the deck; and the cross deck and critical damage would be caused to the web frames under the deck of cargo hold No. 4 in particular, which could be the starting point of the overall structural collapse.

4.4.2.6 And, according to the analysis, structural damage of the web frames under the deck of cargo hold No. 4 would collapse the forward and after transverse bulkheads of the hold. In consequence, structural members supporting lateral loads would also lose their functions, leading to successive collapse of the bottom and side shell plates of WBT No. 4 (P).

4.4.2.7 Still, it is deemed less likely that damage or malfunction of the sea chest valves caused the seawater to enter WBT No. 2 (P)[79]. The inspection reports and repair history of Stellar Daisy written after her conversion do not indicate whether the valves installed in WBT No. 2 were ever broken or repaired. Moreover, no record or probable evidence exists to suggest those valves were used to discharge ballast water by gravitation from WBT No. 2 (P) when cargo was loaded during the accident voyage.

4.4.2.8 Furthermore, it takes more than two hours on average to fill WBT No. 2 (P) with seawater via the valve. And, the damage stability calculation showed the ship would heel as much as about 7° when WBT No. 2 (S) was flooded. Given that, it was unlikely that crewmembers who had been working during the daytime would not have noticed the flooding of WBT No. 2 (P) prior to the accident. If they did recognize such situation, they would have had enough time to respond to it.

4.4.2.9 Meanwhile, SOLAS Regulations XII/4 and 5 prescribe requirements to secure stability to withstand flooding of any cargo holds and to prevent successive structural collapse, which considers the case where any cargo holds are flooded. However, no provisions dictate the stability and structural strength of the ships, just as Stellar Daisy, which have larger ballast tanks than those of typical ore carriers, should their ballast tanks be flooded[80].

4.4.3 Structural strength analysis

4.4.3.1 In this report, a cargo hold structural strength analysis[81], which assesses the adequacy of the hull structures, was conducted to determine which areas were likely to cause flooding if damaged, and then to cause massive damage to the hull later. This analysis was conducted separately from the one KR conducted in Chapter 4.4.2.

79) Efforts were made to check the sea chest valves of WBT No. 2 (P) through the deep-sea search operation. However, it was unable to identify the valves, including WBT No. 2 (P), due to the severe damage to the hull.

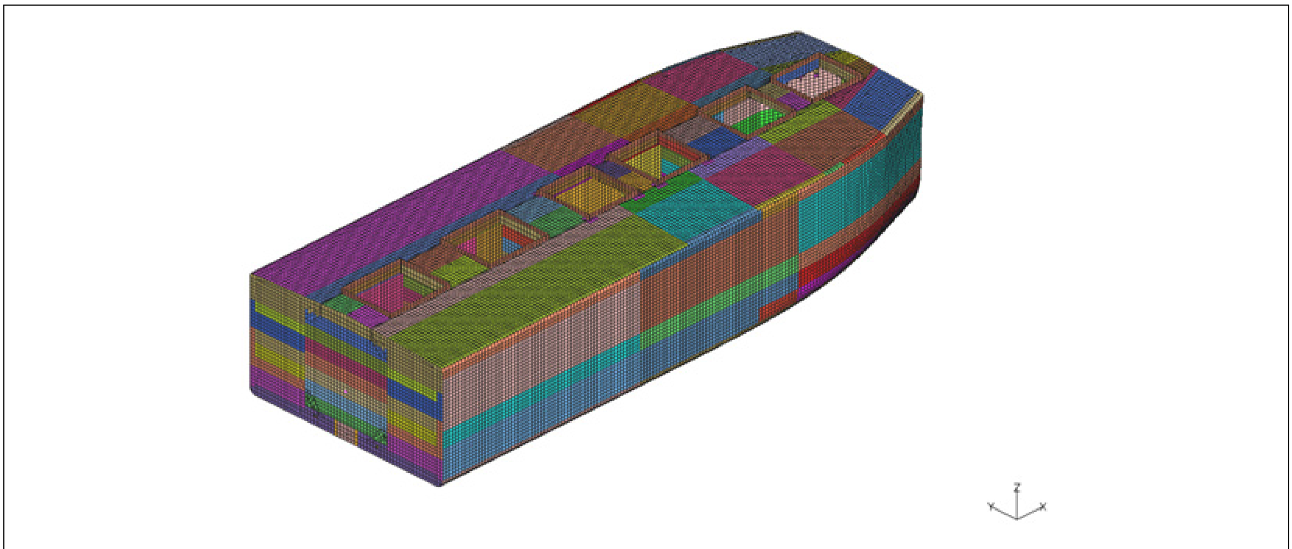
80) The Republic of Marshall Islands pointed out that the converted ore carrier has relatively large ballast tanks and that flooding of such tanks would lead to successive collapse of the structures and recommended the IMO for revising the relevant regulations to prevent such cases in their investigation report on Stellar Daisy on 19 April 2019.

81) The analysis was conducted by MOVENA KOREA (Maritime Consulting and Services)

4.4.3.2 Since this analysis is intended to identify critical areas, including analysis on probability of damage, as part of the investigation into this accident, not to approve the ship's design, the loads and assessment criteria prescribed in the rules of LR[82] were applied to this analysis.

4.4.3.3 WBT No. 2 which was presumed to have been damaged first is located in the area of cargo hold No. 2 (FR. 75-83). Thus, in this analysis, the area of cargo hold No. 2 was designated as the area subject to the analysis, and cargo hold No. 2, and adjacent cargo hold Nos. 1 and 3 were selected as the area subject to modelling. In order to apply the most similar thickness of the ship's members to the actual one at the time of the accident, the ones measured in the 2015 thickness measurement report[83], not the scantlings on the drawing (design thickness), were quoted in this analysis.

4.4.3.4 Also, the finite element analysis (FEA)[84] was conducted with models that idealized shell plates, inner bottom plates, deck plates, and transverse bulkheads as plate elements, while stiffeners such as longitudinals and transverse frames were modelled as beam elements.

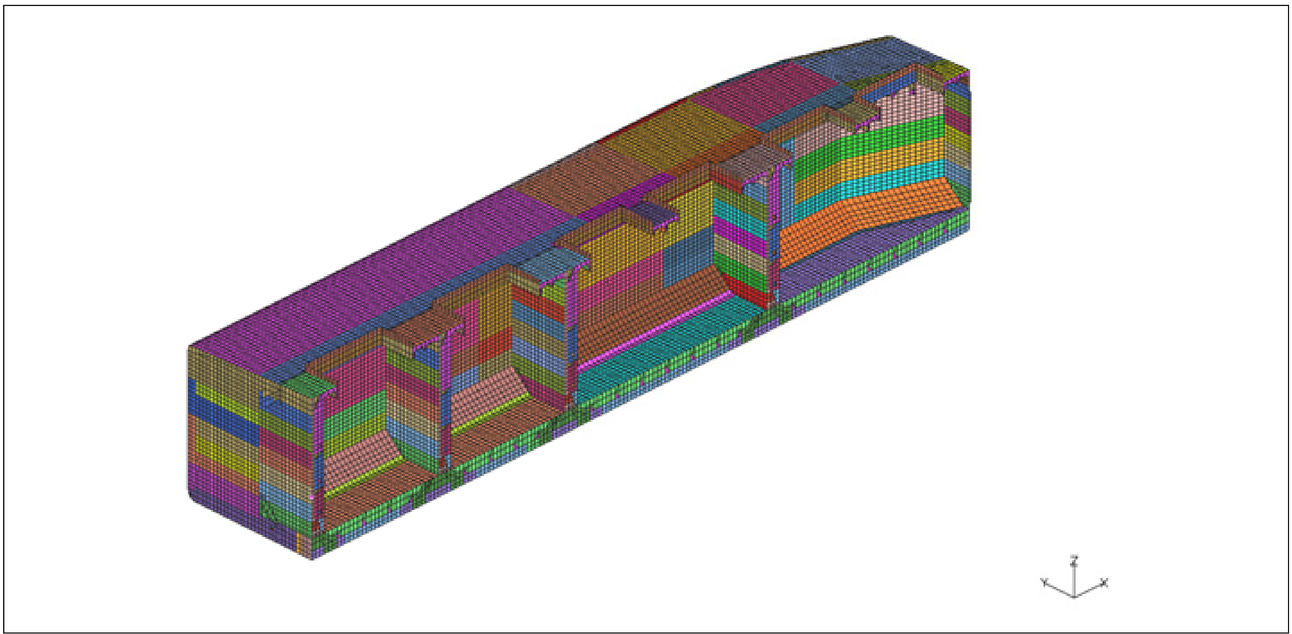


[Figure 44] Example of FEA model (full breadth)

82) Lloyd's Register, 2016. "Structural Design Assessment-Procedure for primary structure of ore carrier," Ch. 2 Sec. 5 Stress acceptance criteria and Sec. 6 buckling acceptance criteria

83) The global hull structures had 3-6% wear and tear while the upper deck plates had 4-6%. The structures with the severest wear and tear were longitudinal bulkheads and side shell longitudinals, where many areas had more than 10% wear and tear.

84) The Finite Element Analysis (FEA) is a numerical analysis technique which develops the simulation very similar to an actual structural behavior by dividing it into numerous pieces and analyzes it.



[Figure 45] Example of FEA model (half breadth)

4.4.3.5 The loads applied to the models are external loads which include still-water loads and wave-induced loads and internal loads in case of loading the cargo with a specific gravity of 3.0 t/㎥ based on the loading manual.

4.4.3.6 As the loading condition, the following seven scenarios were reviewed: four fully loaded conditions with consideration for hogging (bow and stern drooped), sagging (midship drooped), and wave-induced loads, by both wave crests and troughs; ballast conditions; hydraulic test conditions; and damage conditions of the flooded cargo holds.

4.4.3.7 The results showed that a portion of the cargo holds and ballast tanks experienced higher stress than their design stress limits when loaded with cargo of high unit weight (high-density cargo). The areas that experienced stress greater than their design limits[85] are areas in way of the transverse webs around the bilge; stringer plans in way of the corners of ballast tanks; upper deck plates at the corner of the cargo hatchway; and longitudinal bulkheads connected to the upper hopper plate. The areas where their actual stress is higher than their design stress are described in [Table 27].

85) It was considered attributable to the difference in assessment method between the KR rules at the moment of conversion and the 2016 LR rules.

[Table 27] Areas where actual stress is higher than design stress

Location	Critical Area	Actual Stress, A (N/mm²)	Design Stress, B (N/mm²)	Adequacy, A/B (A/B>1, Inadequate)
FR. 77	Bilge area	266.94	236.25	1.130
FR. 78	Bilge area in way of side shell, 1st cross tie	260.44	176.25	1.478
FR. 80	Bilge area in way of side shell, 1st cross tie	270.48	176.25	1.535
FR. 81	Bilge area in way of side shell, 1st cross tie	294.33	176.25	1.670
FR. 82	Bilge area in way of side shell, 1st cross tie	270.84	176.25	1.537
Stringer No. 3	Ballast tank corners	275.19	236.25	1.165
Stringer No. 2	Ballast tank corners	261.59	236.25	1.107
Stringer No. 1	Ballast tank corners	268.02	236.25	1.134
Upper Deck	Aft corners of cargo hatchway	402.35	300.27	1.340
Inner Hull	Top of the hopper plate	280.32	277.18	1.011
FR. 79	Lower end of the hopper plate	310.47	236.25	1.314
Center Girder	Bow part	408.30	277.18	1.473
Top Side	Side part	288.20	277.18	1.010

4.4.3.8 If these areas are forced to endure a high stress level, some parts may not last as long as their intended design life, which however are localized effects. Therefore, it is difficult to conclude whether they caused the hull damage of Stellar Daisy.

4.4.3.9 The KMST analyzed buckling strength as well, based on the actual stress of major structural members calculated from the structural analysis. The results showed that the shell plates were generally in good condition.

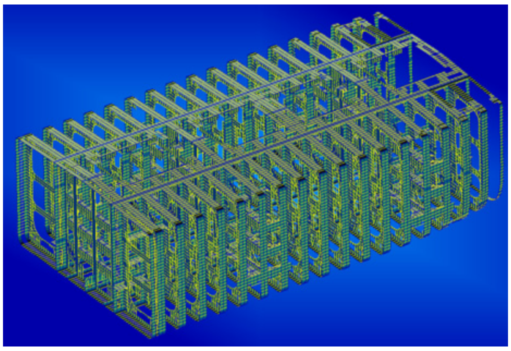
4.4.3.10 Among inner members, several areas exceeded their allowable value for buckling, including the transverse webs on the side plate. Given the strength of those areas was reinforced with buckling stiffeners when the ship was converted, it is considered inappropriate to determine that the buckling of the areas caused the hull damage. However, the fact that the ship had several areas vulnerable to buckling indicates that they can accelerate fracture or other structural damage if such defects initiated by other factors.

4.4.4 Fatigue strength analysis

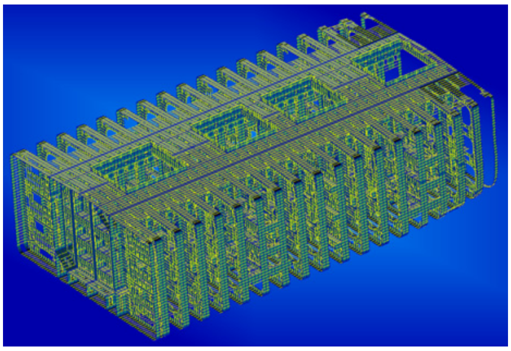
4.4.4.1 A fatigue strength analysis[86] was conducted to review whether Stellar Daisy had structural vulnerability by calculating her fatigue damage which had been accumulated since her launching. This analysis was mainly based on the LR's "Fatigue design assessment level 3 – Guidance on direct calculation (2009)."

4.4.4.2 Since this ship was converted from an oil tanker to an ore carrier, her fatigue strength before (as an oil tanker) and after the conversion (as an ore carrier) should be both assessed. To do that, two models, one for an oil tanker and the other for an ore carrier, were developed, and fatigue strength from the moment the ship was built till the time of the accident was analyzed.

4.4.4.3 The scope of this analysis includes the rear half of cargo hold No. 1, whole of cargo hold No. 2, and the forward half of cargo hold No. 3. Fatigue strength was also analyzed for all members of those structures welded to other members.



Oil Tanker



Ore Carrier

[Figure 46] Structural member for fatigue strength analysis

4.4.4.4 The KMST referred to the ship's service speed in the Noon Report of Stellar Daisy. Therefore, both the oil tanker and the ore carrier were assumed to have sailed at 12.69 knots in fully-loaded condition and 14.00 knots in ballast condition. For the oil tanker, the operation ratios of the fully-loaded condition and the ballast condition were both assumed as 0.425, while the ratios were assumed to be 0.5 and 0.35[87] for the ore carrier.

86) The analysis was conducted by the Research and Development Business (R&DB) Foundation of the Korea Maritime and Ocean University (KMOU).

4.4.4.5 To predict fatigue damage, the analysis used the world's sea state information[88], provided by DNV-GL on the service routes where Stellar Daisy had been deployed as an oil tanker and ore carrier.

4.4.4.6 Load scenarios were developed in accordance with the procedures of the LR's fatigue strength analysis. They covered the BM, external loads, and the loads in both cargo loaded condition and ballast condition. When calculating fatigue damage, the analysis used the fillet weld mean S-N curve[89] of LR[90], recommended as appropriate for evaluating fatigue damage on welded connections in general.

4.4.4.7 For more accurate estimates of fatigue life, the element size of the model should be set as a fine mesh size (20 to 30 mm) as thin as the thickness of the analyzed plate. However, when selecting the area subject to the analysis, it is practically impossible to apply such a fine mesh size to the global analysis model, not a specific area where stress concentration is expected to occur. For this reason, the same element size as that of the structural strength analysis (800 to 900 mm) was applied to the analysis. Instead, the analysis placed more importance on identifying areas relatively vulnerable to fatigue rather than on fatigue life[91].

4.4.4.8 The results showed that the bottom and side plates in way of the bilge area of WBT No. 2 (P/S) were more critical than any other primary members[92] of the hull structures, as presented in [Figure 47] and [Figure 48]. Since these areas are not fitted with structures to reduce the stress concentration effect, they may show a high level of fatigue damage if the finer mesh size is applied in the analysis.

87) The ship's operating ratio of an oil tanker and an ore carrier used in this analysis were based on the rules of the Det Norske Veritas and Germanischer Lloyd (DNV-GL), the Norwegian and German classification societies, which may differ from the actual data of Stellar Daisy.

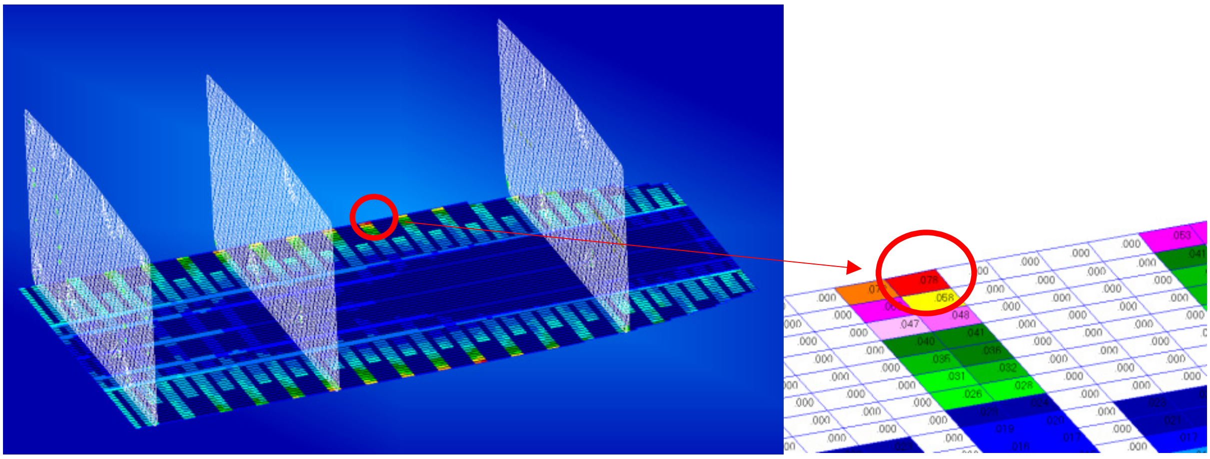
88) Det Norske Veritas, 2014. "Fatigue assessment of ship structures," DNV Classification Notes, No. 30.7.

89) It is a graph presenting the relation between stress range and fatigue life.

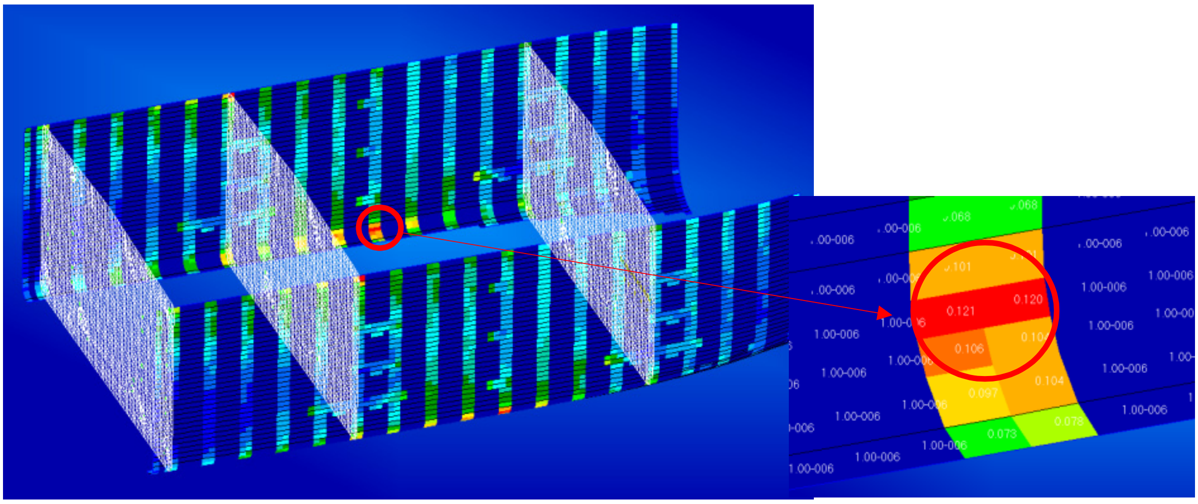
90) Lloyd's Register, 2009. "Fatigue design assessment level 3 -Guidance on direct calculation"

91) The results of the fatigue strength analysis do not mean an absolute fatigue life.

92) Primary members mainly include large members of sheet metal structures, such as upper deck plates, bottom and side plates, transverse bulkheads, and frames, which are designed to secure the structural integrity of the whole ship.



[Figure 47] Fatigue-critical areas of the bottom plate



[Figure 48] Fatigue-critical areas of the side shell plates

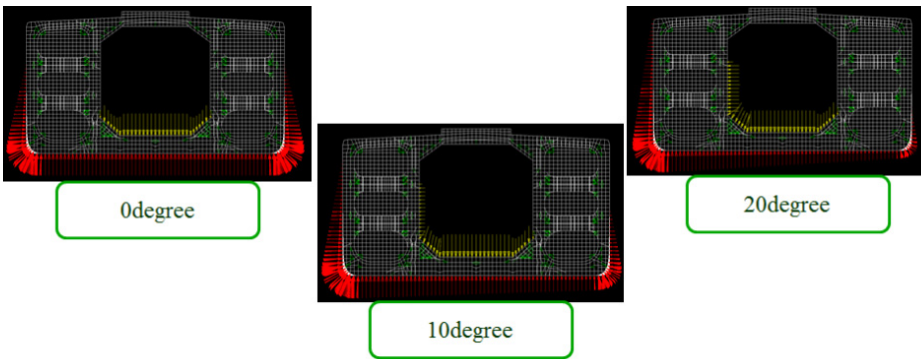
4.4.4.9 Meanwhile, after the accident, KR also calculated fatigue life under the Common Structural Rules (CSR) adopted by IACS as well as the KR rules, Part 3, Annex 3-3 Guidance for the Fatigue Strength Assessment of Ship Structures[93]. The results identified the areas which had lower fatigue strength, among which the fatigue life of the longitudinal members' connections was mostly calculated at over 50 years and that of the side shell stiffener connections in way of the waterline which have relatively low fatigue strength was at over 30 years, exceeding their design life. In other words, the areas with lower fatigue strength were identified from each member, however, none of those were close to the extent of their fatigue life.

93) It is to calculate loads and produce the fatigue life based on the long-term load distribution.

4.4.5 Structural strength analysis at heel angle

4.4.5.1 The cargo hold structural analysis was conducted under the KR rules when Stellar Daisy was converted. At that time, however, the KR rules did not require asymmetric lateral load, and thereby, it was not considered in the analysis as well. Thus, cargo hold No. 4 was added to the models used in the fatigue strength analysis to assess the impact of the asymmetric lateral load. The structural strength of the members connected to cargo hold Nos. 1 to 4 was examined at each heel angle[94].

4.4.5.2 In the analysis, a buoyancy corresponding to the draft similar to the one at sea was applied to the hull at each heel angle. Instead, loads of the cargo holds generated at each heel angle were applied in vertical and transverse directions. Therefore, structural strength was assessed at heel angles from 0˚ to 20˚ with five-degree intervals.



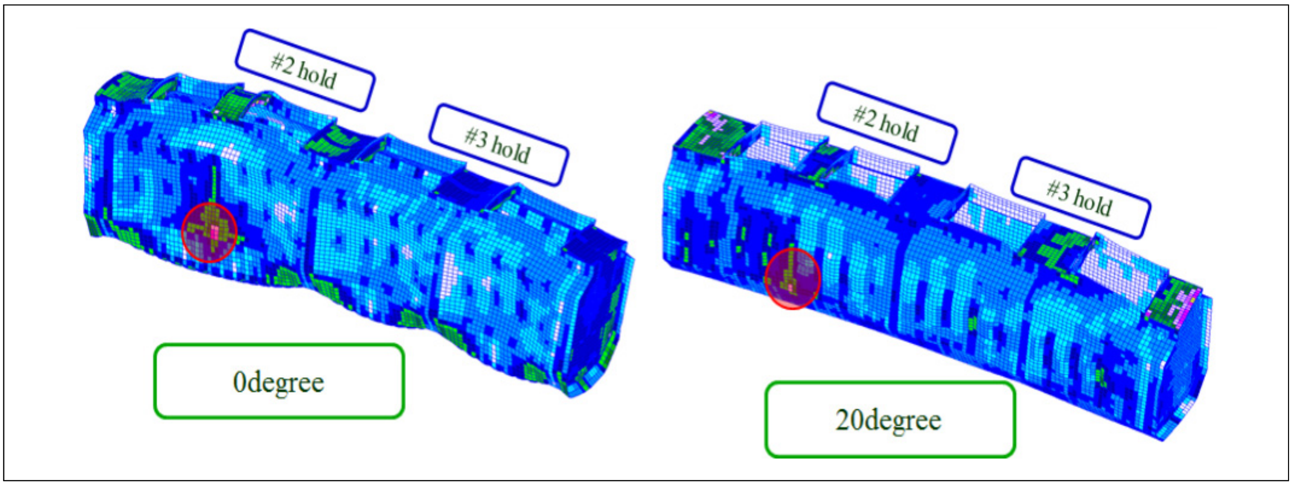
[Figure 49] Application of load at heel angles

4.4.5.3 In addition, the applied load of this analysis considered only a static buoyancy and loads of solid cargo at each heel angle. Since these loads are lower than the dynamic loads that can occur at sea, their actual stress would be calculated at a low value, accordingly. Therefore, the assessment criteria of structural strength at each heel angle were lowered to 80% of the yield stress[95], and the ship was considered susceptible to structural damage if the number exceeded that figure.

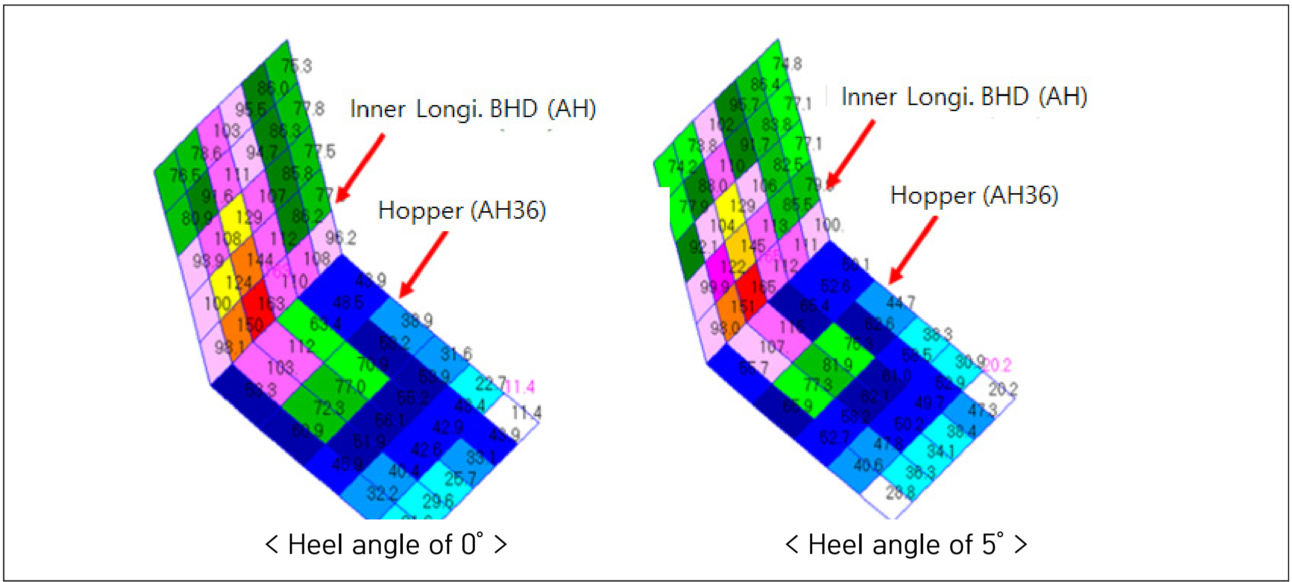
94) The analysis was conducted by the R&DB Foundation of the KMOU.

95) Once the load is applied to a material, its internal stress increases in proportion to the load. And, there is a certain point where only the material's strain increases without a further increase in its internal stress. The yield stress refers to the value of the stress at that point where a material do not return to its original shape even when the applied load is removed.

4.4.5.4 The results from the structural strength analysis of cargo hold Nos. 2 and 3 at heel angles showed that the stress was high at certain locations, including the inner longitudinal bulkheads and hoppers at frame No. 79 of cargo hold No. 2. However, these members' stress was about 53% of their yield stress(315 Mpa), lower than 80%.

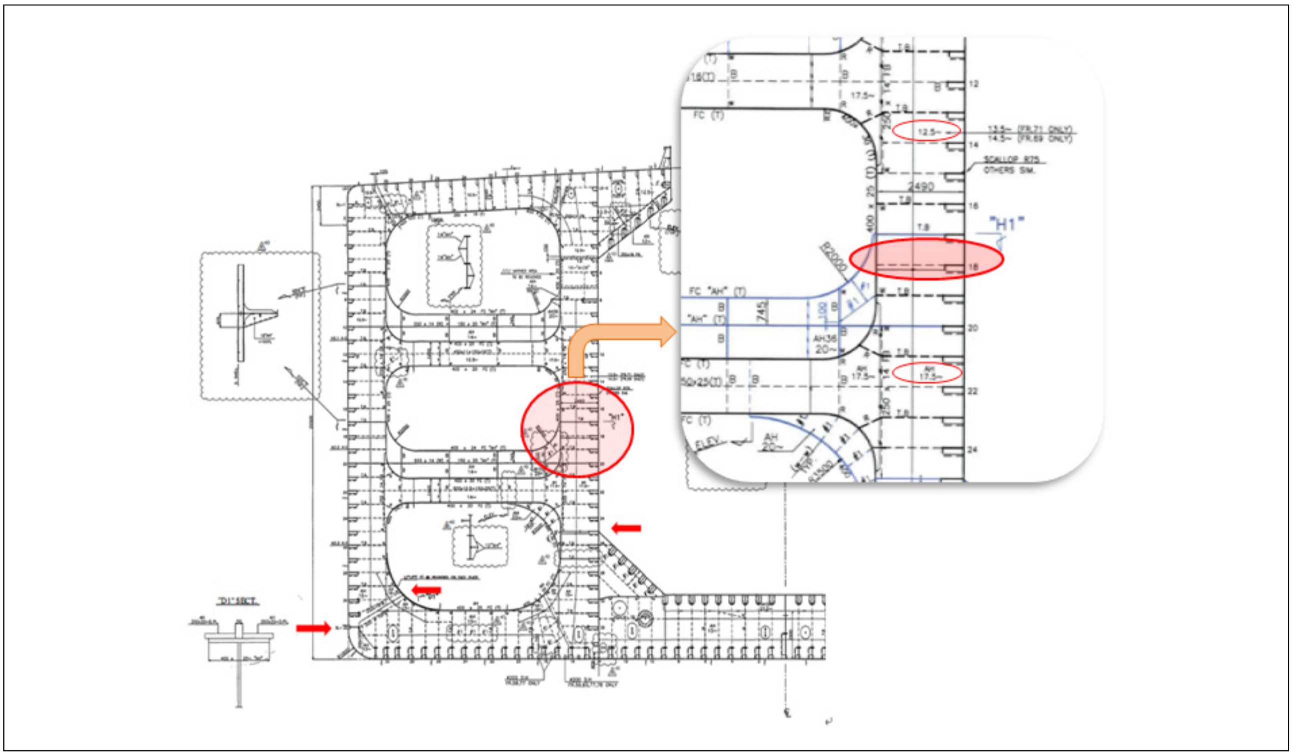


[Figure 50] Stress distribution of C/H Nos. 2 and 3



[Figure 51] Stress of FR. 79

4.4.5.5 Meanwhile, in the structural strength analysis of the members in way of the cargo holds, the stress of certain areas, such as transverse members at frame No. 79 in cargo hold No. 2 and at frame No. 72 in cargo hold No. 3, exceeded their yield stress at heel angles between 0˚ and 10˚. When the angle was 10˚ or larger, several of those transverse members in cargo holds No. 2 and 3 showed the probability of structural damage on their upper side. It is presumably because those transverse members were made of mild steel and there were weld lines going along the lower end of the high stress zones.



[Figure 52] Critical area and high stress zones on the cross section

4.4.6 Ultimate strength analysis

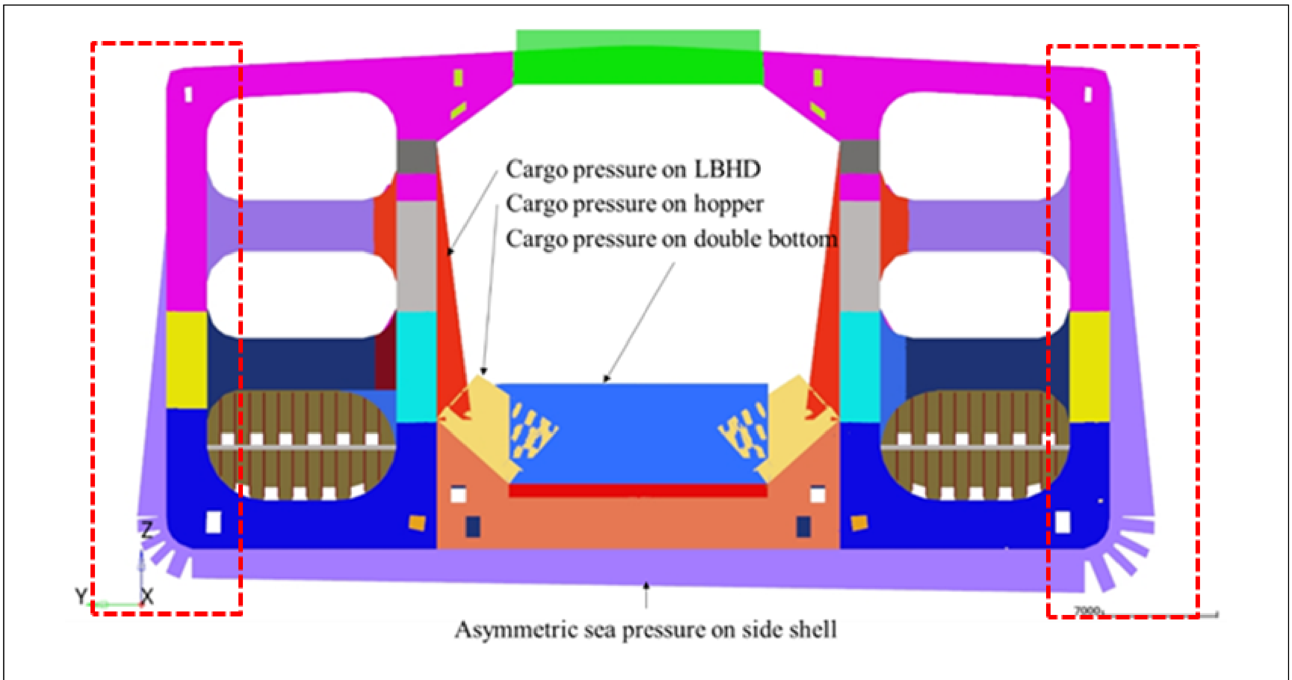
4.4.6.1 An analysis[96] was conducted to ascertain whether the shortage of ultimate strength could cause Stellar Daisy to collapse. The tests compared the values of the ultimate strength between the value acquisited Stellar Daisy and the value required in the 2018 CSR for Bulk Carriers and Oil Tankers issued by IACS. If the former is smaller than latter, the ship has possibility of collapse.

4.4.6.2 The ultimate strength produced according to the procedures defined in the CSR was 15,000 MN-m in sagging condition and 15,900 MN-m in hogging condition, and the ultimate strength of Stellar Daisy is required to be equal to or greater than these levels.

96) The analysis was conducted by the Society of Naval Architects of Korea

4.4.6.3 In this analysis, the following two situations were taken into consideration for design loads: first, where the vertical bending moment (VBM) prevailed due to dynamic wave pressures; and second, where swell-like beam-sea waves hit the ship's side, which is what happened to Stellar Daisy, creating asymmetric pressure (ASP).[97)]

4.4.6.4 For these situations, various scenarios for the ASP could be developed depending on the sea state. However, given the fact that the wave approaching the starboard side was about 3.7 m high at the time of the accident, the beam-sea waves coming from the starboard side were applied in this analysis. Therefore, the pressures applied on the shell plate were calculated based on asymmetric water heads: the upper ends of the water heads on port and starboard were defined as the load line and the upper deck plate, respectively. As described in [Figure 53], the ASP was produced since the water head on starboard was higher than the water head on port.



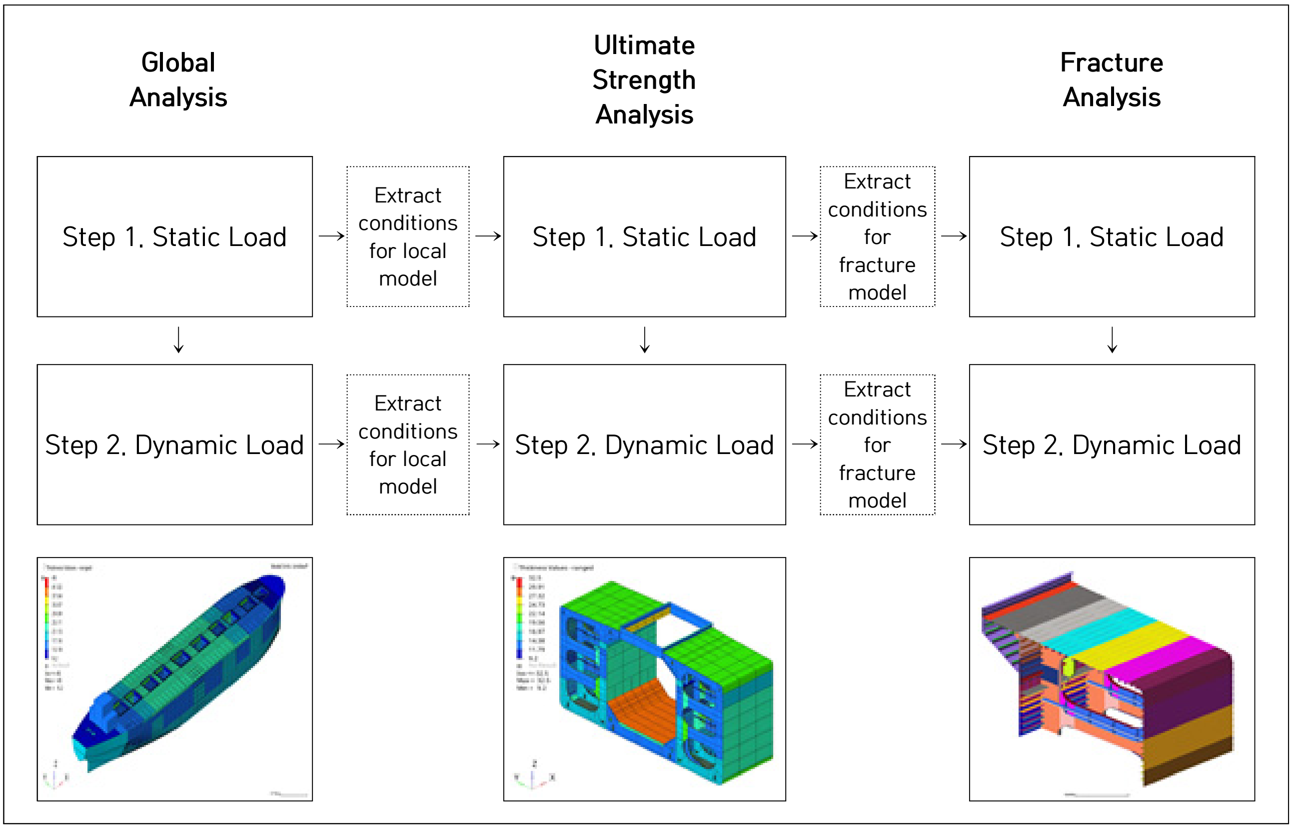
[Figure 53] Load distributed by ASP of both waves and cargo (Step 2: Dynamic loads & ASP)

4.4.6.5 The analysis was conducted in two steps depending on each load case. The first step is a static load[98)] which demonstrated the gravity created by cargo pressures and the self-weight of the ship and the buoyancy in equilibrium. In the second step,

97) Asymmetric pressure (ASP) refers to a situation where the shell plate of a ship is applied with different pressures as sea levels on port and starboard are different due to waves.

98) A static load refers to a load that hardly changes, just like cargo load, a ship's self-weight, and buoyancy.

either the WVBM[99] or the ASP[100] was applied in the dynamic load condition[101]. These conditions were equally applied to the fracture analysis mentioned later in this report as well.



[Figure 54] Procedures of global, ultimate strength, and fracture analyses

[Table 28] Ultimate strength analysis models and load steps

C/H No.	Analysis Model & Load	Load Step			Note
		Step 1	→	Step 2	
No. 2	Global - WVBM	Self-weight/Buoyancy/Cargo pressure	→	WVBM	
	Ultimate Strength - WVBM				
	Global - ASP	Self-weight/Buoyancy/Cargo pressure	→	ASP	
	Ultimate Strength - ASP				
No. 3	Global - WVBM	Self-weight/Buoyancy/Cargo pressure	→	WVBM	
	Ultimate Strength - WVBM				
	Global - ASP	Self-weight/Buoyancy/Cargo pressure	→	ASP	
	Ultimate Strength - ASP				

99) Wave-induced Vertical Bending Moment

100) Asymmetric Pressure

101) A dynamic load is a load that changes over time, just like wave-induced loads.

4.4.6.6 For the ultimate strength analysis, first, the global analysis model was developed with elements equal in size to longitudinal stiffener spacing, and then, displacements of sagging and hogging were calculated for static and dynamic loads. For cargo hold Nos. 2 and 3, the local model was developed with an 100 mm x 100 mm fine mesh[102], after the displacements from the global analysis were mapped onto the boundary surface of the local model, and then the ultimate strength was assessed.

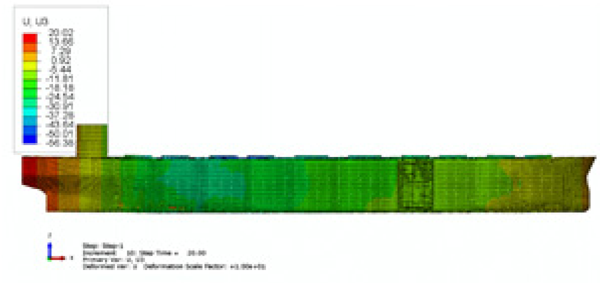
4.4.6.7 The WVBM and the ASP were applied in ultimate strength assessment on cargo hold Nos. 2 and 3. The WVBM caused sagging in both the static and dynamic load conditions. However, when the ASP was applied, sagging was observed in static load while hogging in dynamic load.

[Table 29] Ultimate strength analysis results

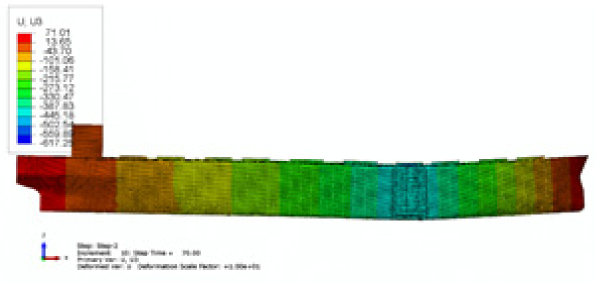
Type	C/H No.	Load Step	Maximum Moment (MN-m)	Remarks
WVBM	No. 2	Static Load (Step 1)	-55	Sagging
		Dynamic Load (Step 2)	-24,700	Sagging
	No. 3	Static Load (Step 1)	-760	Sagging
		Dynamic Load (Step 2)	-23,300	Sagging
ASP	No. 2	Static Load (Step 1)	-529	Sagging
		Dynamic Load (Step 2)	25,500	Hogging
	No. 3	Static Load (Step 1)	-1,150	Sagging
		Dynamic Load (Step 2)	24,500	Hogging

4.4.6.8 In the static load steps, moments did not develop significantly. Even in the dynamic load steps (the WVBM and the ASP), the ultimate strength of the ship was identified as far higher than the external moment (sagging: 15,000 MN-m / hogging: 15,900 MN-m) calculated under the IACS CSR, which means that Stellar Daisy was safe in terms of ultimate strength.

102) In order to save time for the ultimate strength analysis and better control the load speed, researchers developed the local model from the global model of the structural strength analysis. They selected for a local model cargo hold No. 2, presumed to be the first flooded area, and adjacent cargo hold No. 3, located amidships.



Visualization of global analysis results
(After Step 1)



Visualization of global analysis results
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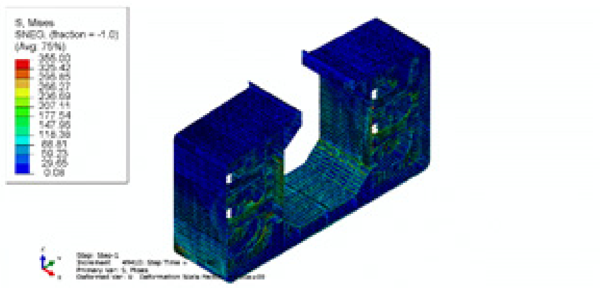
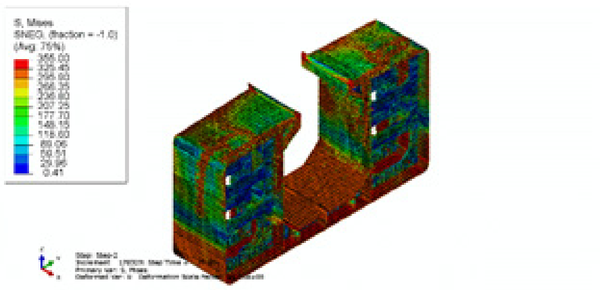
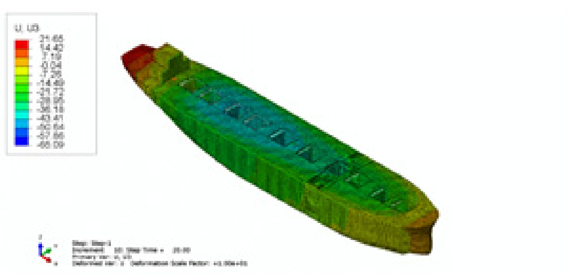


Visualization of local analysis results
(After Step 1)

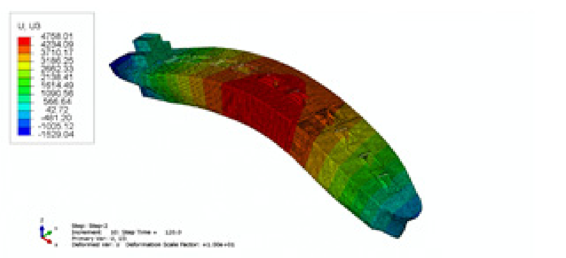


Visualization of local analysis results
After Step 2)

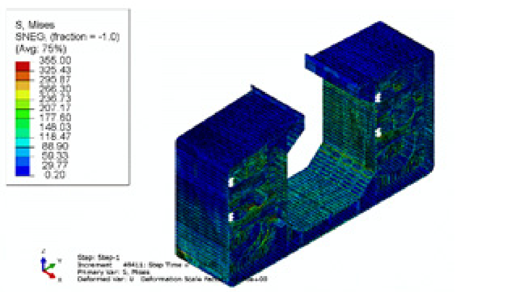
[Figure 55] Development of WVBM for C/H No. 2



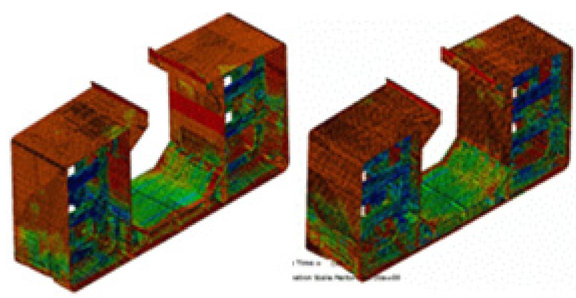
Visualization of global analysis results
(After Step 1)



Visualization of global analysis results
(After Step 2)

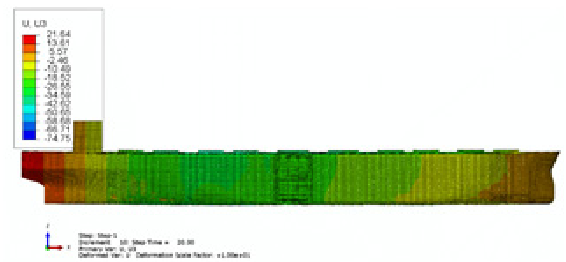
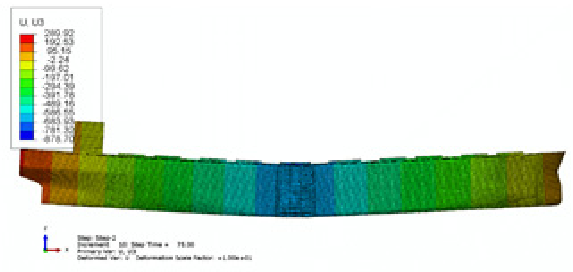
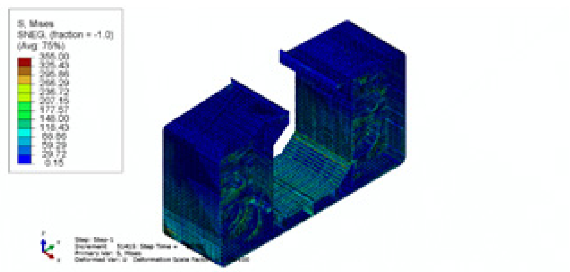
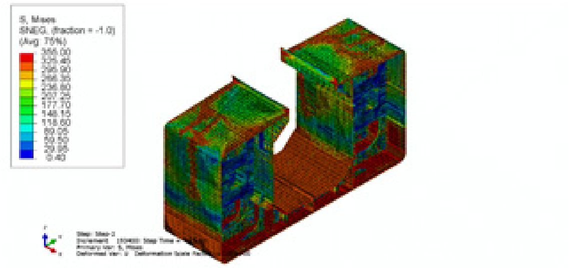


Visualization of local analysis results
(After Step 1)

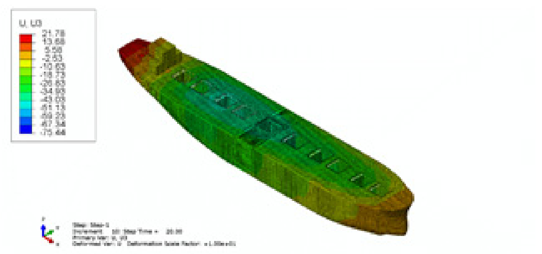
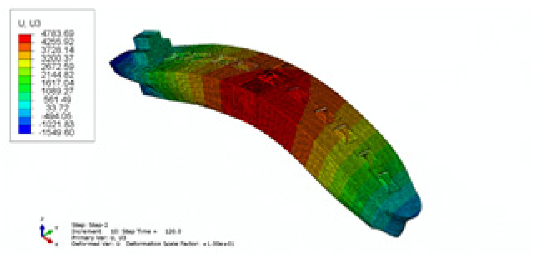
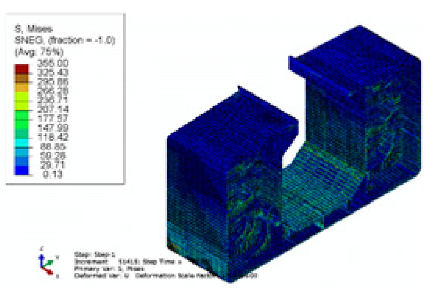
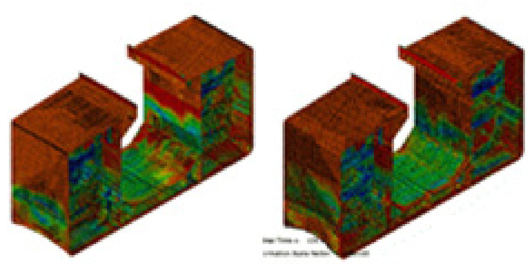


Visualization of local analysis results
(After Step 2)

[Figure 56] Development of ASP for C/H No. 2

 Visualization of global analysis results (After Step 1)	 Visualization of global analysis results (After Step 2)
 Visualization of local analysis results (After Step 1)	 Visualization of local analysis results (After Step 2)

[Figure 57] Development of WVBM for C/H No. 3

 Visualization of global analysis results (After Step 1)	 Visualization of global analysis results (After Step 2)
 Visualization of local analysis results (After Step 1)	 Visualization of local analysis results (After Step 2)

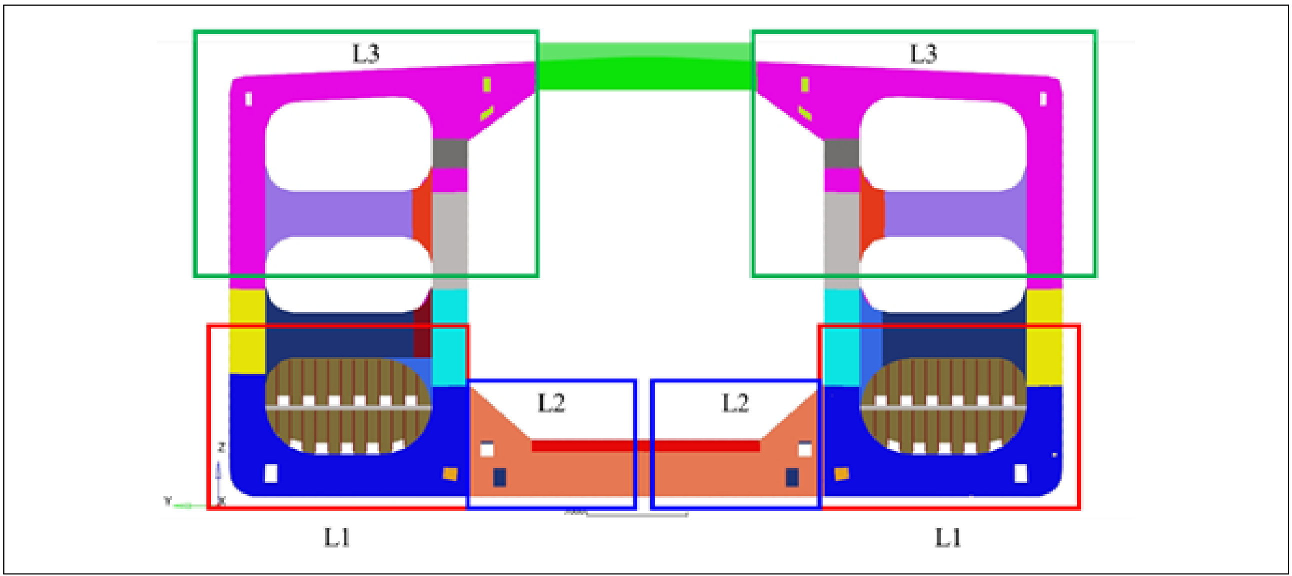
[Figure 58] Development of ASP for C/H No. 3

4.4.7 Fracture analysis

4.4.7.1 A fracture analysis is designed to identify whether there is excessive stress or strain applied to the ship structures, causing tearing or fracture[103]. If the numerical value of the structures' cumulative damage reaches 1.0 in this analysis, it is deemed to cause a fracture of the structures.

4.4.7.2 This analysis was conducted by the Society of Naval Architects of Korea. There are a variety of standards recommended for determining damage. In this report, however, the HC-LC fracture model[104], known to be one of the most appropriate models for sheet metal structures such as ships, was used for the fracture analysis.

4.4.7.3 The fracture analysis model is basically the same as the one used for the ultimate strength analysis (local model). In this analysis, the following three local models were developed for more efficient analysis: L1 (the ballast tank compartments close to the bottom plate), L2 (lower areas of the cargo hold), and L3 (the ballast tank compartments close to the deck plate).



[Figure 59] Local fracture analysis models

103) In this report, fracture means a condition where the structures first experience plastic deformation due to loads and later end up in tearing or fracturing.

104) The HC-LC fracture model is the combination of the merits of the Hosford-Coulomb Fracture Model (HC Fracture Model) and the Localized Necking Fracture Model (LN Fracture Model): the former, first developed in 2015, is appropriate mostly for the 3D stress condition of solid structures, while the latter can be applied to sheet metal structures when the structures experience tensile stress. These two models have been introduced in the relevant academic journals in recent years, but have yet to be adopted in the KR or IACS rules related to the ship surveys.

4.4.7.4 In the fracture analysis, cargo hold Nos. 2 and 3 were divided into three local models, L1, L2, and L3, and two load types, the WVBM and the ASP, were applied to each model. Therefore, a total of 12 cases were examined.

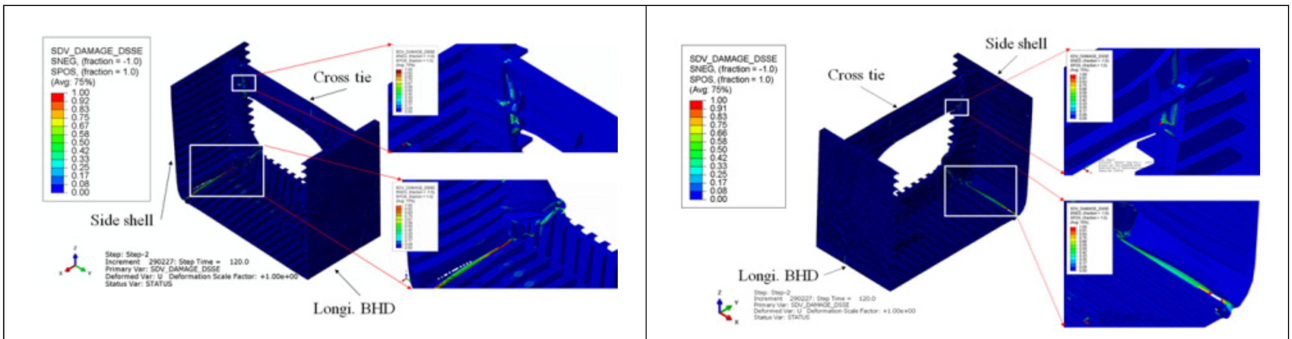
[Table 30] Fracture analysis cases

Ultimate Strength Analysis Case	Fracture Analysis Case (12)
C/H No. 2 w/WVBM (HOLD2-LOC-WVBM)	HOLD2-LOC-WVBM-L1
	HOLD2-LOC-WVBM-L2
	HOLD2-LOC-WVBM-L3
C/H No. 2 w/ASP (HOLD2-LOC-ASP)	HOLD2-LOC-ASP-L1
	HOLD2-LOC-ASP-L2
	HOLD2-LOC-ASP-L3
C/H No. 3 w/WVBM (HOLD3-LOC-WVBM)	HOLD3-LOC-WVBM-L1
	HOLD3-LOC-WVBM-L2
	HOLD3-LOC-WVBM-L3
C/H No. 3 w/ASP (HOLD3-LOC-ASP)	HOLD3-LOC-ASP-L1
	HOLD3-LOC-ASP-L2
	HOLD3-LOC-ASP-L3

4.4.7.5 The findings revealed some cases where the cumulative damage reached 1.0 locally if the WVBM was applied to the ship. However, such structural damage was relatively limited or less likely to spread to other structures.

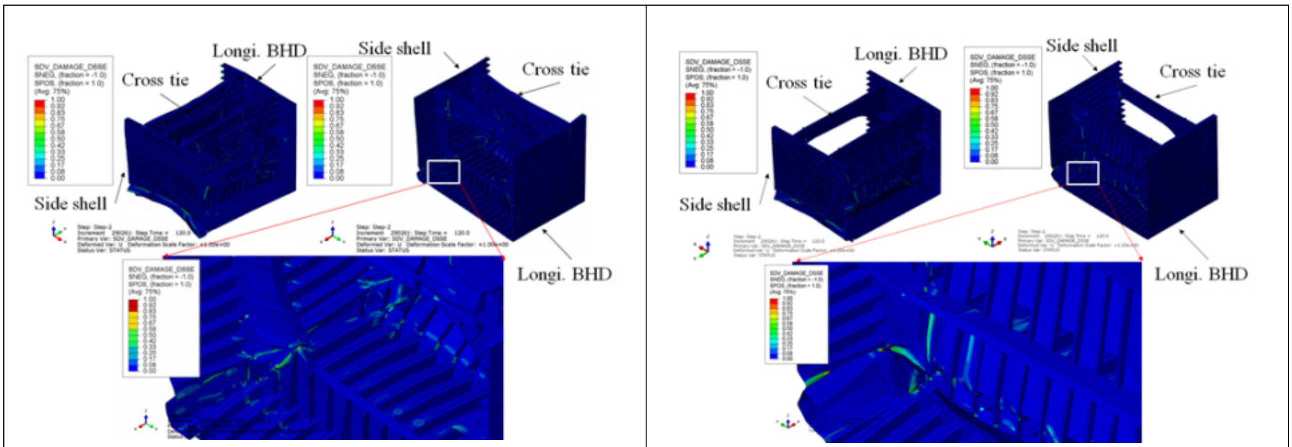
4.4.7.6 In contrast, when the ASP was applied to the structures, fracture, including buckling and structural damage, were likely to occur extensively in such areas as the bilge plate, inner cross tie, and the transverse frame connections of the local model, L1. The extent of the damage to the local models (L1) of cargo hold Nos. 2 and 3 are well visualized in [Figure 60] and [Figure 61], respectively.

4.4.7.7 In addition, when the ASP was applied from the ship's starboard side, both the port and starboard sides experienced similar damage in the local model, L1. Even when the ASP was applied from the port side, the result was the same as the former.



HOLD2-LOC-ASP-L1 (S)   HOLD2-LOC-ASP-L1 (P)

[Figure 60] Visualization of damage to L1 of C/H No. 2



HOLD3-LOC-ASP-L1 (S)   HOLD3-LOC-ASP-L1 (P)

[Figure 61] Visualization of damage to L1 of C/H No. 3

4.4.7.8 The results of the fracture analysis show that if a ship sails under the ASP[105] in beam seas for a long time, she may suffer damage (fractures) on the bilge plate, the inner cross tie, and the transverse frame connections of WBT Nos. 2 and 3 (P/S). And, when such damage is accumulated, it can undermine transverse strength, thereby causing structural vulnerability to the ship.

105) In the fracture analysis, it was assumed that the applied ASP had been equally distributed throughout the ship's overall length. Therefore, if the ASP had been applied to only a portion of the ship's length due to a short length of wave crest or a different incidence angle, the actual ASP value might have been different from the one applied to this analysis.

4.4.8 Sub-conclusion

4.4.8.1 The KMST considered a wide range of probabilities, starting from areas of cargo hold No. 2 which is the first flooded location reported by Stellar Daisy, and added various conditions for the analysis of naval architecture in order to scientifically evaluate the causes of the sinking of Stellar Daisy.

4.4.8.2 Experts conducted the analysis of structural strength and buckling strength to determine the probability of damage and critical locations of the ship structures. The results showed that loads of high-density cargo led to high stress on the areas, including the transverse webs around the bilge of cargo hold No. 2, but such stress was locally generated. Moreover, several inner members were observed as vulnerable to buckling, but they had been reinforced during the conversion. Thus, it is considered inappropriate to determine that the hull of Stellar Daisy had been damaged due to buckling.

4.4.8.3 Also, a fatigue strength analysis was conducted to check fatigue accumulated during the ship's overall period of operations, including the operation periods before the conversion and the resulting safety weakness as well. In this analysis, the bottom and side shell plates around the bilge of WBT No. 2 (P/S) were proven to be more critical in terms of fatigue strength.

4.4.8.4 In addition, the KMST reviewed stress resulting from the hull inclination 0° to 20° to establish the impact on the ship's structural strength when the hull inclined. As the result, when the heel angle was 10° or above, several transverse members of cargo hold Nos. 2 and 3 were determined to be likely to suffer structural damage.

4.4.8.5 Meanwhile, the ultimate strength of Stellar Daisy satisfied the criteria required in the IACS CSR on a condition where the ship experienced the ASP on her both sides due to waves.

4.4.8.6 Also, the fracture analysis was carried out to establish whether the ship might experience damage (fractures) if the ASP was applied. The findings showed that when such pressure was applied to the ship for an extended period, damage, i.e., fractures, would be made to the bilge plate, the inner cross tie, and the transverse frame connections of WBT Nos. 2 and 3 (P/S).

4.4.8.7 Therefore, the results from all of the post-casualty structural analyses suggest that as the ASP caused by the waves coming from the side was applied to the hull which had been gradually damaged due to cumulative fatigue over a long period, the probability was high that the relatively critical side and bottom plates around the bilge of WBT No. 2 would be damaged first.

4.4.8.8 The analysis led to the following presumptions: WBT No. 2 (P) flooded after being damaged first and the ASP caused by the waves coming from the side further aggravated heeling, which resulted in loads increasing significantly onto the port side; simultaneous and extensive structural damage was made to the hull, such as collapse of transverse members and bulkheads of ballast tanks on port; and then flooding expanded up to WBT Nos 3-4 (P) accordingly.

section

5

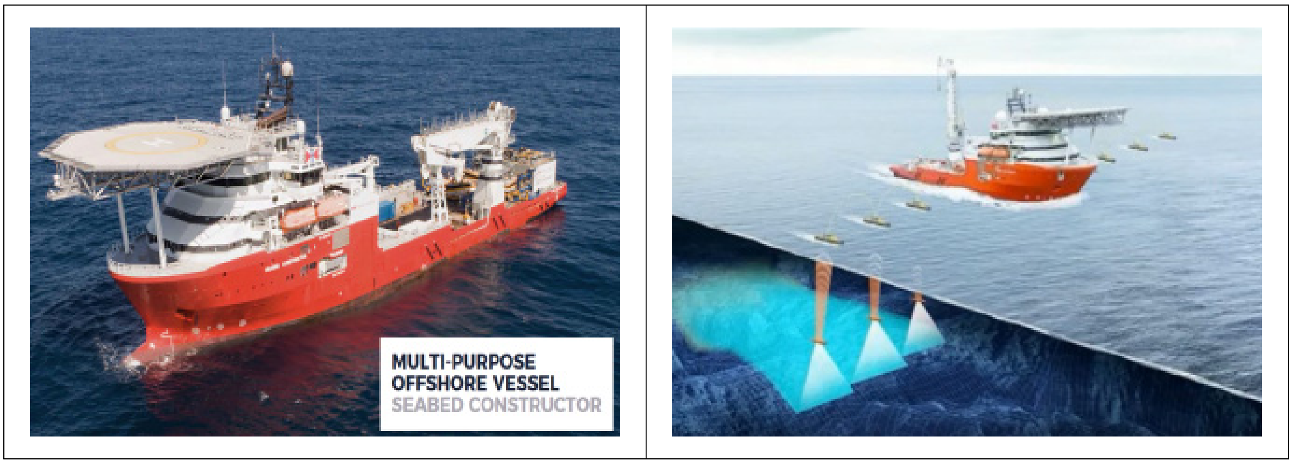
Analysis on Deep-sea Search Results

5. Analysis on Deep-sea Search Results

5.1 Overview

5.1.1 On 28 December 2018, the government of the Republic of Korea signed a service contract with Ocean Infinity[106] to conduct a deep-sea search of Stellar Daisy in order to accomplish the following goals: locate the sunken ship, Stellar Daisy; film the hull and reproduce 3D mosaic images; search for and identify a missing liferaft and the VDR; and retrieve the VDR, if possible.

5.1.2 Ocean Infinity decided to deploy the following fleet to accomplish its mission of the deep-sea search operations for Stellar Daisy: one multi-purpose offshore vessel (MPOV), named M/V Seabed Constructor; four autonomous underwater vehicles (AUVs) fitted with sensors, such as a side-scan sonar (SSS) and a multi-beam echo sounder (MBES), and two remotely operated vehicles (ROVs) with a high definition (HD) camera.



[Figure 62] M/V Seabed Constructor

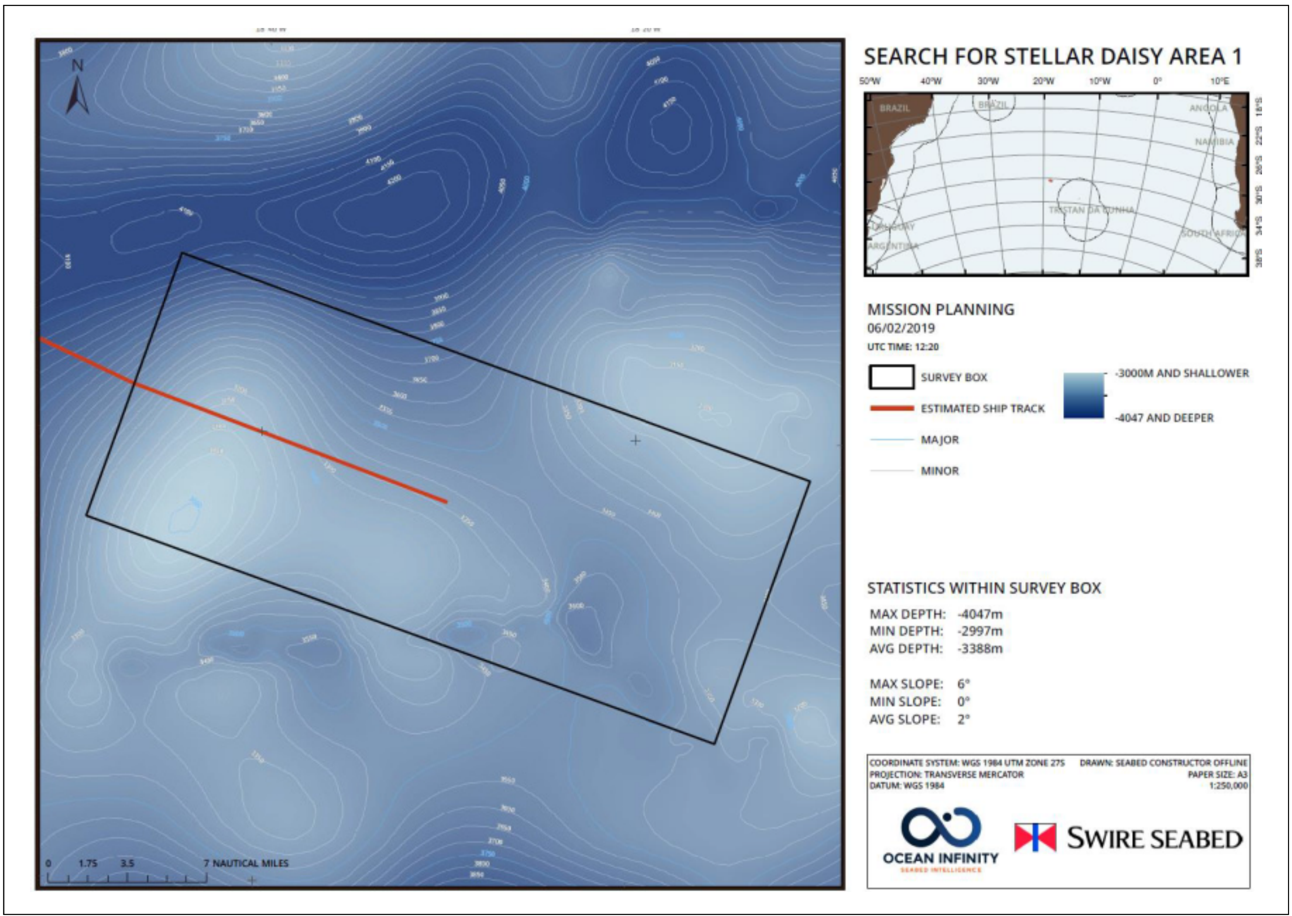
106) Ocean Infinity is a marine robotics company that deploys autonomous robots, typically in fleet formation, to obtain large amounts information from the oceans and seabed.The company was founded in the U.S., in 2017, and its major achievements include searching for the missing aircraft of Malaysia (MH370) in 2018 and locating the missing Argentine Navy submarine (ARA San Juan).

[Figure 63] Autonomous Underwater Vehicle (AUV)

[Figure 64] Remotely Operated Vehicle (ROV)

5.1.3 Prior to the operations, the company established a 55 km x 22.5 km search area in the waters where the accident of Stellar Daisy was presumed to have occurred based on the signals which INMARSAT-C DSC and EPIRB sent out at the accident. The ocean in the search area was about 3,400 m deep.

5.1.4 The MPOV, M/V Seabed Constructor, departed from Cape Town in the Republic of South Africa for her mission on 8 February 2019 and arrived at the search area on 14 February.

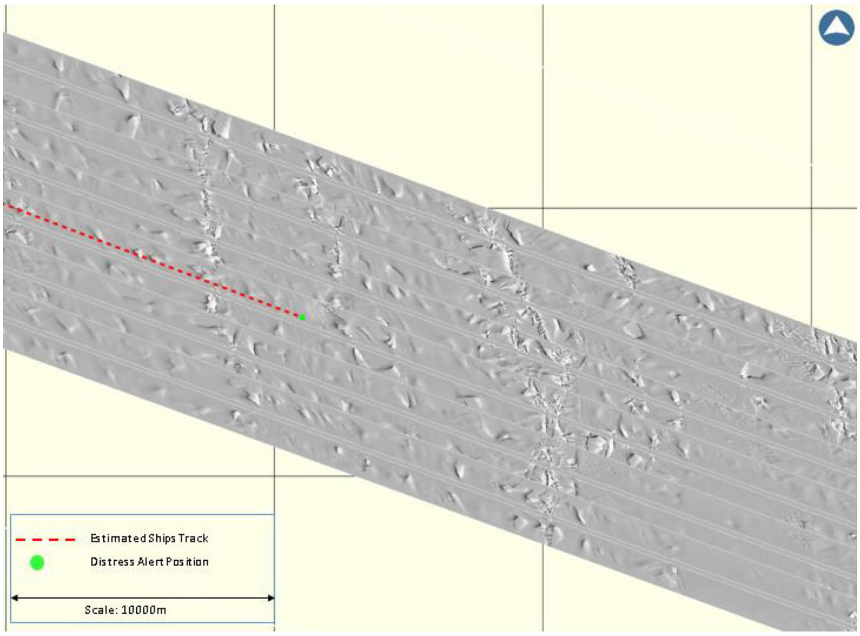


[Figure 65] Search area

5.2 Initial low-frequency survey

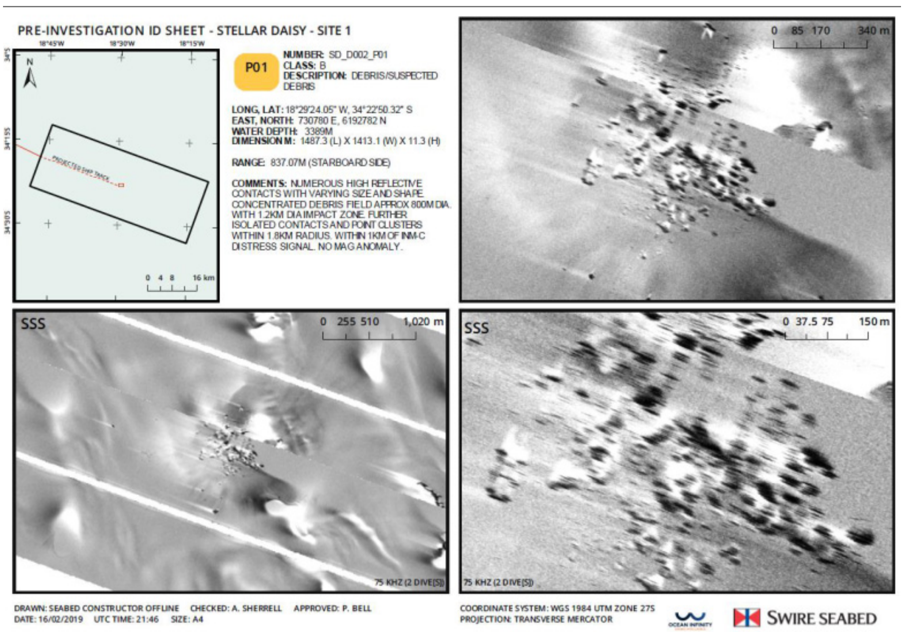
5.2.1 Ocean Infinity deployed four AUVs to the overall search area and conducted an initial low-frequency survey with the SSS and MBES from 14 to 16 February in 2019.

5.2.2 They found rock outcrops with a high reflectivity ranging north and south on the seabed of the search area, while deep-sea sediments with a low reflectivity were situated on the seabed of the rest area.



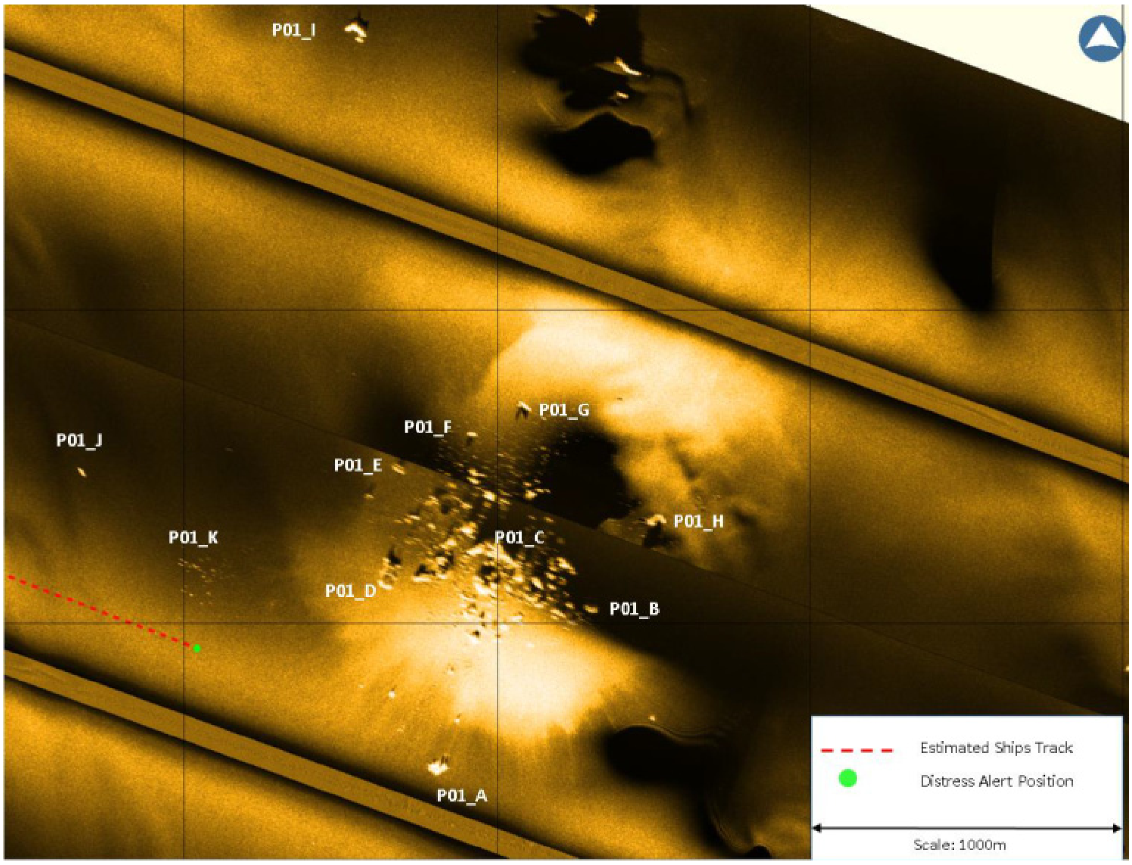
[Figure 66] Low-frequency SSS mosaic of the search area

5.2.3 The survey failed to identify any objects similar in size to the hull of Stellar Daisy. However, there were high reflective point contacts in various sizes and shapes, which were presumed to be the ship's debris, on an 1 km x 0.8 km seabed area in way of rock ridge about 1 km away from the EPIRB signal location.



[Figure 67] Low-frequency SSS mosaic of the area presumed to have the ship's debris

5.2.4 Ocean Infinity designated these point contacts as the points of interest (POI), more specifically divided them into P01_A to P01_K, and set out a detailed plan to conduct inspections with ROVs.



[Figure 68] Detail classification of the POIs

5.3 Initial visual inspection survey

5.3.1 On 16 February 2019, Ocean Infinity deployed ROVs and commenced the initial visual inspection to verify whether the debris of Stellar Daisy was located at the POIs as confirmed during the low-frequency survey.

5.3.2 The initial visual inspection observed a significantly large metal fragment painted red and debris of hatch covers. Also, a structure of the ship´s accommodation area marked with an IMO No. was found at the BC03 POI, which confirmed that it is the area where the debris of Stellar Daisy is located.

Hull debris

C/H hatch cover

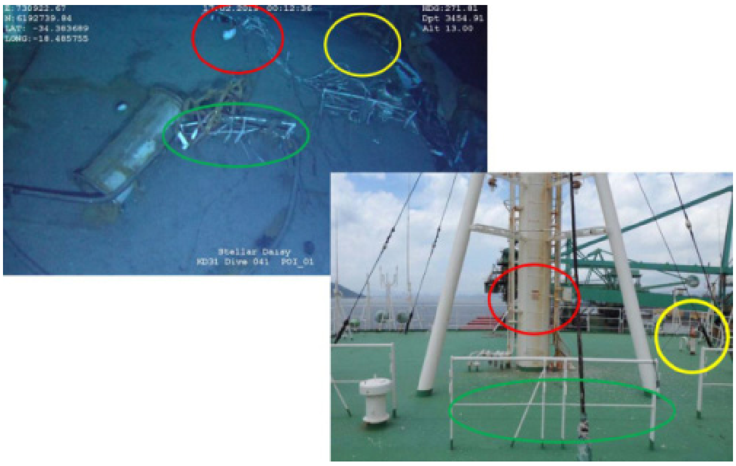
Topside structure

Structure marked with an IMO No.

[Figure 69] Debris of Stellar Daisy

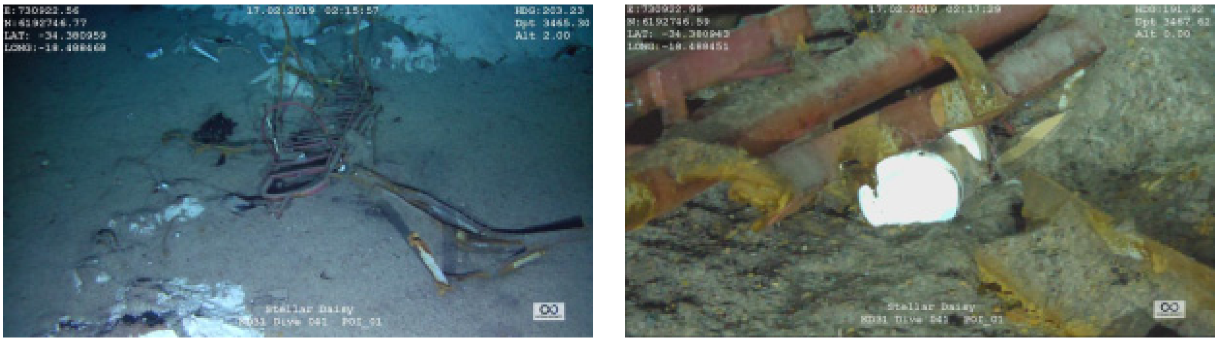
5.3.3 Later, the visual inspection continued to search for the VDR protective capsule of the ship.

5.3.4 The VDR protective capsule was originally installed on the compass deck above the wheel house. However, the compass deck was identified as detached from mast, handrails, and antenna or deformed during the visual inspection.



[Figure 70] Compass deck above the steering room before and after the accident

5.3.5 The protective capsule was observed under the object presumed to be a ladder on the starboard side of the bridge while conducting the visual inspection on the areas in way of the accommodation structures.



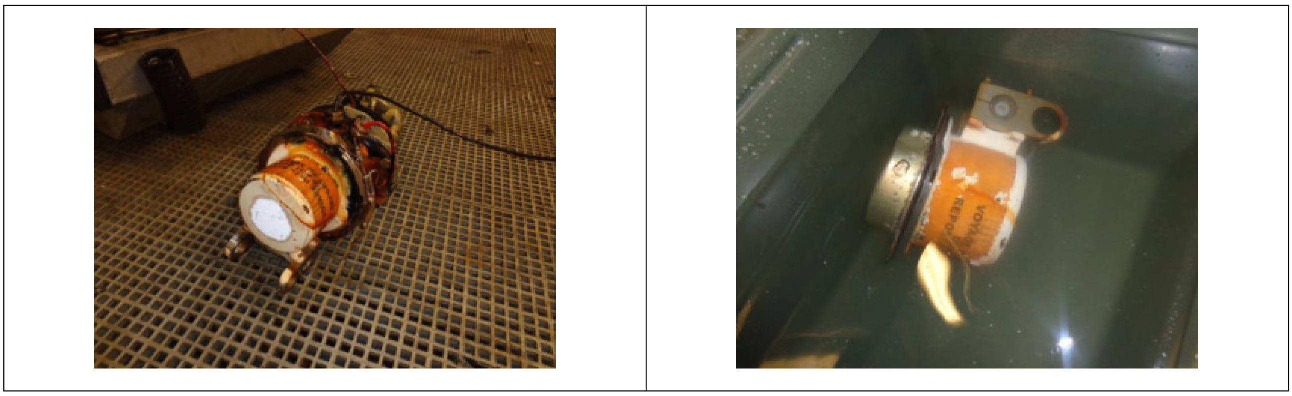
Where VDR was sighted

VDR was retrieved

[Figure 71] Finding and retrieving the VDR

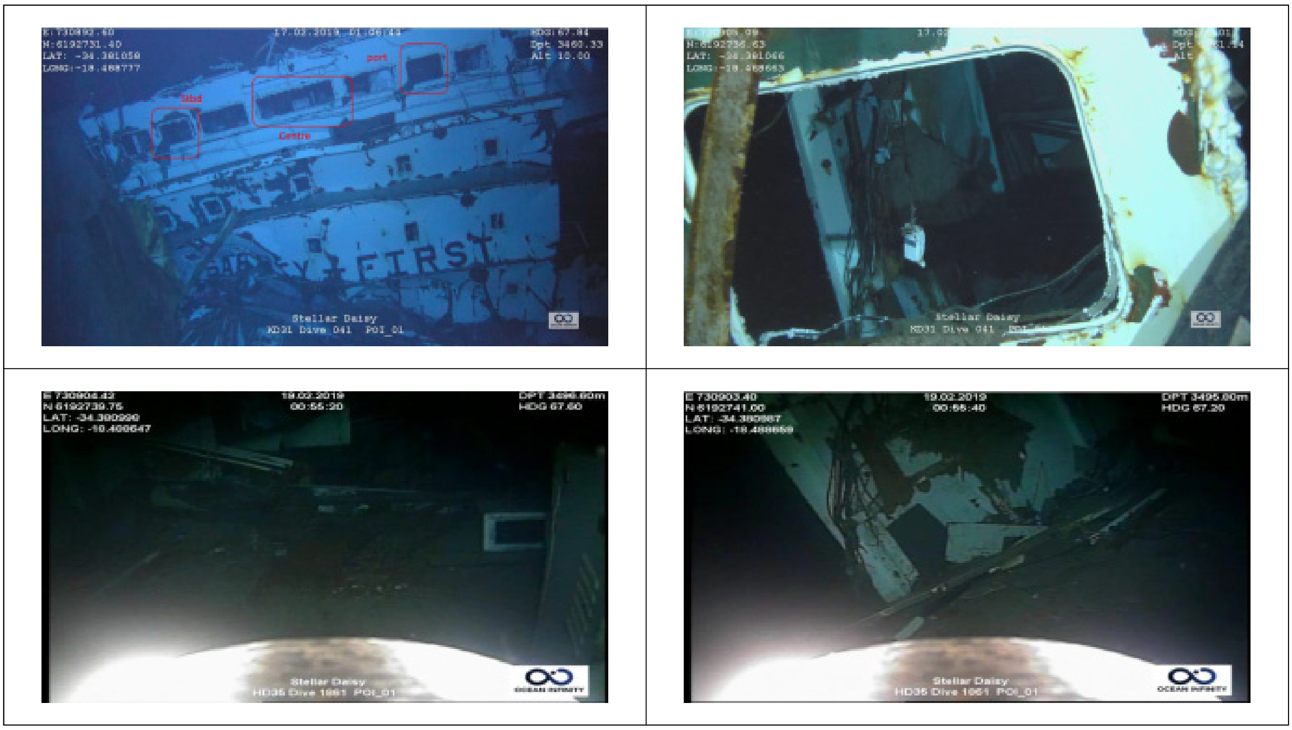
5.3.6 The VDR protective capsule discovered during the visual inspection was raised to the deck of M/V Seabed Constructor by ROVs on 17 February. It was kept in a box with deionized water and stored on board in accordance with the guidelines of its manufacturer.[107)]

107) L3Harris Technologies, Inc.



[Figure 72] How the VDR was stored

5.3.7 Meanwhile, compared to the size of AUVs, the bridge access door or windows were relatively narrow, making it difficult to enter the bridge. Therefore, the AUVs checked the inside through the windows from the outside and observed widespread damage inside the bridge; the panels in the walls and ceiling were mostly broken, and cables inside the bulkheads were also exposed.



[Figure 73] Details of topside structures

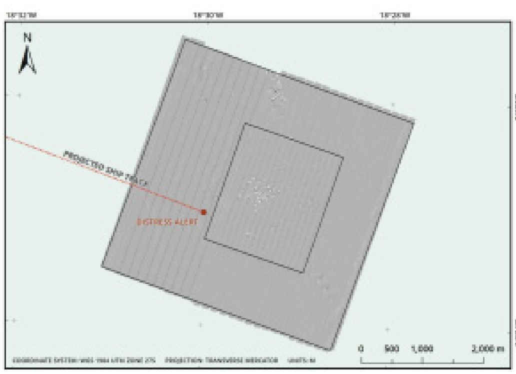
5.3.8 The SART mounting bracket was discovered inside the wheel house. However, the SART unit was not mounted on the bracket. In addition, the main body of the VDR was supposed to be installed next to the bracket, but it was not discovered, either.

5.4 High-resolution debris survey

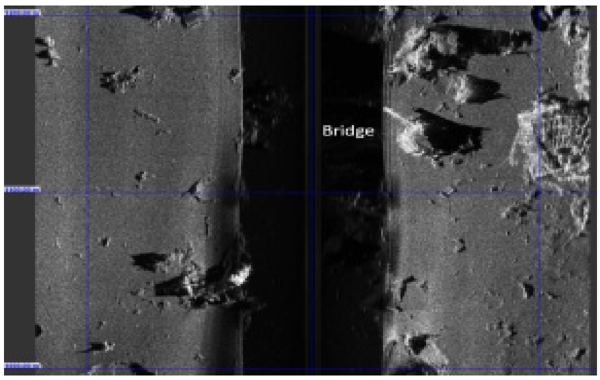
5.4.1 Ocean Infinity deployed two AUVs and conducted a high-resolution debris survey with the SSS and MBES on 20 February 2019.

5.4.2 The high-resolution debris survey was intended to support visual inspections by focusing on the areas where the debris scattered with much higher resolution.

5.4.3 The company surveyed 4 km x 4 km areas at 75 m intervals on the seabed where the debris of Stellar Daisy was found and closely examined extra 2 km x 1.5 km areas at 50 m intervals on the seabed.



Survey area: 4 km x 4 km, 2 km x 1.5 km

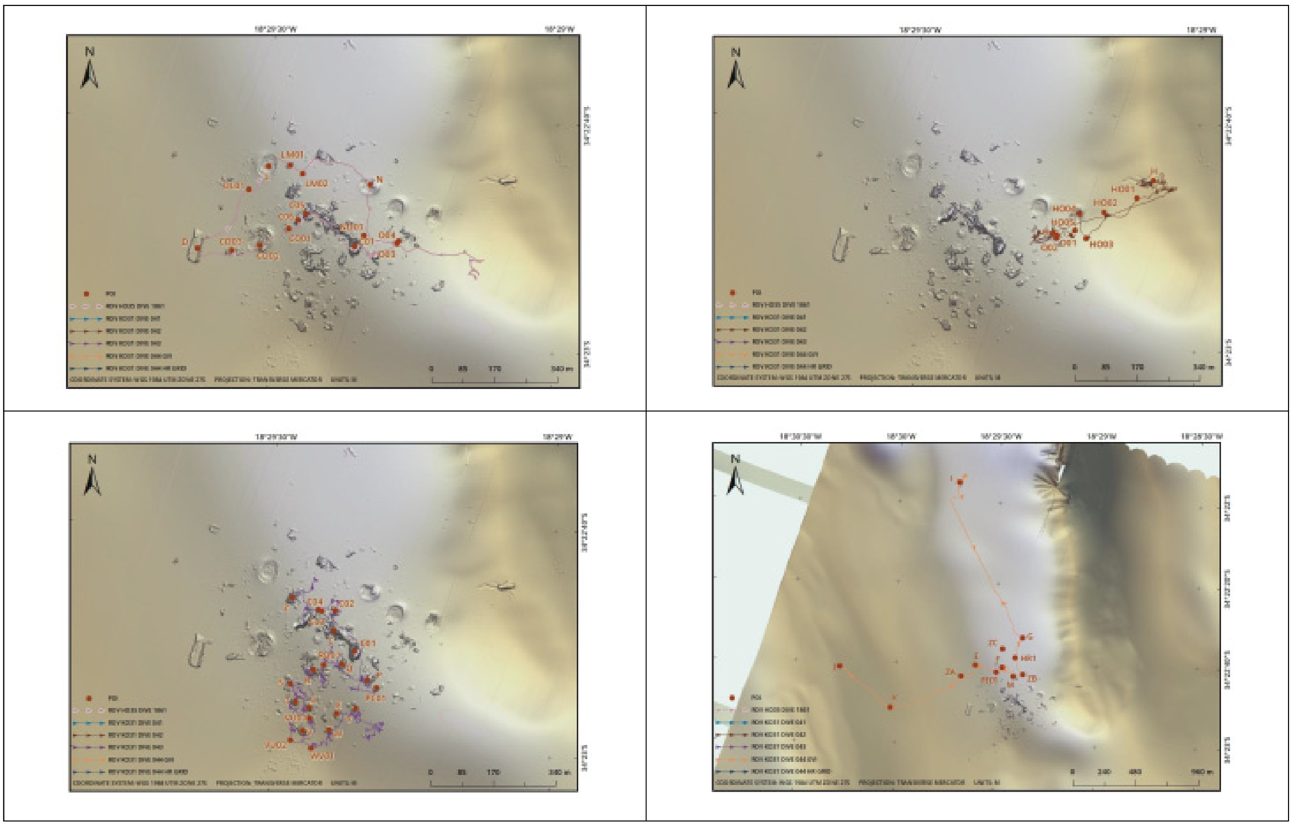


Bridge area

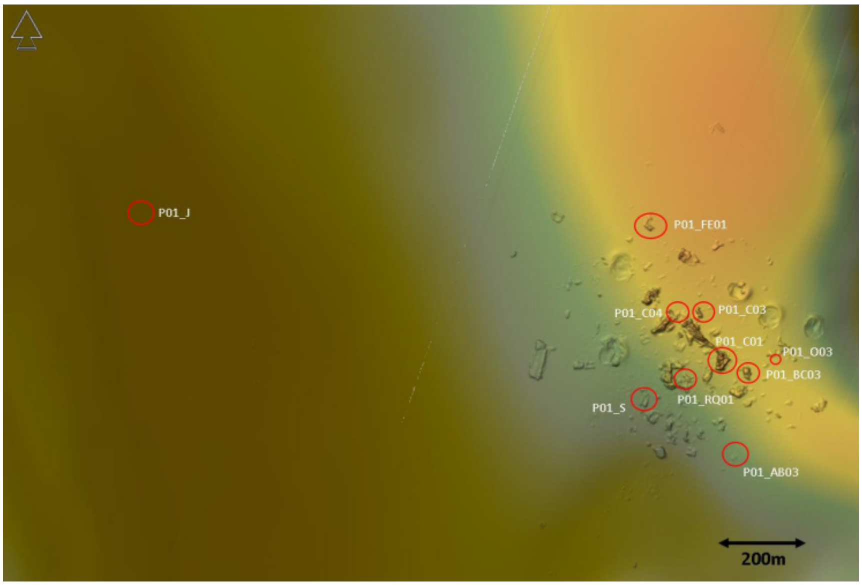
[Figure 74] High-resolution debris survey using SSS

5.5 Visual inspection survey outline

5.5.1 Ocean Infinity categorized the POIs from A to Z as the debris of Stellar Daisy was widely dispersed in terms of size and shape. The company also conducted visual inspection using ROVs along the well-categorized routes.



[Figure 75] ROV's exploration routes for the overall visual inspection



[Figure 76] Location of major hull debris

5.5.2 [Figure 77] illustrates major hull debris identified during the visual inspection. More details are described in Appendix I.


C/H hatch cover (P01_AB03)


Bridge (P01_BC03)


Bow mast (P01_C01)


C/H hatch cover (P01_C02)


Aft body (P01_C04)


C/H hatch cover (P01_FE01)


Gangway (P01_J)

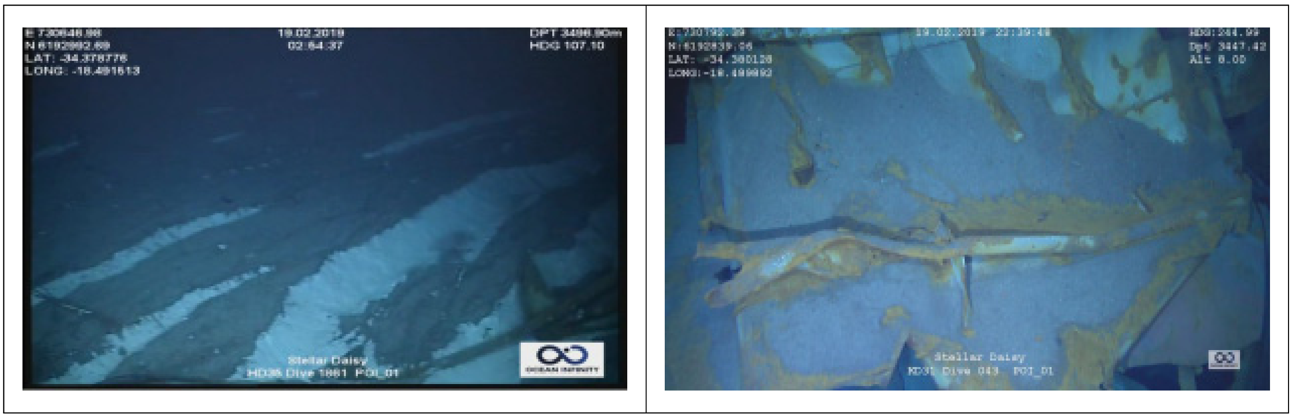

Mast (P01_O03)


Bow area (P01_RQ01)


C/H hatch cover (P01_S)

[Figure 77] Major hull debris identified during the visual inspection

5.5.3 The cargo of iron ore loaded on Stellar Daisy was deposited around the debris, and gray or brown metallic luster was observed.



[Figure 78] Iron ore around the debris

5.5.4 After completing the visual inspection on 23 February, M/V Seabed Constructor set sail for Montevideo in Uruguay on 24 February 2019.

5.6 Video analysis results of hull debris

5.6.1 The debris of Stellar Daisy was dispersed in a variety of sizes and shapes in an 1 km x 0.8 km area approximately 3,400 m below the sea.

5.6.2 Most of the debris was so severely deformed and damaged that it was difficult to guess their original shapes, but the original locations or functions of some debris could be identified as in [Figure 77]. The debris of the shell plate and inner bulkheads in cargo holds where cargo was loaded were too damaged to deduce their original locations.[108]

5.6.3 Even after reviewing the video of the damaged parts of the debris identified, it was difficult to determine whether such damage had occurred before or during the sinking, while the ship was settling, or as the ship hit the seabed.

108) It was unable to identify or assume to which frame of the hull the debris of the shell plate or inner bulkheads belong.

5.6.4 Importantly, the structures or debris of WBT No. 2 (P), which were presumed to be where the damage had first occurred, could not be verified by the footage. The same was true with the other ballast tanks. In addition, it was unable to identify from which part of the cargo hold the debris came, except for certain cargo hold hatch covers.

5.6.5 Also, the company failed to discover the hull equipment, such as main engine, propeller, rudder and anchor, which are very large in size and easily identifiable even when damaged or deformed. Even the cargo hold hatch covers that were identified were just limited

5.6.6 The figure of the debris filmed during the search operation is just a few parts of the ship. Still, much debris is buried in deep-sea sediments or covered by other debris, including the iron ore cargo, meaning that every hull component cannot be identified through the video analysis on the deep-sea search operations.[109)]

5.6.7 Since the results from the analysis on the hull debris observed during the search showed that it was insufficient to identify which part of the hull had been damaged first, it was not able to figure out what was the cause of such damage from this footage.

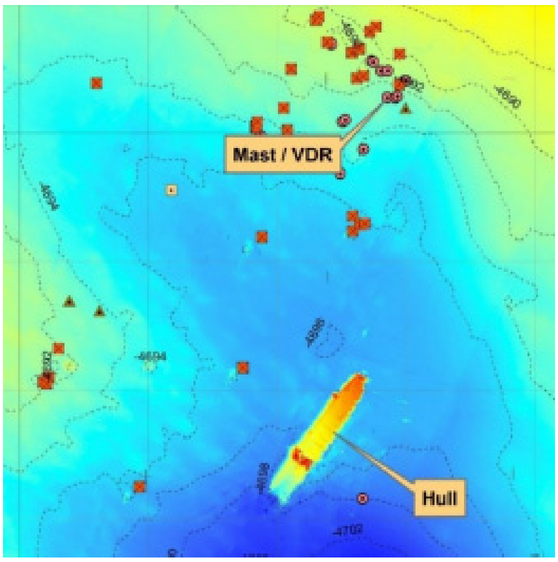
5.7 Implosion analysis

5.7.1 If a ship that contains enclosed compartments sinks, pressure outside the enclosed compartments (water pressure) increases as the ship goes deeper. When the external pressure goes beyond the maximum resistance limit of the enclosed compartments (collapse pressure), the compartments begin collapsing, a process known as "implosion.“

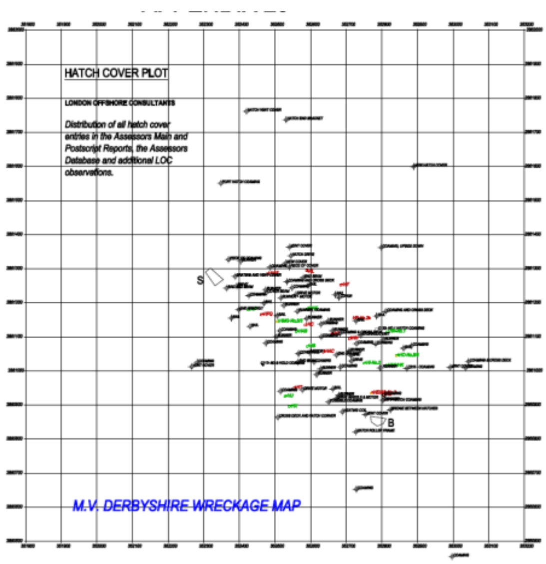
109) When adding up total areas of the steel plates used for cargo hold Nos. 1 to 5 (deck, side, and bottom plates, and longitudinal and transverse bulkheads, approx. 250 m in length), except for the bow, stern, and the accommodation area, the calculated area would be at least 100,000 ㎡, amounting to about 15 times the size of the soccer field. However, the sum of the 2D areas of the debris presumed to be cargo hold Nos. 1 to 5 identified in the deep-sea search is estimated at less than 50,000 ㎡.

5.7.2 The shapes of Stellar Daisy's debris discovered during the deep-sea search raise the possibility of implosion while the ship was sinking. An implosion analysis[110] was carried out to determine whether it did indeed occur.

5.7.3 In general, when a ship was sinking and her compartments were watertight, the ship would be likely to experience implosion due to the external pressure. And if the compartments were not watertight, the possibility would be low. The debris of the sunken ship helps to assume whether the ship suffered implosion. As in [Figure 79], El Faro, a containership that sank in the Atlantic Ocean in 2015, had most of her compartments flooded when sinking. That fact led to the conclusion the ship did not implode. However, the debris of an ore carrier, Derbyshire, was dispersed in many pieces when sinking in the North Pacific Ocean in 1980, indicating that most of the carrier's compartments remained watertight while the ship was sinking. And, implosion is presumed to have occurred while the ship was sinking further into the sea.



Results from the deep-sea search of El Faro
(Quoted from the investigation report of the National Transportation Safety Board (NTSB))

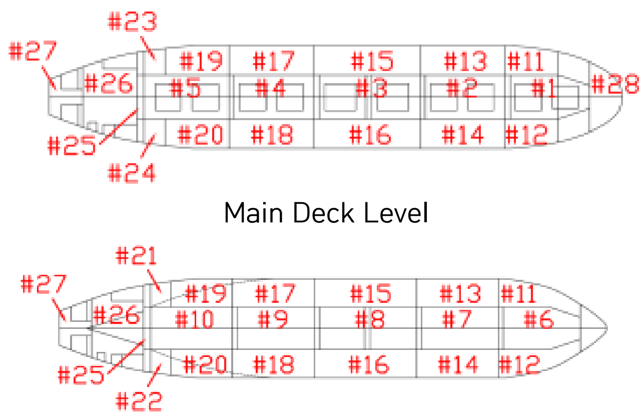


Results from the deep-sea search of Derbyshire
(Quoted from the investigation report of the UK's Admiralty Court)

[Figure 79] Deep-sea searches of other sunken ships

110) The analysis was conducted by the Society of Naval Architects of Korea

5.7.4 According to the results of the deep-sea search, Stellar Daisy's debris of various sizes was widely dispersed in an 1 km x 0.8 km seabed area at a depth of about 3,400 m. Given that, the hull is presumed to have undergone implosion[111] while sinking. In order to confirm the possibility of implosion and measure the collapse pressure, 28 enclosed compartments were identified on Stellar Daisy as in [Figure 80].



[Figure 80] Identification No. of enclosed compartments

5.7.5 If external pressure collapses structures (plates) of the enclosed compartments or an access hatch fitted over the enclosed compartments, the individual enclosed compartments will also collapse. Therefore, the minimum values which collapsed the structures or access hatches of each enclosed compartment can be regarded as the collapse pressure for imploding its respective enclosed compartment.

5.7.6 First, the KMST estimated the collapse pressure of the following openings of all enclosed compartments as 1.5 times of the design pressure[112] on the drawing of Stellar Daisy: the access hatch and the main hatch of the cargo holds; the manhole, the air vent, and the bilge line of the void tanks; the access hatch, the air vent, and the ballast line of the ballast tanks; and the manhole, the air vent, the filling line, and the suction line of the fuel oil tanks. Such collapse pressure was produced based on the length, width, and depth of the structures above.

111) As each enclosed compartment has a different collapse pressure, implosion could occur repeatedly at different depths. If a ship suffers implosion, structures of the enclosed compartments may be crushed inward and sometimes ruptured.

112) In this analysis, the collapse pressure is regarded as the pressure of the hydraulic test applied to the pressure proof test of the enclosed pressure vessel. The hydraulic test pressure is set as 1.5 times the design pressure.

5.7.7 The collapse pressures of the openings and the structures of the enclosed compartments were compared in [Table 31]. As in the following table, cargo holds, if enclosed, and ballast tanks may collapse from implosion at a depth of 5-10 m (0.054-0.101 MPa) and about 35.7 m, respectively. And, it was determined that double-bottom void tanks were likely to collapse right after the ballast tanks collapsed as they adjoined each other.

[Table 31] Collapse pressure of enclosed compartments

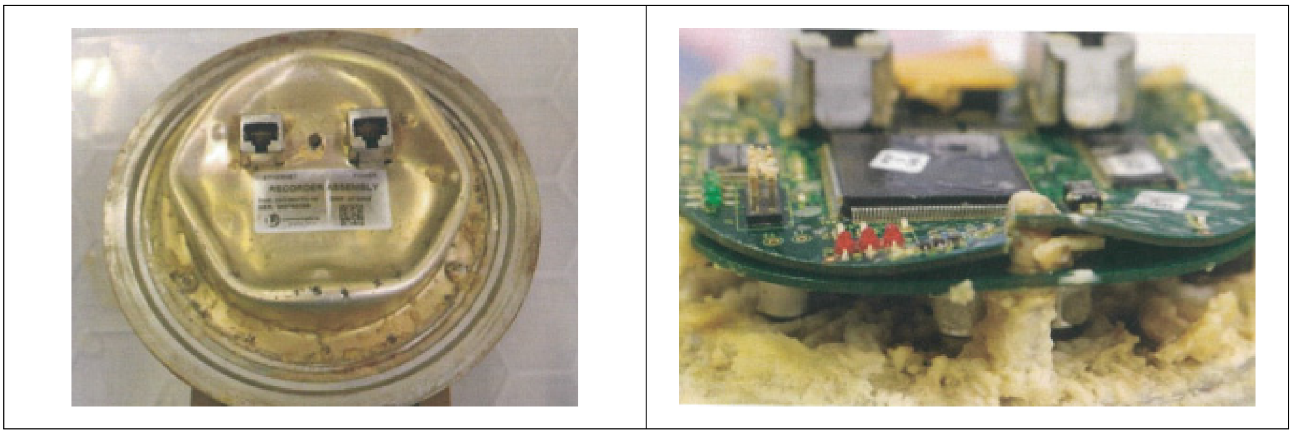
Enclosed compartment		Collapse pressure of openings (MPa)	Collapse pressure of structures (MPa)	Collapse pressure of enclosed compartment (MPa)	Collapsed location
#1	C/H No. 1F	0.101	0.257	0.101	Hatch Cover
#2	C/H No. 2	0.101	0.434	0.101	Hatch Cover
#3-5	C/H Nos. 3-5	0.054	0.434	0.054	Hatch Cover
#6-12	Void Space	0.375	0.117	0.117	Center Girder
#13-20	WBT	0.375	0.357	0.357	BHD
#21-22	Void Space No. 6	0.525	0.475	0.475	Upper Deck
#23-24	FWD FOT	0.525	0.289	0.289	Longi. BHD
#25-26	Pump Room, Engine Room	Open end	-	Open end	-
#27-28	Fore Peak, Aft Peak Tank	0.525	0.538	0.525	Manhole

5.8 VDR data recovery

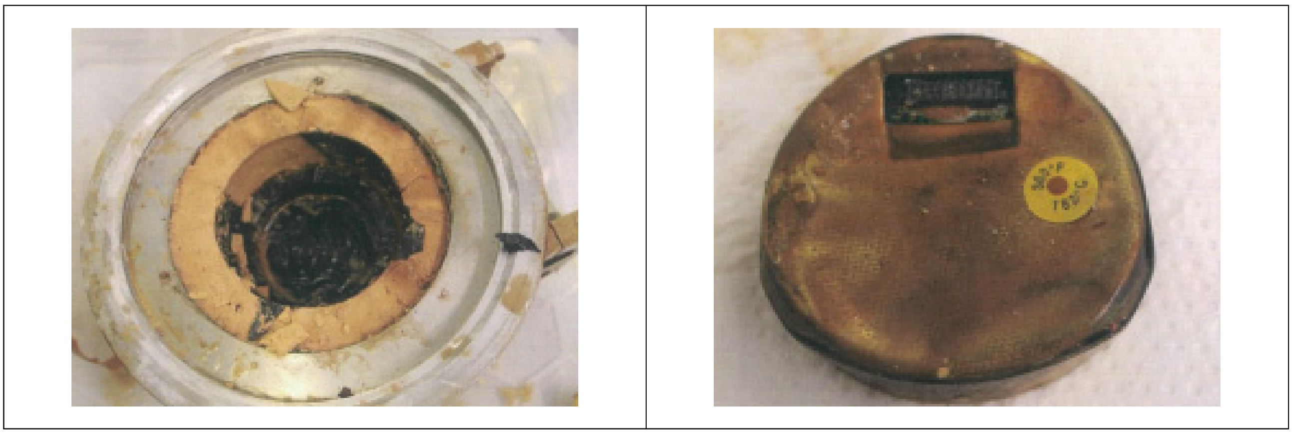
5.8.1 The team of forensic specialists engaged in data recovery[113] of the S-VDR from its protective capsule, which had been retrieved during the deep-sea search operation.

5.8.2 The casing of the retrieved protective capsule was damaged. After removing it, the specialists found out that the processor board had been also damaged. They separated the board, took out the insulation materials inside, and ascertained that the memory module case was also deformed in many places.

113) It was led by the Special Investigation Commission on Humidifier Disinfectants & 4.16 Sewol Ferry Disasters

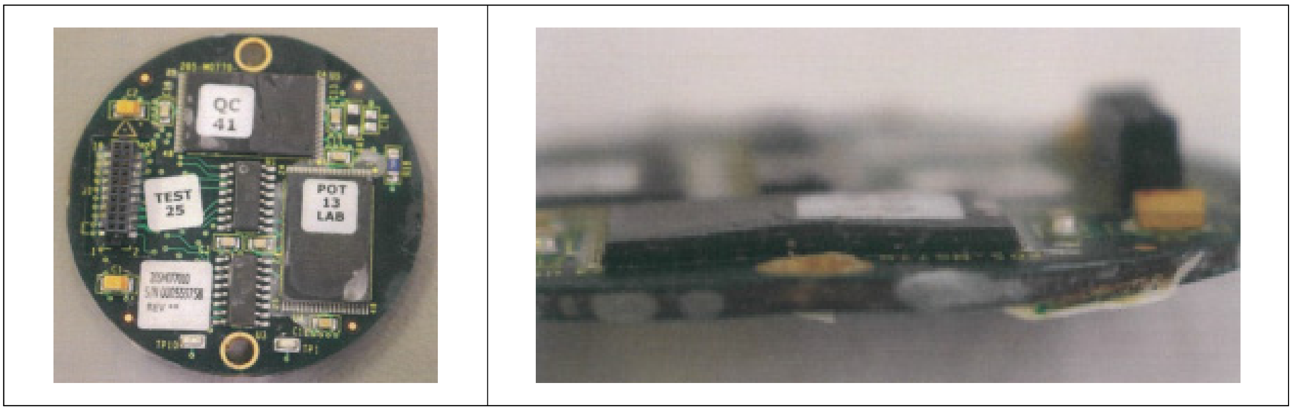


[Figure 81] Protective capsule's casing and processor board



[Figure 82] Memory module case

5.8.3 After opening the memory module case and examining the module's printed circuit board (PCB), they found there were two memory chips, which are the key components, and one of them was damaged. The other memory chip also indicated possible damage. The controller chip, another key component, was damaged as well.



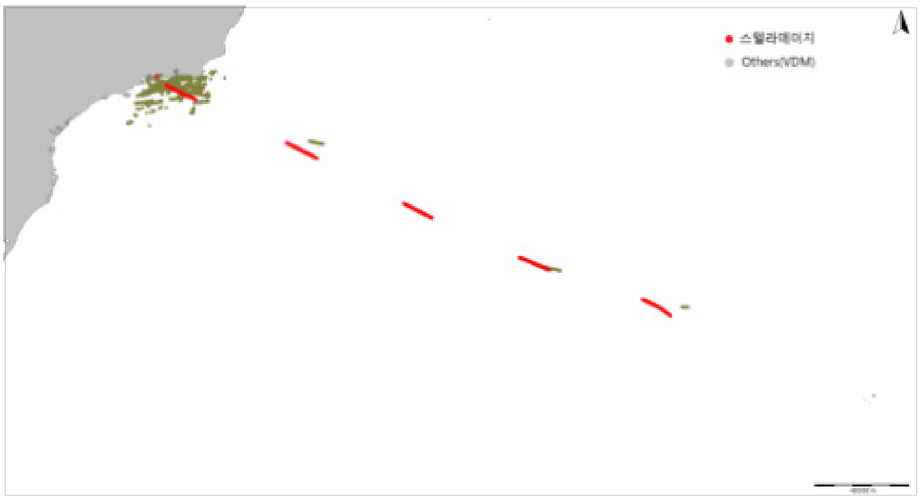
[Figure 83] Memory module

5.8.4 The specialists recovered data from the relatively less damaged memory chip by removing it from the PCB and reading it with a chip reader. They discovered that 50 % of the data were invalid[114], 43 % were empty, and only 7 % remained valid.

5.8.5 The intact 7 % was processed and identified as GPS and AIS information. A total of 47 hours of information was saved as listed in [Table 32], and the data were divided into seven storage sections, which are marked on the chart as in [Figure 84].

[Table 32] Recovered data

Ship	Time to Start	Time to End	Location Information (case)
Stellar Daisy	2017/03/24 00:16:22	2017/03/24 07:01:44	24,339[115]
	2017/03/25 03:12:48	2017/03/25 09:50:56	23,899
	2017/03/26 05:58:04	2017/03/26 12:46:59	24,549
	2017/03/27 09:12:46	2017/03/27 15:55:20	24,158
	2017/03/28 12:19:34	2017/03/28 19:09:20	24,594
	2017/03/29 15:33:08	2017/03/29 22:16:13	24,202
	2017/03/30 18:50:20	2017/03/31 01:26:55	23,812
213 adjacent ships			93,328



[Figure 84] Track of Stellar Daisy from the recovered data

114) The manufacturer of the chip reader considered invalid data as unreadable, which is presumably because the chip was damaged.

115) The data on 24 and 25 March are the ship's location data while berthing, which indicate the positions the same as in [Figure 84].

5.8.6 The recovered data are the objective source as the tracking data confirm the sailing route of Stellar Daisy during the accident voyage. However, the data are of limited utility for analyzing causes of damage and sinking of the ship.

5.9 Sub-conclusion

5.9.1 The video of the ship's debris obtained from the deep-sea search operations was not able to pinpoint which area of Stellar Daisy had been damaged first or what had caused the damage. However, the debris was scattered in many pieces, leading to the conclusion that the ship had experienced implosion due to water pressure while sinking.

5.9.2 To confirm the possibility of implosion more accurately, an implosion analysis was conducted for identifying the enclosed compartments on Stellar Daisy and then evaluating the collapse pressure of each one. The results from the implosion analysis also confirmed that implosion had occurred when the ship had been sinking, as previously suggested by the video of the ship's debris.

5.9.3 The VDR is a device which stores information, including conversations on the bridge, radar images, and a ship's track. However, the retrieved VDR of Stellar Daisy was damaged to the point that only part of its tracking data could be recovered. Those data are insufficient to play an important role in analyzing what caused the damage and sank the ship.

section

6

Conclusions

6. Conclusions

6.1 Stellar Daisy went missing after sending a message: "The ship's No. 2 Port is leaking. The ship is rapidly inclining to port," right before the accident occurred. In the statement of the two surviving crewmembers, the ship had been sailing along and then suddenly made a thundering sound and vibrated. They also stated that the ship had sunk within as little as five minutes after a sudden inclination to port.

6.2. In this case, the hull sank suddenly and the crewmember who first witnessed her sinking went missing, which made it difficult to obtain direct evidence to reveal the causes and process of the sinking. Thus, the KMST developed the premises that, given the factual information presented in the social media message and the statements given by the survivors, a large damage should be made to the shell plate on the port side; the seawater should start entering the ship; and the flooding should suddenly expand to adjacent compartments so as for the ship to sink within about five minutes. And, under such premises, the agency reviewed probable scenarios. The KMST endeavored during the investigation to identify the probability of these premises, in particular the primary cause behind the first damage made to the hull. Also, a multi-faceted analysis was made to determine the probability that the water ingress expanded further so that the ship lost buoyancy after being damaged initially.

6.3 First, the KMST looked into weather conditions, the ship's stability at the time of the accident, longitudinal strength under cargo loading, and the probability of cargo liquefaction in order to check whether those typical factors of the navigation process have caused this accident. However, the results showed that nothing was identified as a direct risk factor which may have caused this accident.

6.4 Next, the KMST examined records of ship surveys and the shipping company's management history to search probable causes of this accident from the management process while the ship had been operated from the moment of being converted till the time of the accident. The results showed the following findings: constant corrosion in several ballast tanks and void tanks; a delay in repairing damage made to the hull's major members; a lack of effort to identify causes of the damage; and alternate offloading operations which had not been reviewed in advance. It seems difficult to determine that such findings caused sufficient hull damage to sink the ship. However, if they are combined simultaneously in multiple ways with other critical factors, they could serve as a potential cause which may accelerate the damage to the hull.

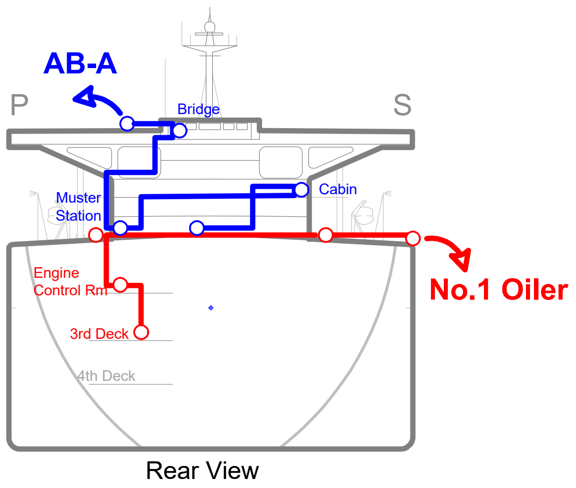
6.5 Also, the KMST conducted a variety of naval architectural analyses on which area had been first damaged and whether such initial flooding had expanded to other compartments by assessing hull structural strength, fatigue strength, ultimate strength, and fracture to determine the structural safety or critical locations of the ship. The results showed that while the hull of Stellar Daisy had been gradually weakened due to accumulated fatigue for a long period of time, the ship would have experienced the ASP caused by waves coming from the side. While doing so, it seems highly likely to have damaged the relatively weakened side shell and bottom plates at the bilge area of WBT No. 2 (P) for the first time. Also, the analyses confirmed that structural damage would have been made to several transverse members if the ship had inclined more than 10°

6.6 In summary, the agency presumes that the first damage was made to the lower shell plate of WBT No. 2 (P) by a combination of the following factors and the seawater first entered the ship through such damaged area: the strength of the structural members weakening over a long period of time; fatigue accumulated by causes, including the ship’s alternate offloading operations which had not been reviewed in advance; and the ASP caused by waves.

6.7 It is presumed that the flooding of the initially damaged WBT No. 2 (P) would have caused the ship to heel fast, resulting in a sudden load shift on the port side; a collapse of the transverse members and bulkheads of the ballast tanks on port; and water ingress into WBT Nos. 3 and 4 (P) accordingly. Last, as the ship's heel and immersion accelerated, the damage progressed even to some of the cargo hold hatch covers and longitudinal bulkheads. The situation deteriorated to the point where the seawater entered the cargo holds and ballast tanks on starboard; the ship lost her buoyancy, and she quickly sank.

6.8 The following are presumed detailed developments of the accident based on the investigation results:

1) The location of the surviving crewmembers, their travel routes, and other important information at the time of the accident are demonstrated in [Figure 85] and [Table 33] based on their statements, a message sent to the shipping company via a social media application, and EPIRB distress calls.



[Figure 85] Location of the surviving crewmembers at the time of the accident

[Table 33] Restructured time-based travel routes of surviving crewmembers

Estimated Time (LT)	Able Seaman A (AB A)	No. 1 Oiler	Heel Angle (Estimated)
Before 13:20	At the corridor of the quarters area on the upper deck: • Felt strong vibration • The ship started inclining to port	On the 3rd deck of the engine room: • Felt strong vibration	0°
At 13:20 A message was sent via social media	At the muster station on port: • Heard the master's announcement twice	On the 3rd deck of the engine room: • Heard the master's announcement twice	5°-40°
	At portside quarters area: • Moved to the bridge	On the 2nd deck of the engine room: • Moved to the bridge	
	On the bridge: • Arrived at the bridge	On the upper deck: • Couldn't move to the bridge	

Estimated Time (LT)	Able Seaman A (AB A)	No. 1 Oiler	Heel Angle (Estimated)
At 13:22	On the bridge: • The ship inclined further	On the starboard upper deck: • Moved to the starboard lifeboat	40˚-50˚
	In the steering room: • Approached to the sea surface on port	Next to the starboard lifeboat on the upper deck: • Grasped the handrails	
13:24	On the port bridge wing: • Jumped into the sea	Next to the starboard lifeboat on the upper deck: • Grasped the handrails	50˚-70˚
	• Was thrown into the sea	• Fell into the sea by the waves washing over the starboard deck	
At 13:25 (EPIRB Distress Call)	• Spun with circulating current and went under the water	• Was drawn into the sea and spun with the circulating waters	
	• Could not find the ship after being pushed on the surface	• Could not find the ship after being pushed on the surface	

2) The accident broke out at the time the two surviving crewmembers felt strong vibrations. That is estimated to have occurred about one minute before the message reporting the flooding of the ship was sent via a mobile phone and the master of Stellar Daisy made an announcement at 13:20. At that time, the shell plate of the hull was severely damaged.

3) The first damaged area is either the side shell plate or the bottom plate of WBT No. 2 (P), through which the seawater entered the hull, and as the result, the ship heeled to port. At that time, the ship reported her urgent situation to the company by sending a social media message and made the announcement on board.

4) At the time of heeling to port due to the flooding of WBT No. 2 (P), the ship instantly inclined 10˚ or more to port due to the pressure of beam-sea waves coming. The asymmetric loads stemming from the heeling caused damage to most transverse webs and bulkheads of WBT Nos. 2-4 (P).

5) Therefore, the transverse bulkheads of WBT Nos. 2 and 3 (P) collapsed, causing WBT No. 3 (P) to be flooded. Then, as the transverse bulkheads between WBT Nos. 3 and 4 (P) collapsed successively, WBT No. 4 (P) started to be flooded as well. The hull inclined almost 40° to port.

6) After WBT Nos. 2 to 4 (P) were flooded, the heel angle increased and the end of the upper deck on port was immersed. As the result, the hatch covers of the cargo hold Nos. 1 and 2 were damaged, and the seawater started flowing into the holds.

7) Such flooding of the holds accelerated the hull's immersion. As the transverse bulkheads of WBT Nos. 4 and 5 (P) collapsed, WBT No. 5 was flooded. Then, the FOT also collapsed, leading to a fuel oil spill. At that time, the hull inclined about 50°, and AB A jumped from the bridge wing into the sea. Following that, No. 1 oiler, who was grasping the handrails on the starboard upper deck, was washed overboard by the waves.

8) Then, as most of the longitudinal bulkheads adjoining the cargo holds were collapsed, the cargo shifted to the ballast tanks on port. The hatch covers of cargo hold Nos. 3 to 5 were also damaged, resulting in the flooding of the holds.

9) As the seawater flowed into the holds, the double-bottom tanks inside the holds were damaged and the longitudinal bulkheads on the starboard side also collapsed, causing the seawater to enter into the ballast tanks on starboard as well. Therefore, the ship lost buoyancy, further inclined to port, and sank completely. After a while, AB A and No. 1 oiler who had jumped into the sea popped up onto the surface. However, they could not find the hull.

6.9 After the accident, hull debris was discovered at a depth of about 3,400 m during the deep-sea search. However, they were dispersed in a damaged condition over an 1 km x 0.8 km area. Except for several structures, such as the accommodation area or cargo hold hatch covers, severe fracture and deformation left the debris unidentifiable.

6.10 The implosion analysis was conducted to identify whether the ship had experienced implosion during sinking. The results showed that the compartments which had been intact during the flooding remained enclosed. Then, seawater pressures are presumed to have imploded these enclosed compartments. The hull was shattered into so many pieces, which seems attributable to implosion.

section

7

Actions Taken After Accident

7. Actions Taken After Accident

7.1 Actions taken by the Korean government

7.1.1 The government of the Republic of Korea launched a joint inspection unit consisting of the public and private sectors and conducted inspections on a total of 14 converted ore carriers, including ten vessels belonging to Polaris Shipping, from April 2017 to September 2019.

7.1.2 The joint inspection did not identify any major structural deficiencies. When jointly inspecting Stellar Eagle, an ore carrier operated by the company, from 15 to 20 March 2018, the unit found out that a pipeline had been installed in the bilge well of the cargo hold without any approval from her RO and ordered the company to return it to the original condition[116].

7.1.3 The government revised the "Standards on Enhanced Surveys, Etc." (Public Notification of the MOF) on 24 May 2018, and strengthened hull surveys for aged ships by deploying more surveyors to examine the areas with structural vulnerability and assigning them exclusively to the ships based on the ships' size and age.

7.1.4 In particular, the government had a close-up survey followed for the critical areas with structural vulnerability and the suspected areas by designating additional surveyors on single-hulled bulk carriers, and double-hulled bulk carriers and oil tankers aged 10-15 years.

7.1.5 The government encouraged its shipping lines to stop operating their 29 ore carriers converted from single-hulled oil tankers by scrapping them earlier than their life. Therefore, those 29 carriers were phased out of commercial ship operations by December 2020.

116) Polaris Shipping identified and removed such pipelines fitted in the bilge wells of six converted ore carriers in total, including Stellar Eagle.

7.2 Actions taken by KR

7.2.1 In response to the request made by the Korean government, KR conducted all-out internal inspections[117)] on the 29 converted ore carriers registered to verify their structural safety. These inspections began in April 2017 and continued through November of that year.

7.2.2 KR could not find any significant structural deficiencies during these investigations. Instead, KR identified minor cracks or deformations on areas like the upper deck plate and structural stiffeners, and thus, they were replaced or reinforced accordingly

7.2.3 Also, the organization revised the KR rules as of 1 January 2020 as follows: survey cycles were shortened for converted ore carriers aged 25 years or more (adding occasional surveys at six-month intervals between special surveys); requirements of the surveys, including close-up and overall surveys, were enhanced; and new load conditions which reflect the up-and-down rolling motion created by beam-sea waves were added to the direct strength assessment of ore carriers to enhance safety of the transverse strength.

7.3 Actions taken by Polaris Shipping

7.3.1 Immediately right after Stellar Daisy accident, Polaris Shipping commissioned both KR and LR to conduct structural analysis and close-up surveys on 18 converted ore carriers being operated by the company to identify their areas of structural vulnerability.

7.3.2 Furthermore, the company took the following measures as recommended in the investigation report published by the RMI: the company revised the safety management procedures; it reinforced shore staffs responsible for safety, quality, and management of crew and technology; and after the accident, it scrapped all of its converted ore carriers or terminated their operations in phase by July 2020.

117) Ships which have periodical surveys, such as annual or special surveys, received the all-out inspections in line with their regular schedules. The ships with no such schedules received occasional surveys separately.

section

8 Recommendations

8. Recommendations

8.1 Considering the ASP when reviewing the hull's strength

8.1.1 If the stress applied to the hull by the still water, waves, and cargo loads exceeds the allowable limit of the hull's strength, the result will be hull damage, including buckling, cracks, or fractures. Therefore, the hull structures should have sufficient strength and stiffness to bear their design load.

8.1.2 Such hull strength is classified into longitudinal, transverse, and local strengths, and if the hull structures satisfy the criteria of the longitudinal and local strengths, it generally means the ship's transverse strength falls into an appropriate level as well. That is why the current structural criteria for the steel ships do not sufficiently consider the ASP created by the beam-sea waves which all ships may encounter at sea.

8.1.3 However, the ASP would have a greater impact on an ore carrier laden with high-density cargo and having an opening on the deck than on other types of ships. Thus, when building or converting such ships, their strength should be assessed in light of the ASP applied to the hull. Moreover, it is considered necessary that the IMO must review measures for applying the ASP to its current standards related to hull strength.

8.2 Reviewing safety of the way of loading cargo

8.2.1 When any ships are to be built or converted, their shipowners write a loading manual which describes various loading conditions of cargo, including the condition of cargo loaded homogeneously, and they submit the manual to their RO. Then, the organization, who received the manual, reviews the ship's strengths, including longitudinal and local strengths, based on their cargo loading conditions and then approves the manual. In accordance with the loading manual, the RO approves a loading computer.

8.2.2 In case where cargo is to be loaded in a condition not mentioned in the loading manual, the master or the C/O of each ship use the loading computer to set and verify their cargo loading plan. The loading computer indicates the ship's stability and longitudinal strength for each way of cargo loading. However, there are no such measures to check the ship's local strength.

8.2.3 Therefore, if a ship is operated in a condition not included in the ship's loading manual, such as alternate cargo hold offloading, the shipowner should review the ship's safety by checking her local strength with the RO in advance. And, the shipowner should make sure the master or navigational officers of the ship clearly understand the necessity of such procedure.

8.2.4 To do that, the ship operator needs to regulate such procedures in the ship's safety management manuals and train the masters and other relevant persons to comply with the procedures. Also, the RO needs to clearly add precautionary statements or place warning signs in the ships' loading manual and loading computer so that the relevant persons, including the masters, can easily understand that they are required to receive a preliminary review and an approval from the RO if their cargo is to be loaded or offloaded in a way (alternate loading or offloading) clearly different condition from their loading manuals.

8.3 Improving record management of the RO

8.3.1 When any ship is to be built or converted, the RO reviews and approves her structural adequacy under the relevant rules and guidance and conducts periodic surveys on the ship's condition.

8.3.2 The records of such reviews and approvals, made pursuant to the rules and guidance, or checklists for ship surveys are to be properly managed in accordance with the organization's rules and regulations. Still, the way of recording hull repairs or how details are included in such records varies with individual surveyors.[118)]

118) When KR conducted a survey for the conversion of Stellar Daisy, it did not record whether that examination had been applied to the provisions of the hull section modulus (KR rules, Pt. 3, Ch. 3, Sec. 2, Para. 4) and the buckling criterion (KR rules, Pt. 3, Annex 3-2, Para. 3). Also, several repairs were not documented in its survey report when KR conducted intermediate and special surveys after the conversion.

8.3.3 Therefore, it is considered necessary for KR to establish the standard way of recording detailed histories for their surveyors who write survey reports on major repairs so that records can be thoroughly managed.

8.4 Managing their ships strictly

8.4.1 Shipowners or operators are obliged to continuously maintain their ships in the same condition as they are when their surveys are completed. Therefore, if damage is made to a hull, the company has to report it to the RO to determine out causes and make immediate repairs.

8.4.2 Also, shipping companies must ensure their ships load or offload cargo on board in a way approved. Otherwise, the shipping companies must apply for reviews or approvals by the RO in advance.

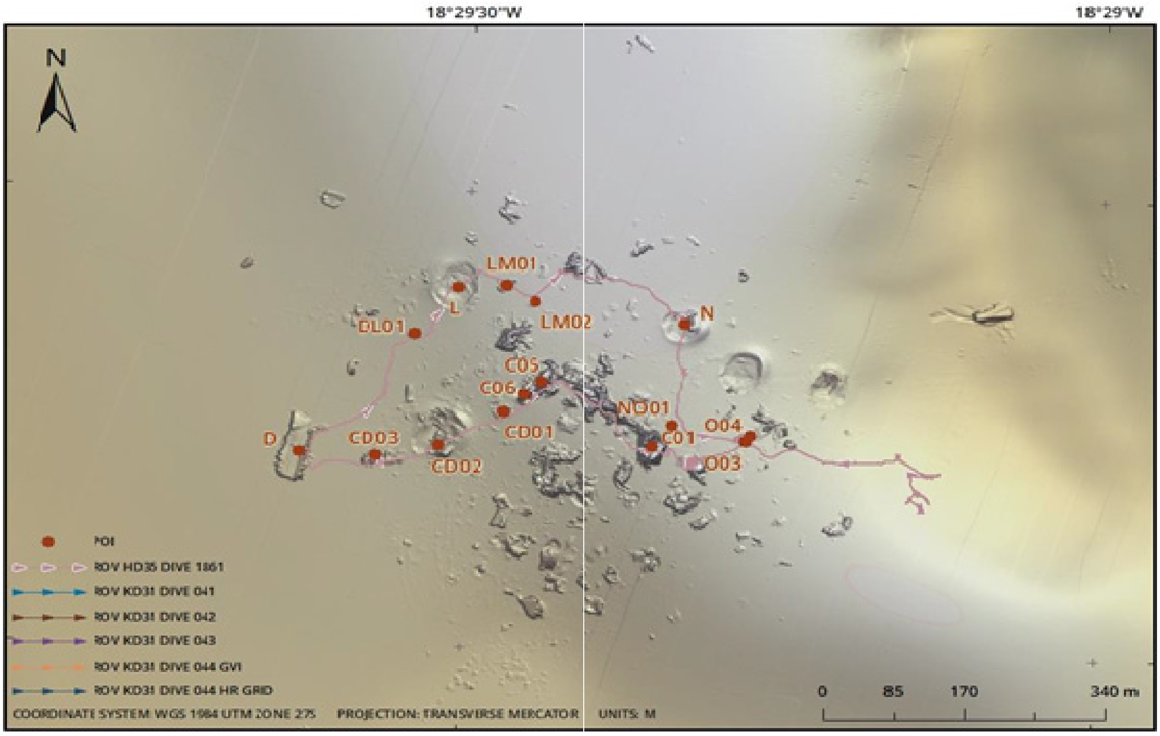
8.4.3 Currently, detailed procedures for the safety management manual are being developed on issues, including how to maintain ships the same as they were surveyed and appropriate ways of loading cargo on board. Thus, Polaris Shipping, the shipowner, needs to thoroughly implement such revised procedures and verify the implementation progress on a regular basis.

section

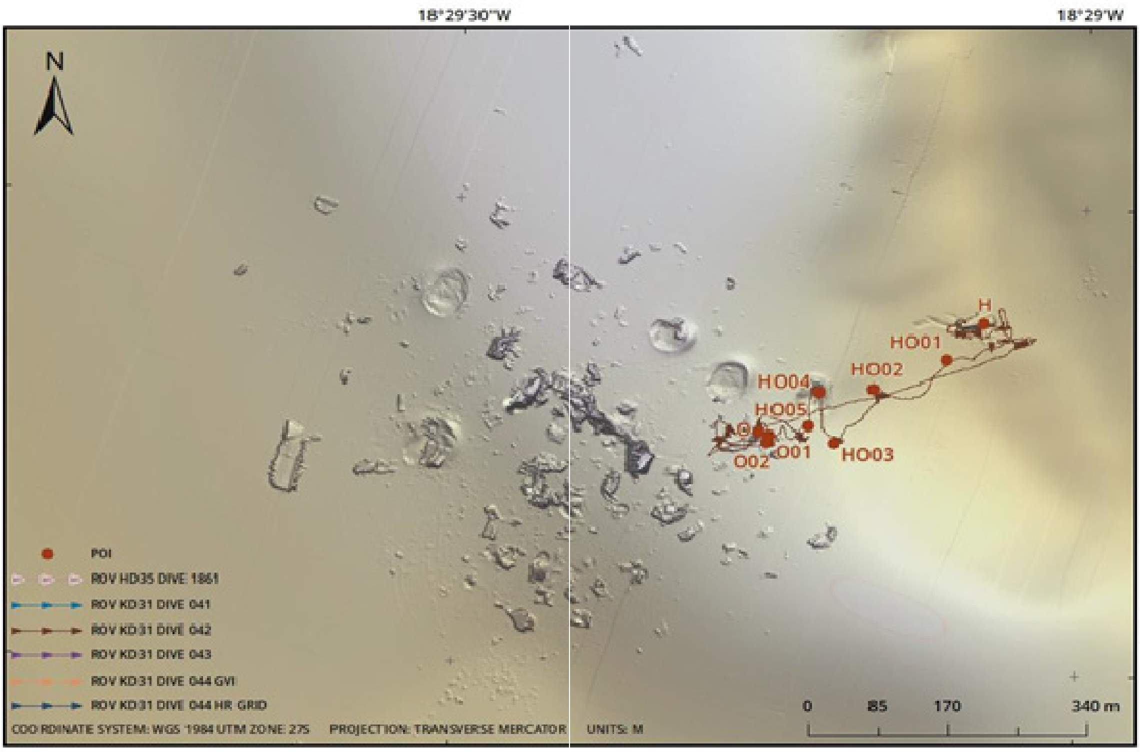
App.

Detailed Results of Visual Inspection

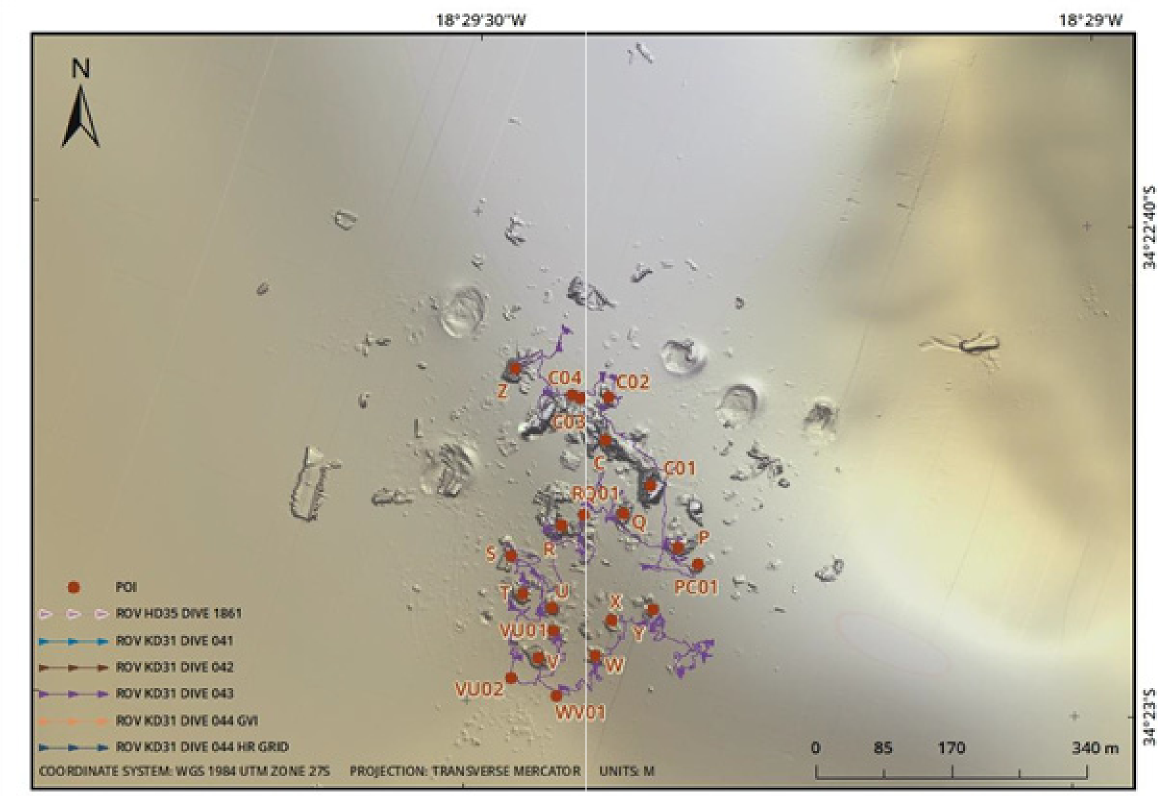
I. Exploration Routes for Visual Inspection



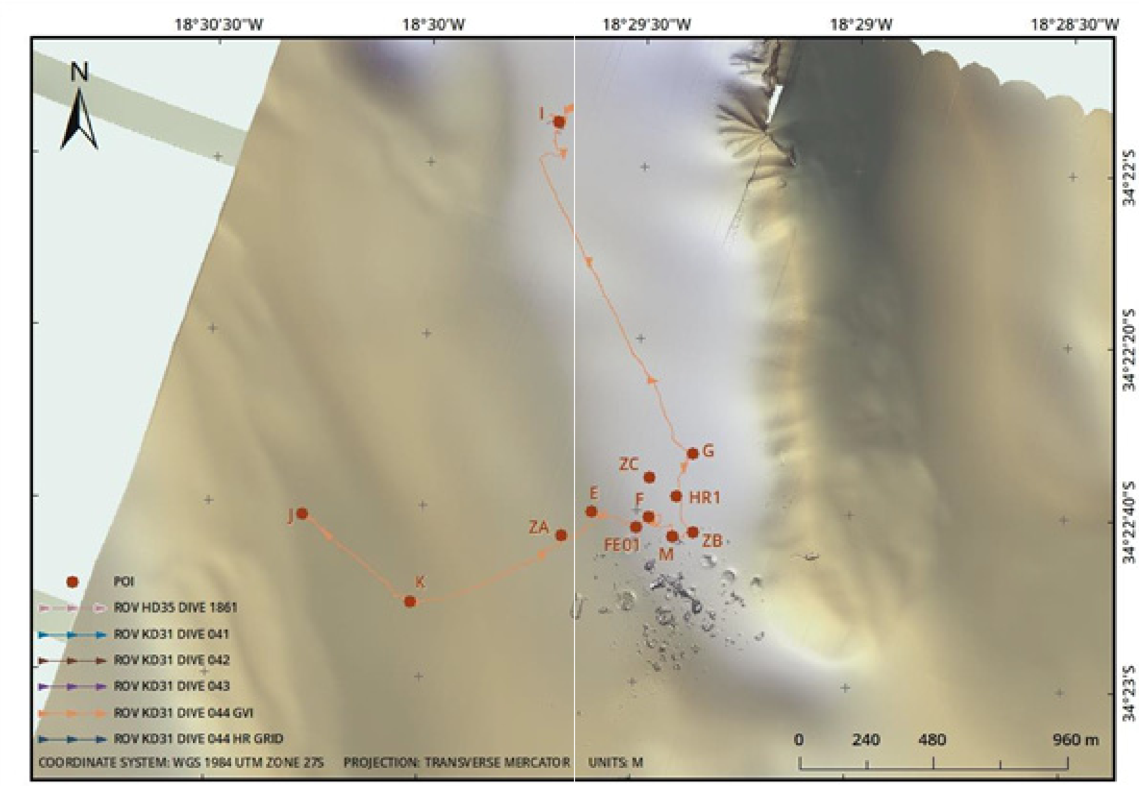
① ROV's exploration route



② ROV's exploration route



② ROV's exploration route

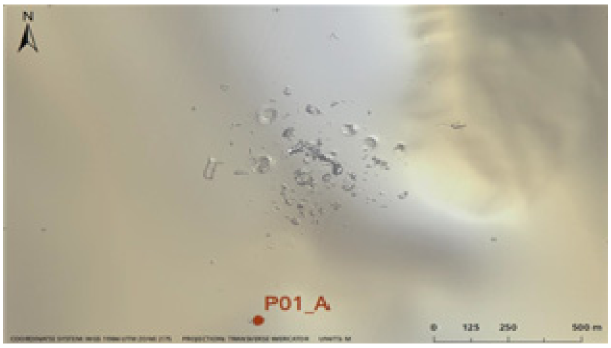


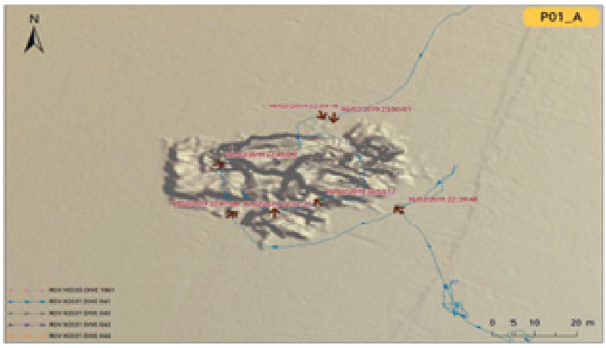
④ ROV's exploration route

II. Visual Inspection Results

1. P01_A

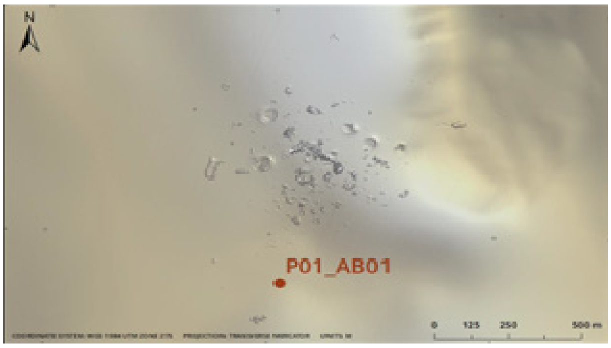
These stiffened plate structures with many small stiffeners attached are severely torn and crushed. They are presumed to be part of bulkhead structures inside the hull.

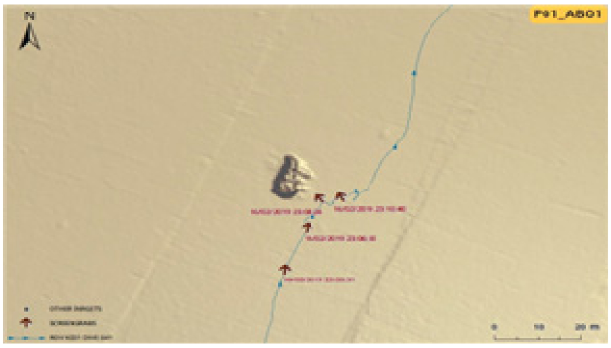




2. P01_AB01

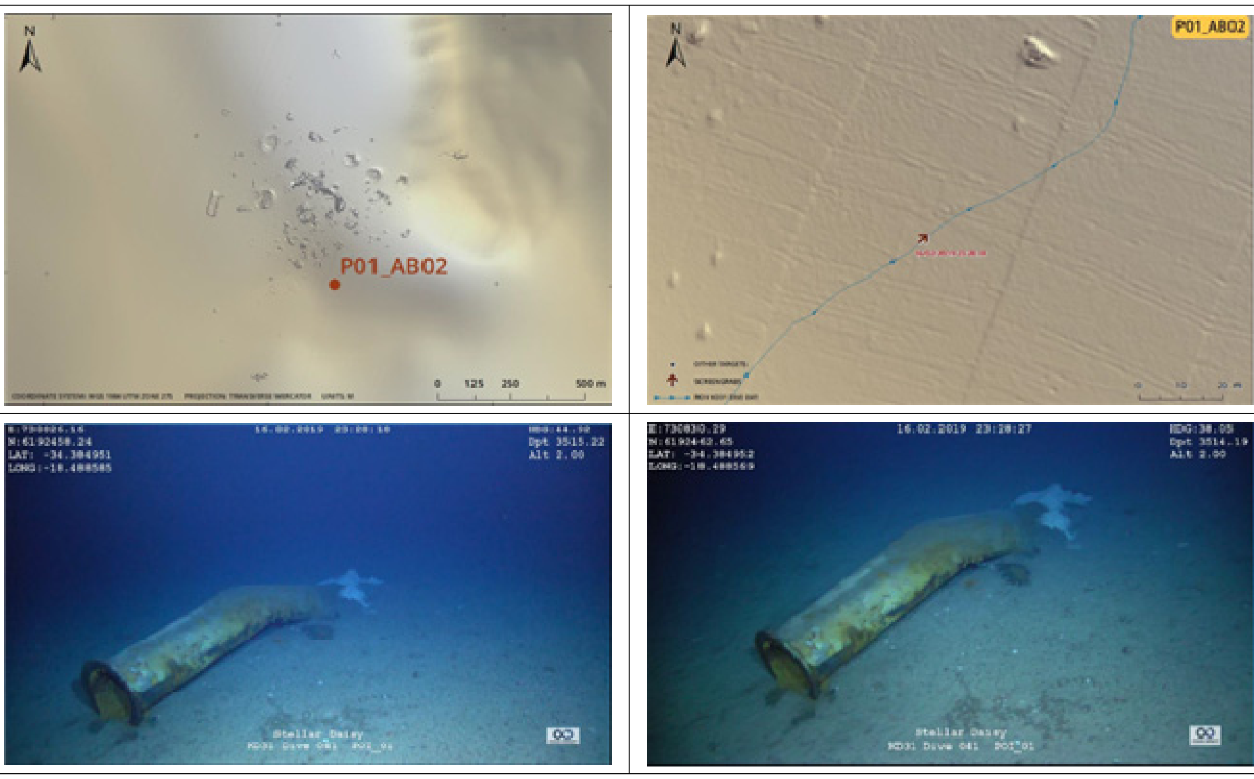
These objects are presumed to be part of the deck structure where mooring bollards were located.





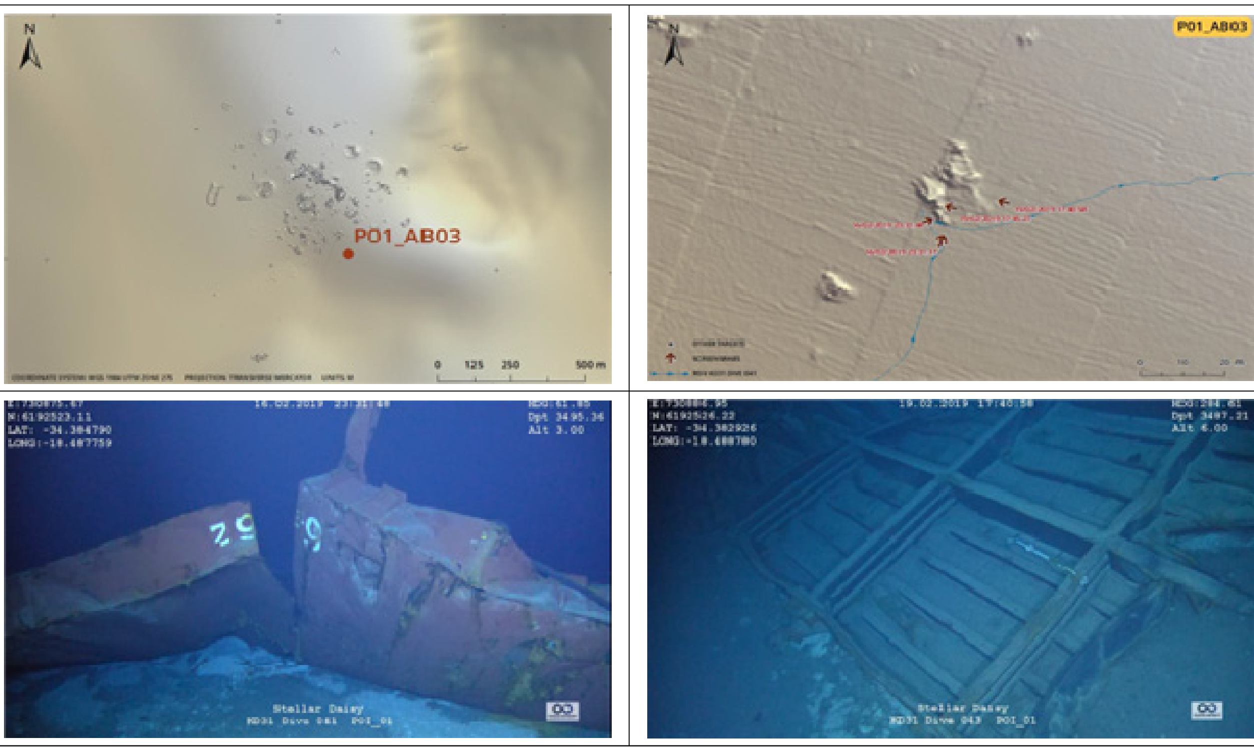
3. P01_AB02

This is a pipe that is crushed and cut out on one side. It is difficult to identify which part of the ship it came from.



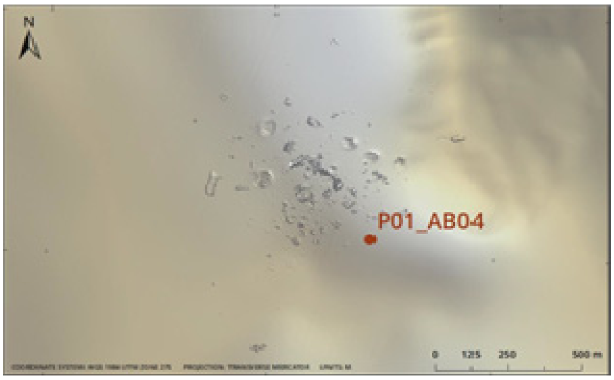
4. P01_AB03

The objects were identified as cargo hold hatch cover No. 6-2.



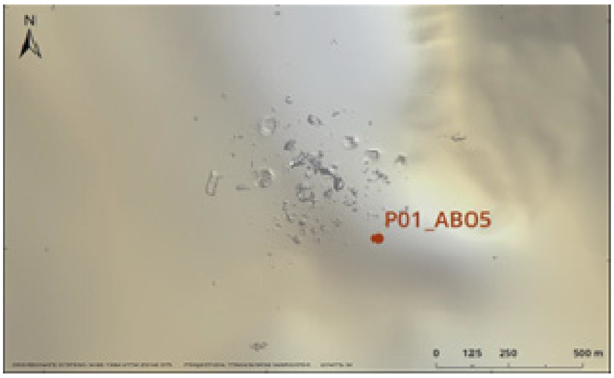
5. P01_AB04

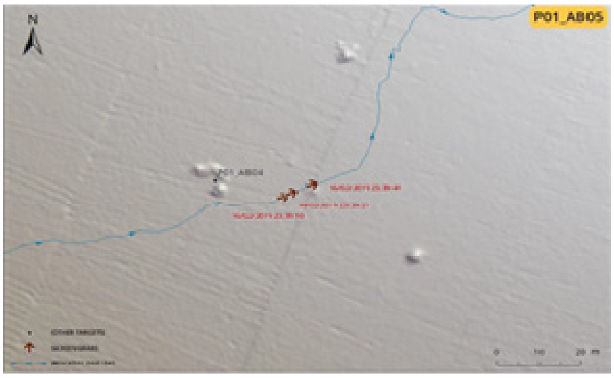
These object are stiffened plates torn off in the direction of the attached stiffener. It is difficult to identify which part of the ship they came from.

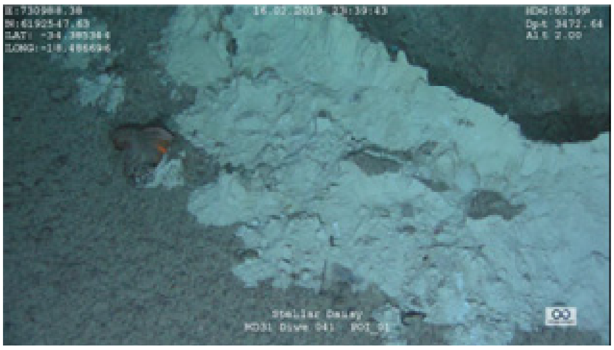


6. P01_AB05

The crater was presumably produced as the deformed and hardened cargo of iron ore collided onto the seabed.

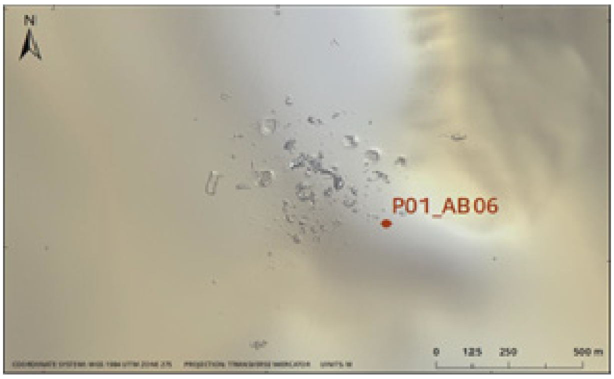


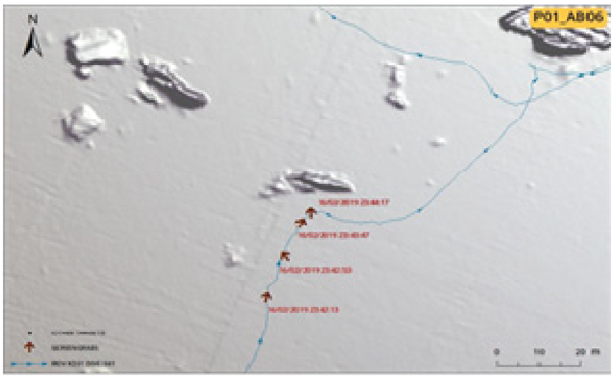




7. P01_AB06

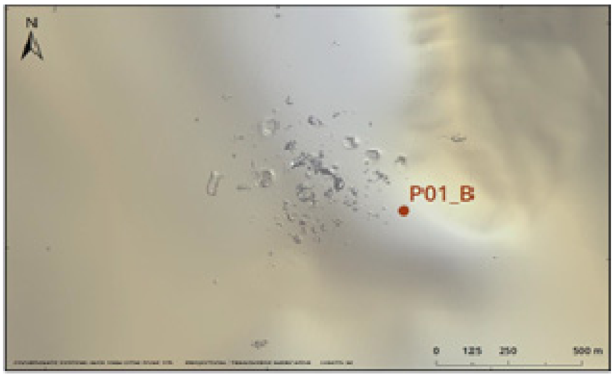
The objects are torn and crushed stiffened plate structures, which are presumed to be part of bulkhead structures inside the hull.





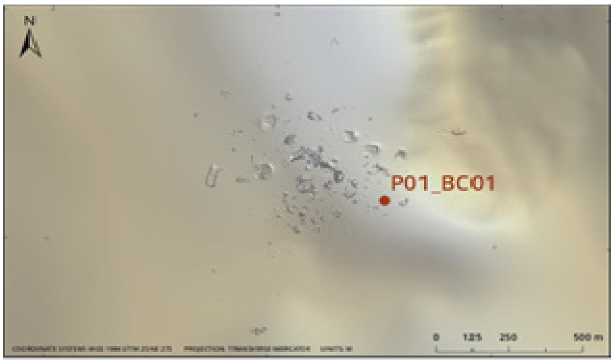
8. P01_B

The objects are torn and crushed stiffened plate structures. They are presumed to be part of the bottom structures (which presumably were cut abruptly).



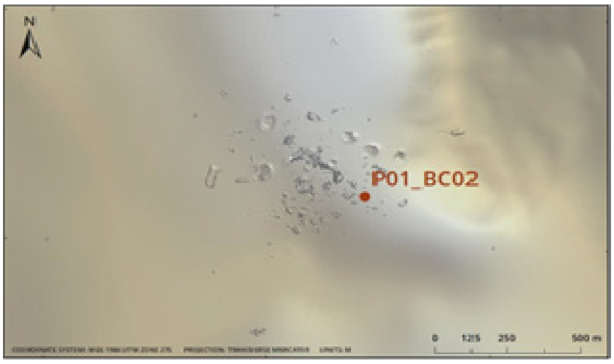
9. P01_BC01

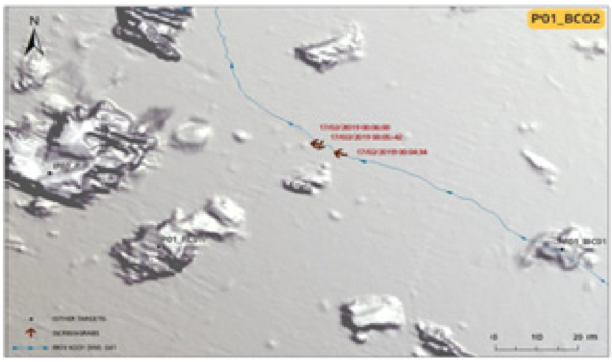
The objects are torn and crushed stiffened plate structures, which are presumed to be part of the shell plating structures located below the draft or the deck structures.



10. P01_BC02

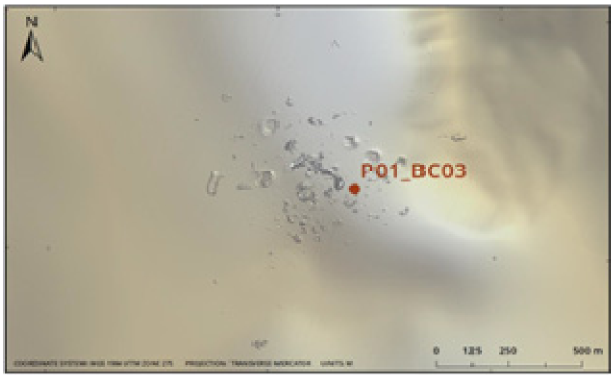
The object is thought to be a ladder attached to the ship's structures. Its location is presumed to be in way of load line on the shell plating or in the connection to the shell plating and the upper deck.

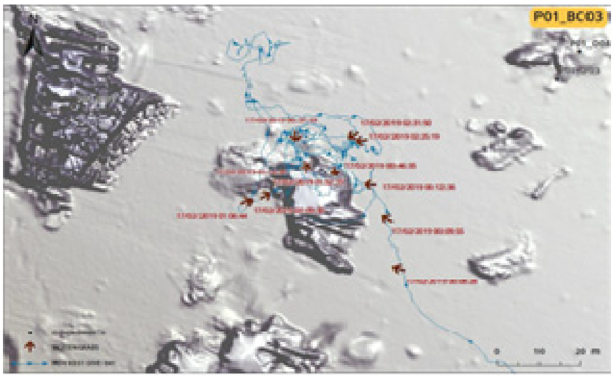


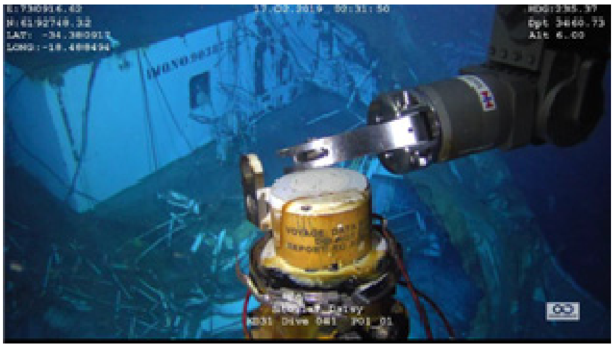


11. P01_BC03

The objects were identified as part of the bridge of Stellar Daisy.

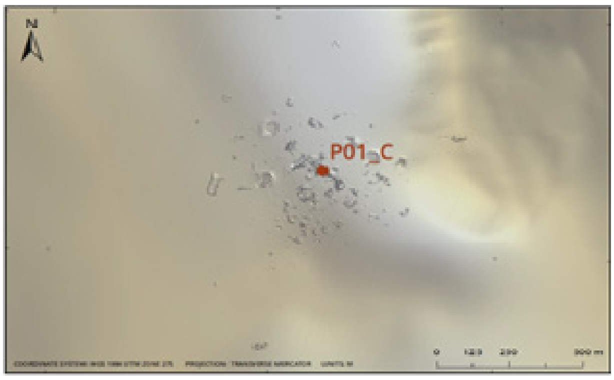


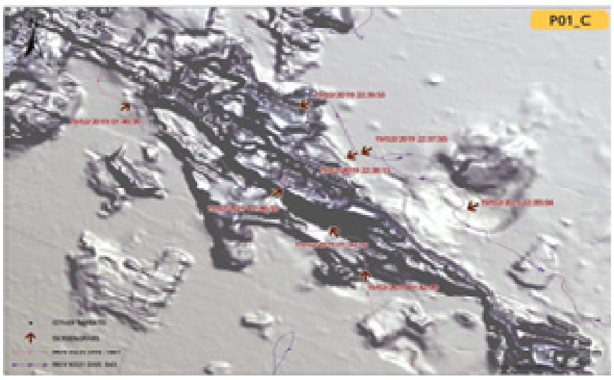


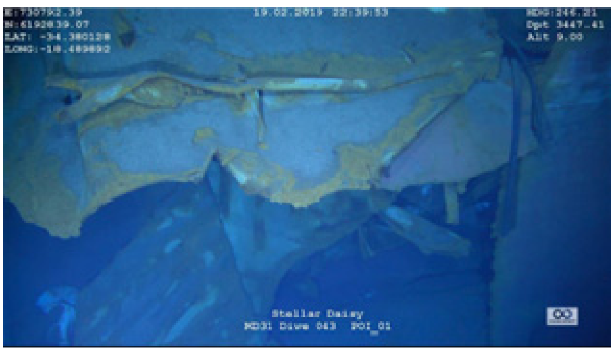


12. P01_C

The objects are torn and crushed stiffened plate structures. A large white beam structure was sighted but could not be identified.

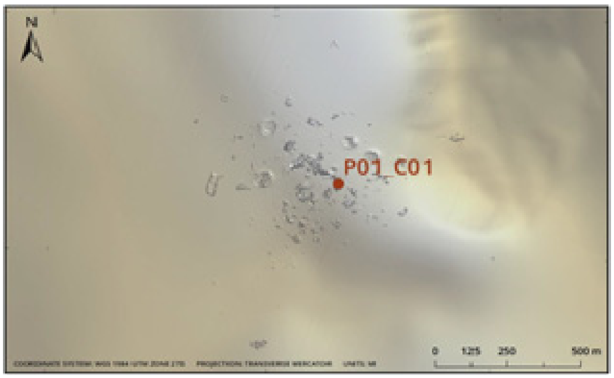


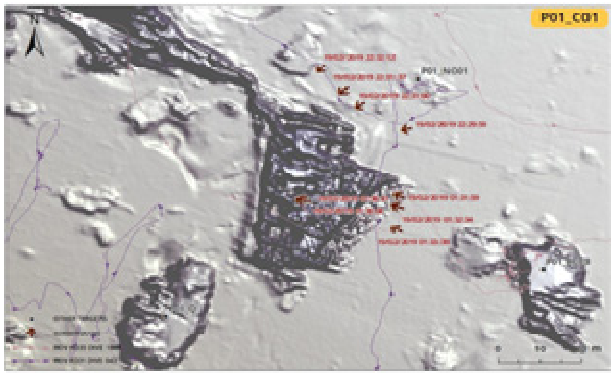




13. P01_C01

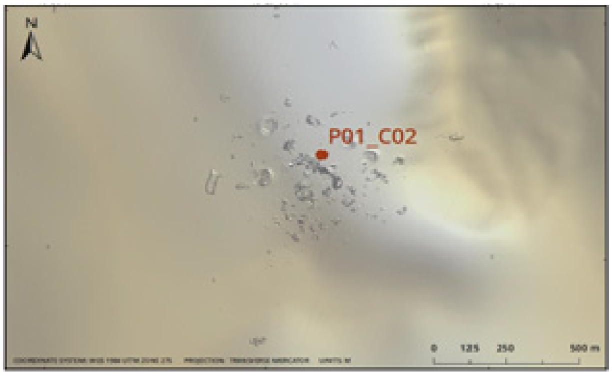
The objects were identified as part of the bow part and its structures (bow mast).

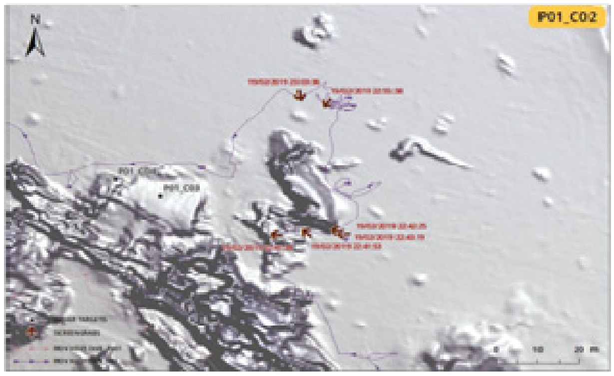




14. P01_C02

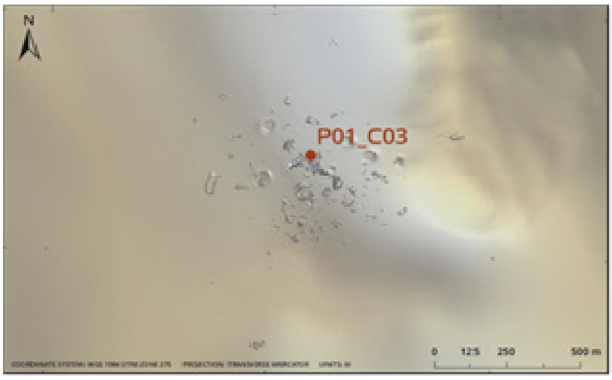
The objects were identified as cargo hold hatch cover No. 6-1.

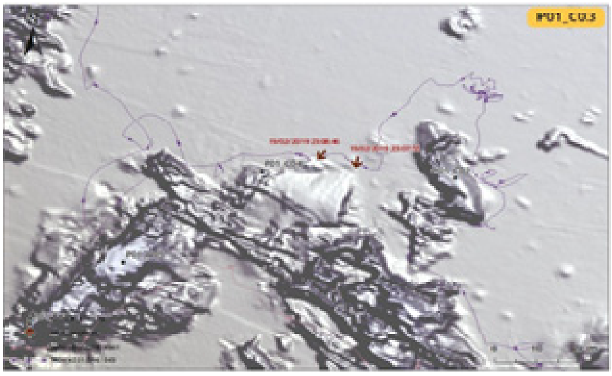




15. P01_C03

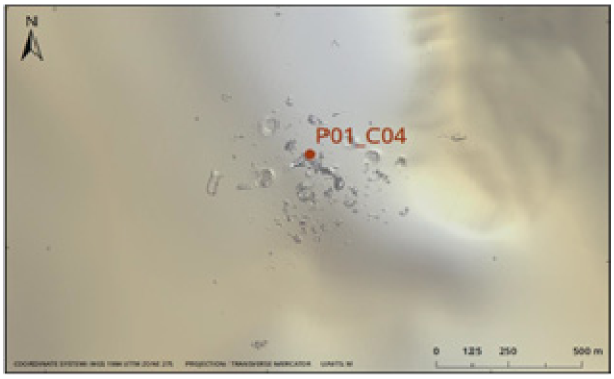
The objects are presumed to be swash bulkheads installed in the water ballast tank.

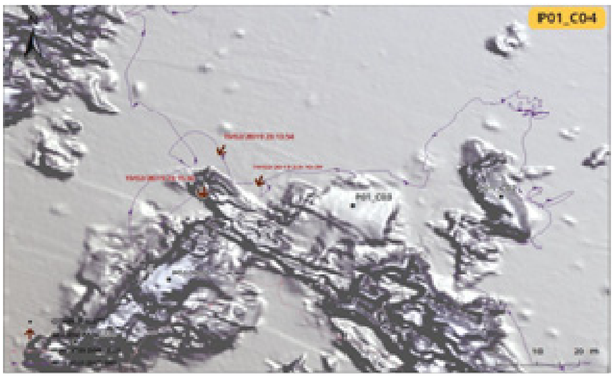




16. P01_C04

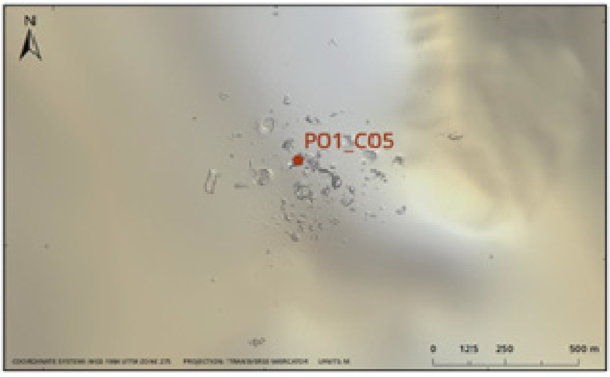
The objects are identified as part of the stern structures.

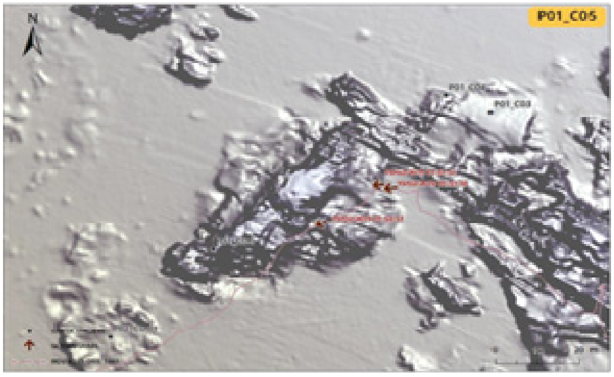




17. P01_C05

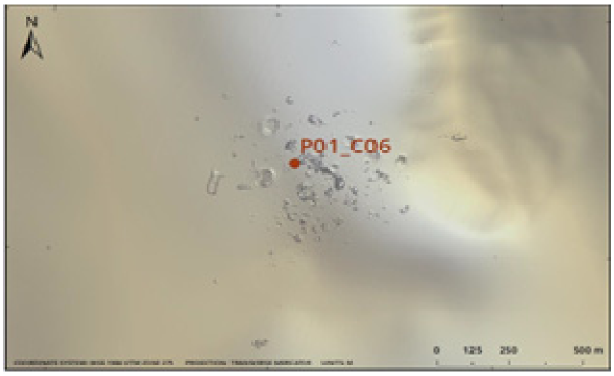
Bollard structures, where mooring lines are secured, were observed. The red paint on the side may indicate they are part of the ship's deck and side structures.

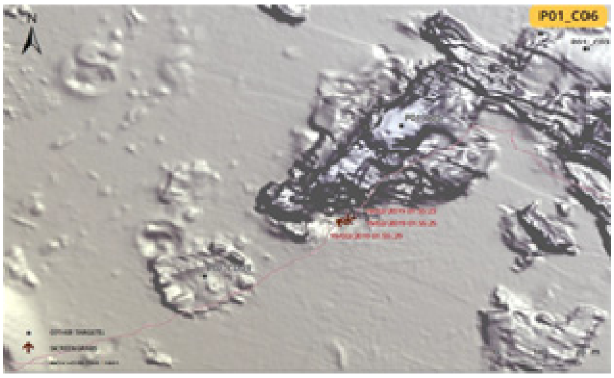


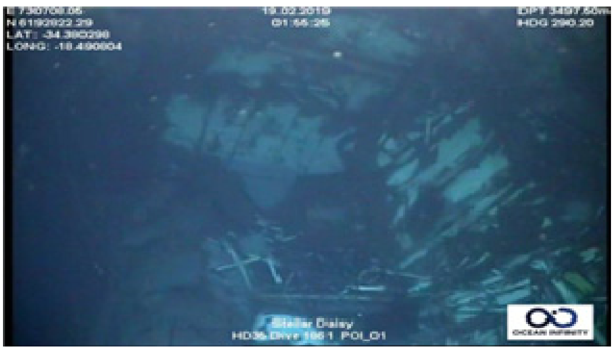


18. P01_C06

Many thin pipes and one large white pipe structure were observed. They are presumed to be the structures of the engine room or those in way of it.

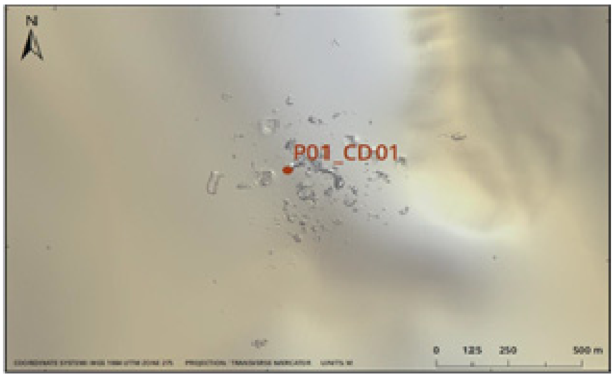






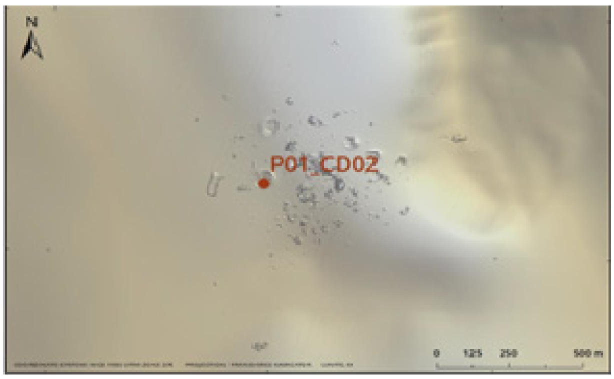

19. P01_CD01

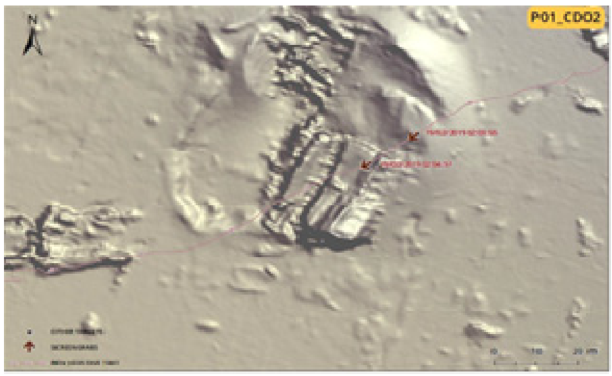
The objects are debris of the torn and crushed stiffened plate structures. It is very difficult to identify which part of the ship they came from.



20. P01_CD02

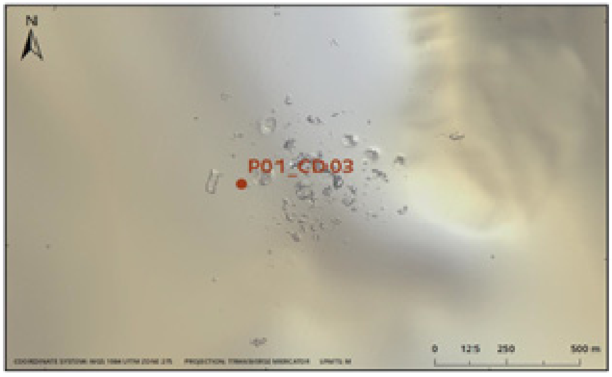
There is scattering debris of the torn and crushed stiffened plate structures inside a massive crater presumed to have been collided when the ship sank.

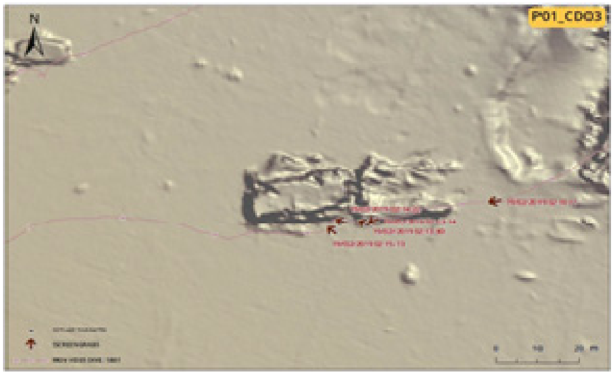




21. P01_CD03

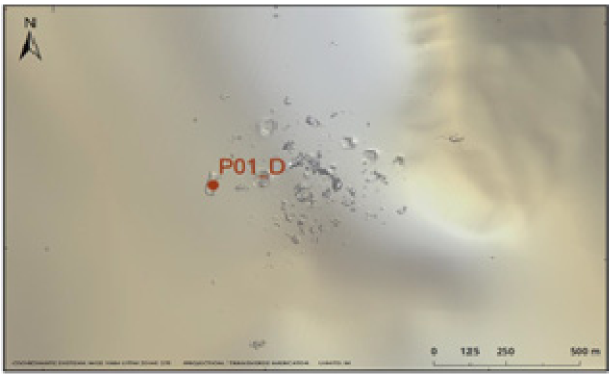
There are cables and wires attached in stiffened plates and debris of several kinds of equipment, all of which are severely distorted.

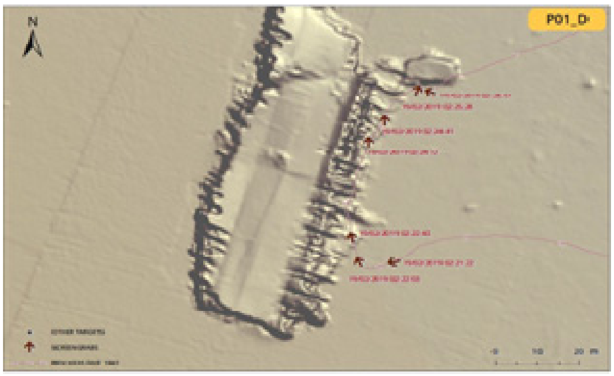




22. P01_D

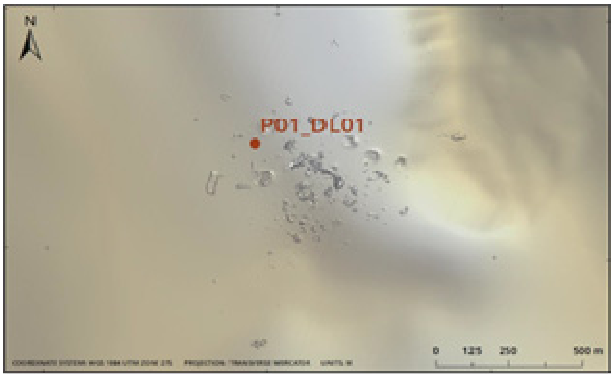
The objects are presumed to be internal structures between cargo holds and decks. They are torn and crushed, making them difficult to identify.





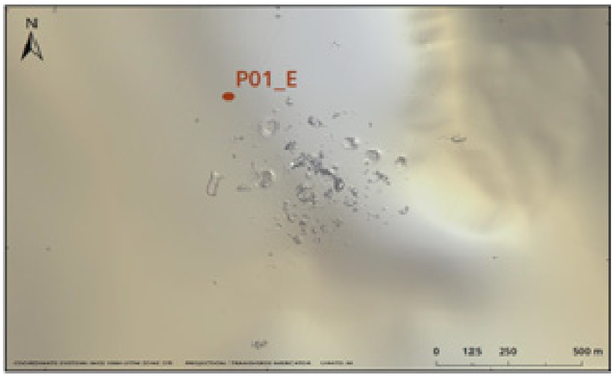
23. P01_DL01

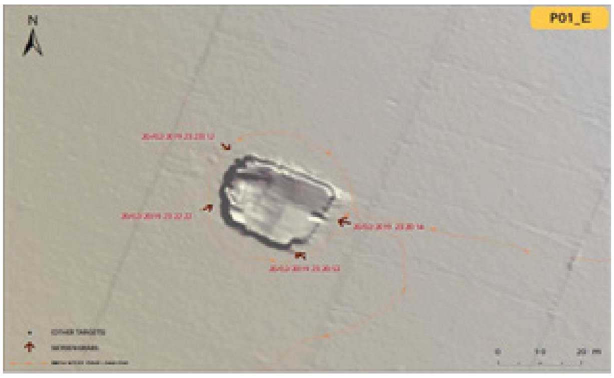
The objects are distorted stiffeners presumed to be a highly stiffened structure related to bulkheads inside the cargo holds.



24. P01_E

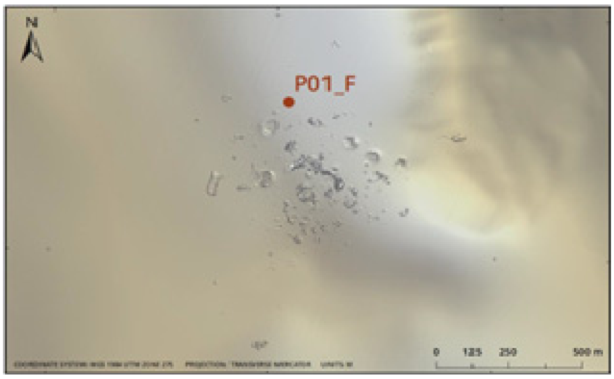
The objects are presumed to either be torn deck structures or part of the hull structures below the draft.

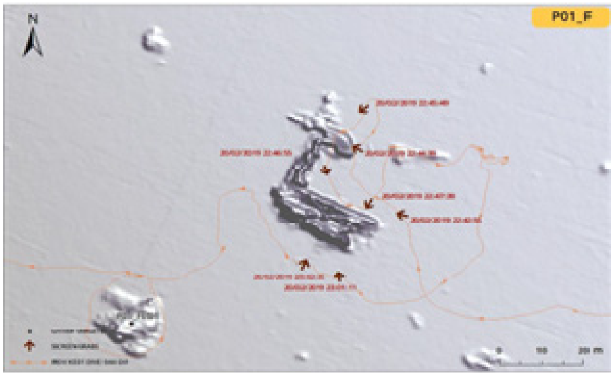




25. P01_F

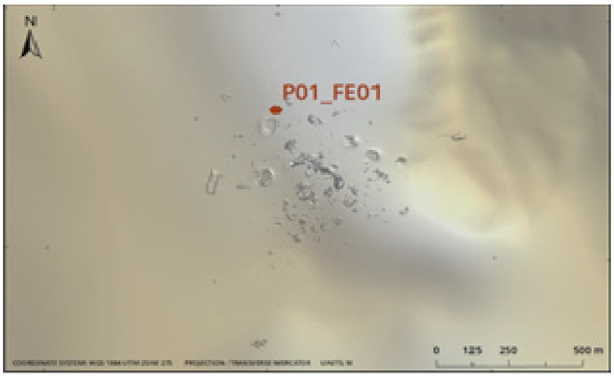
The objects are the torn and crushed structures presumably located close to the outside the hull. However, it is difficult to identify which part of the ship they came from.

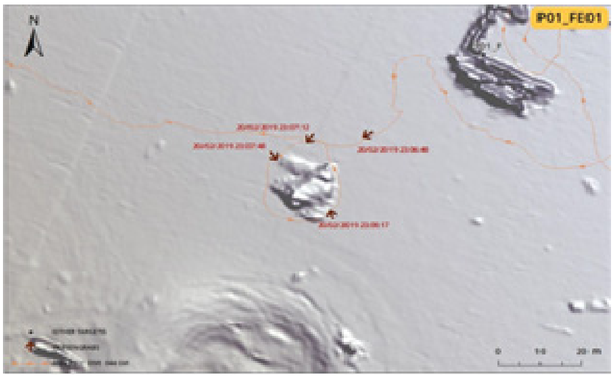




26. P01_FE01

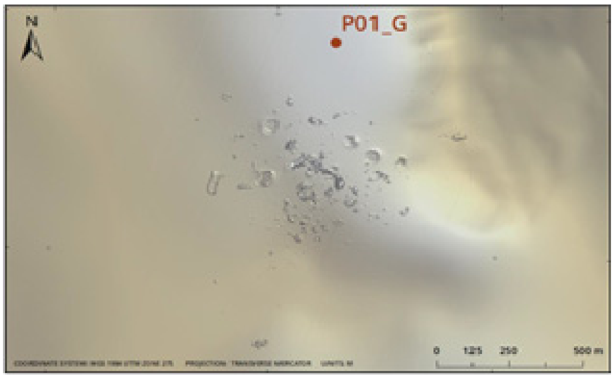
The objects were identified as cargo hold hatch cover No. 2-2.





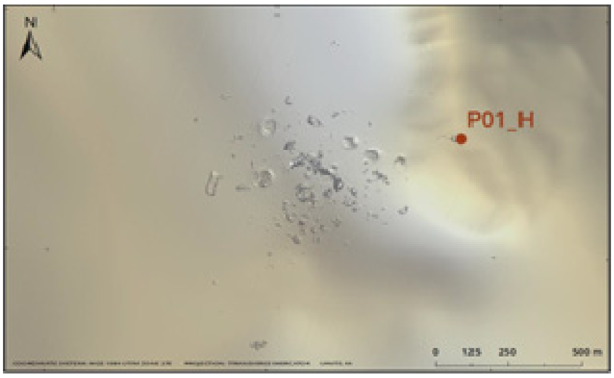
27. P01_G

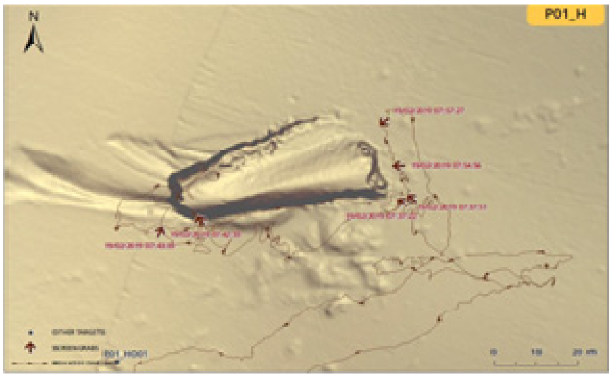
The objects are two stiffened plates torn, crushed, and fitted with a ladder. They are presumed to be part of the structures in way of the shell plating.



28. P01_H

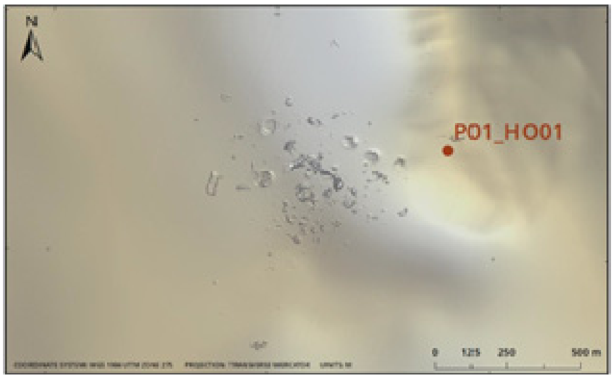
These are debris of the torn and crushed panel structures attached with a ladder. They are presumed to be part of the bulkhead structures inside the hull.

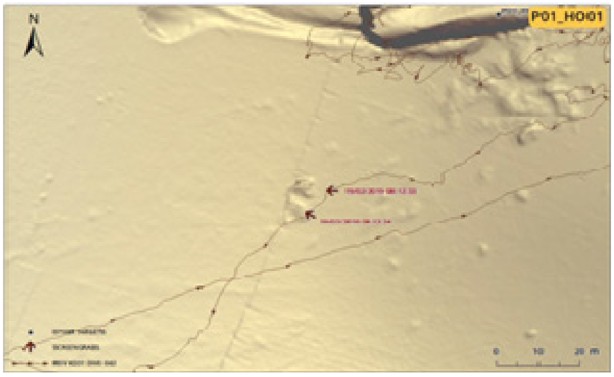




29. P01_HO01

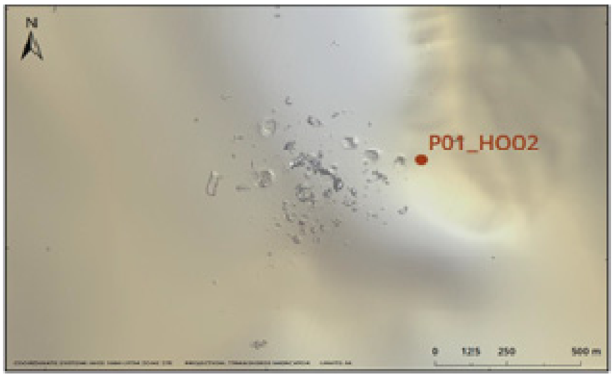
The objects are torn and crushed stiffened plate structures, which are very difficult to be confirmed, but probably are part of the bulkhead structure of cargo holds.





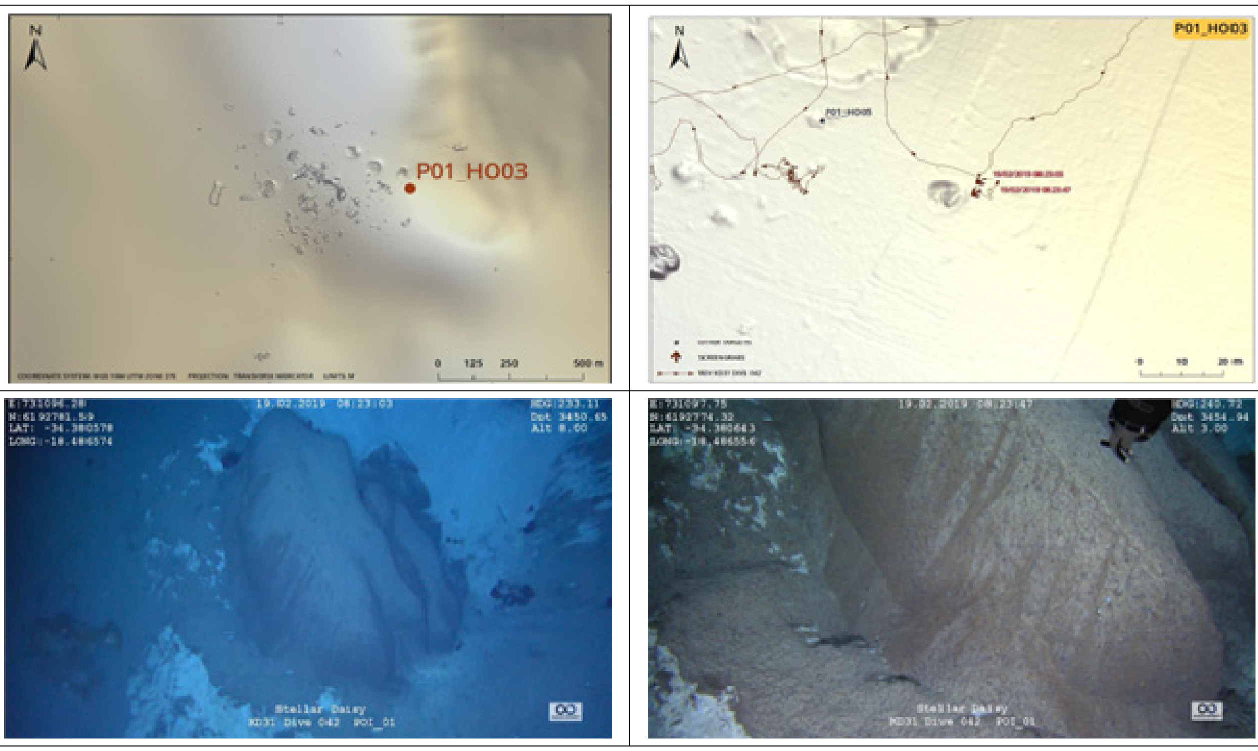
30. P01_HO02

These are grey torn and crushed structures, which are extremely difficult to be identified but presumed to be from the cargo hold bulkhead.



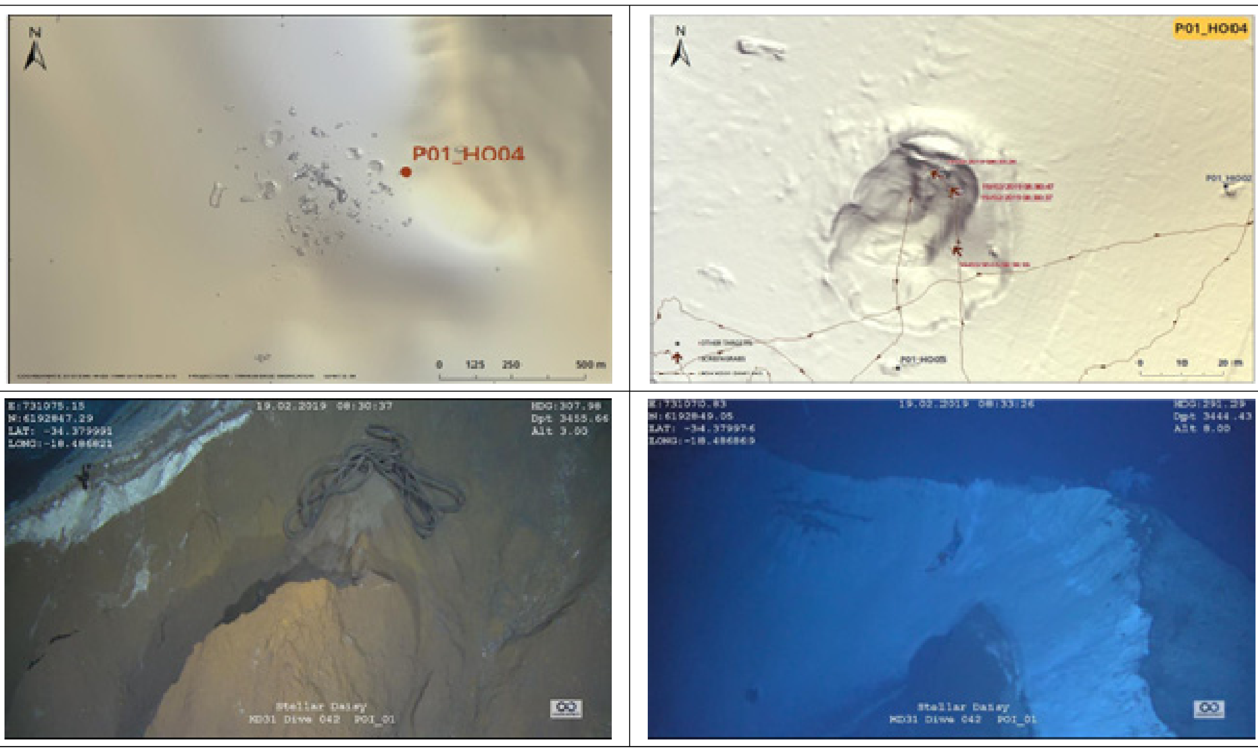
31. P01_HO03

Solid objects were discovered inside a crater presumed to be produced by an impact when the ship struck.



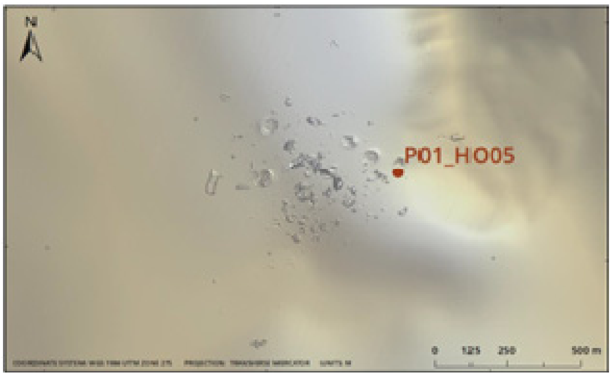
32. P01_HO04

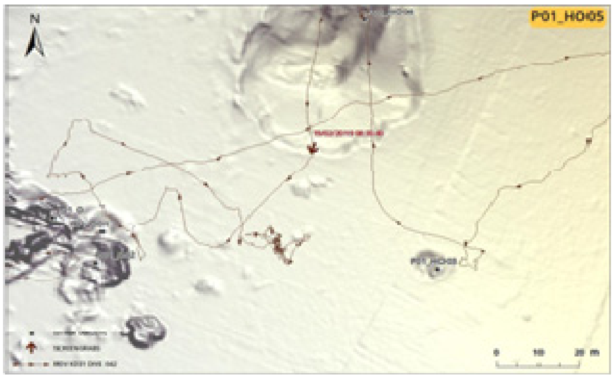
The objects include solids presumed to be iron ore and something identified as a rope.



33. P01_HO05

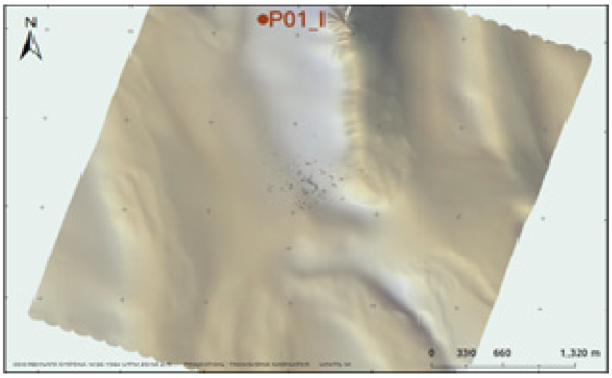
There are torn and crushed stiffened plate structures with unidentifiable debris scattering around them.





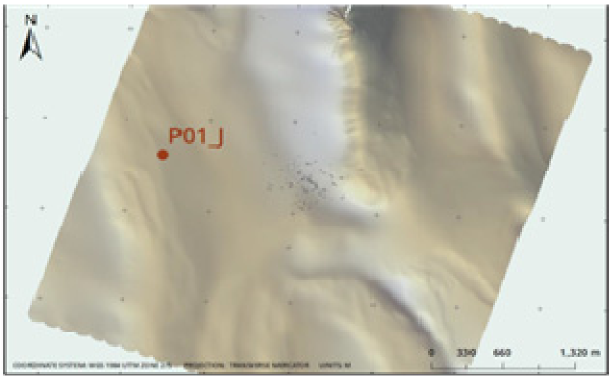
34. P01_I

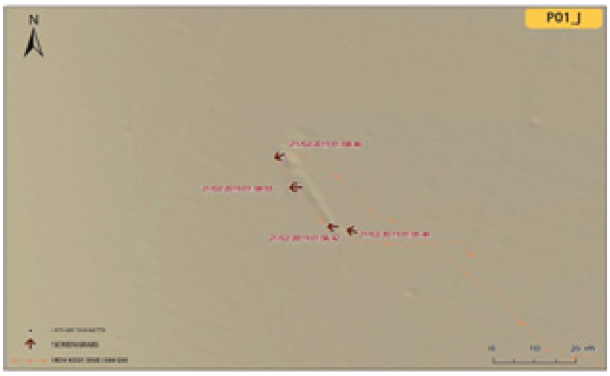
Ladders attached to the ship's structures were observed; they are presumed to be part of the outfitting structures of the hull.



35. P01_J

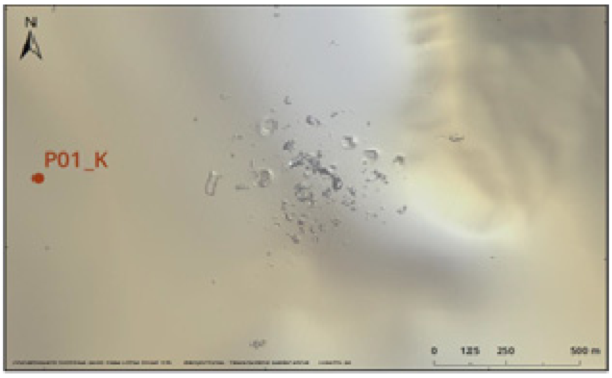
The objects were identified as gangway structures.

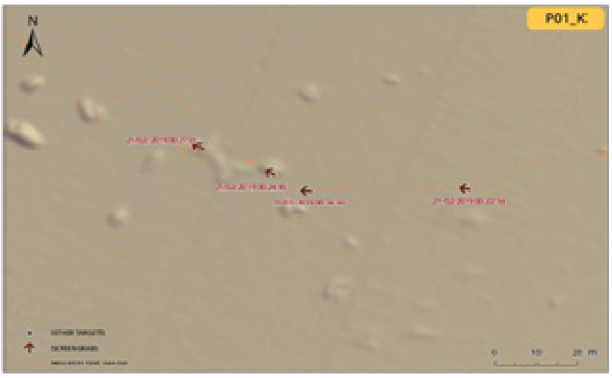


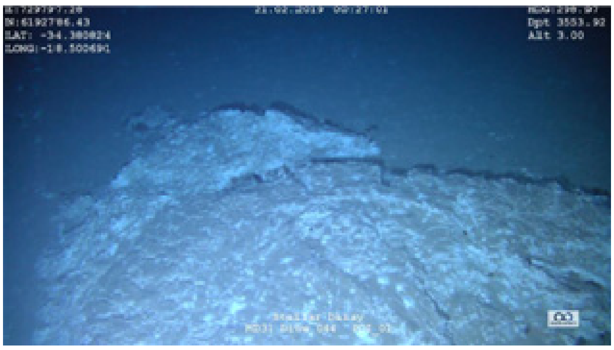


36. P01_K

There is debris scattering broadly and partly tainted with oil. But there is no debris from the hull structure. Given that, this point of interest is presumed to be where part of the fuel oil immersed.

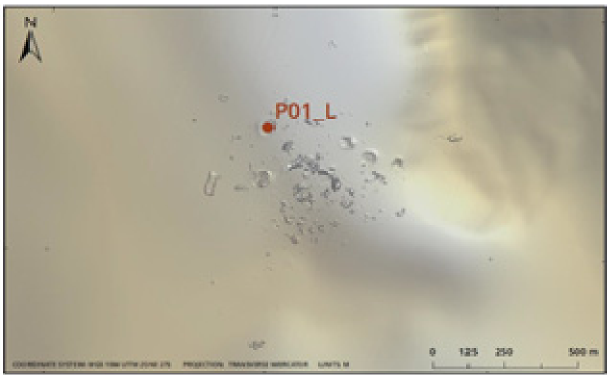


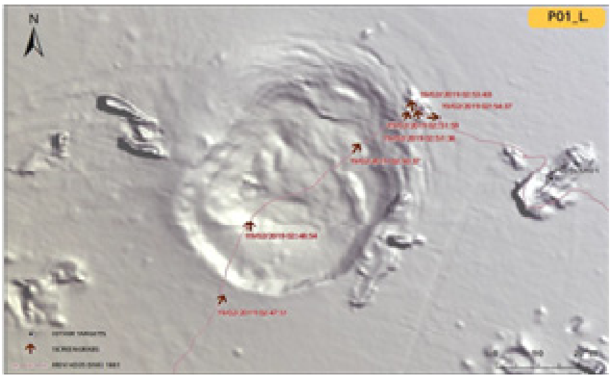




37. P01_L

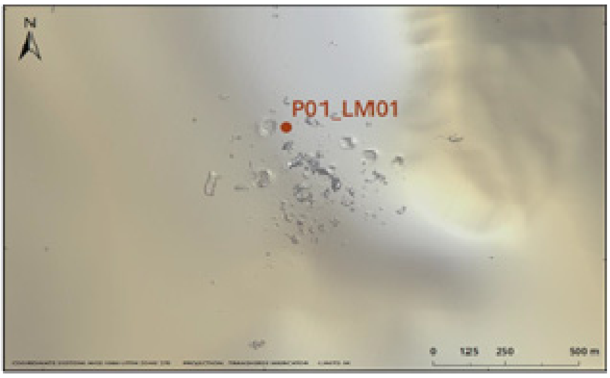
There is debris identified as part of a ladder along with iron ore. The debris is difficult to determine but presumed to be part of structures inside the hull.

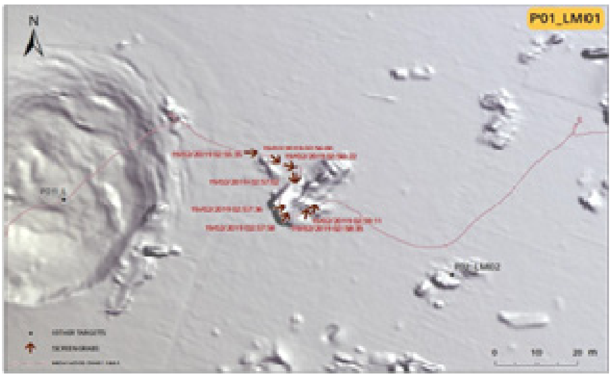




38. P01_LM01

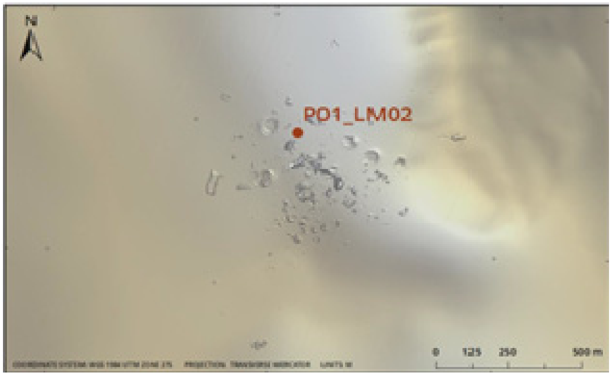
The objects are pipe and torn and crushed stiffened plate structures with bar-type stiffeners. They are presumed to be part of the cargo hold or ballast tank structures.





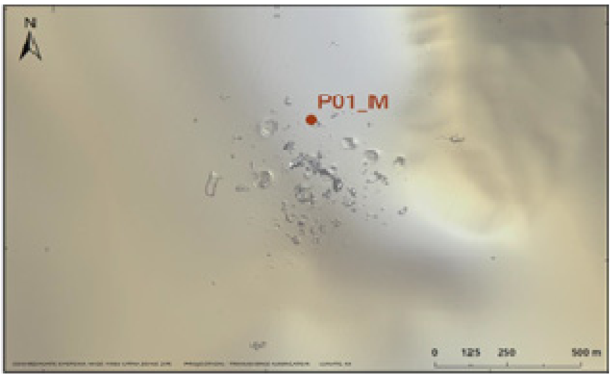
39. P01_LM02

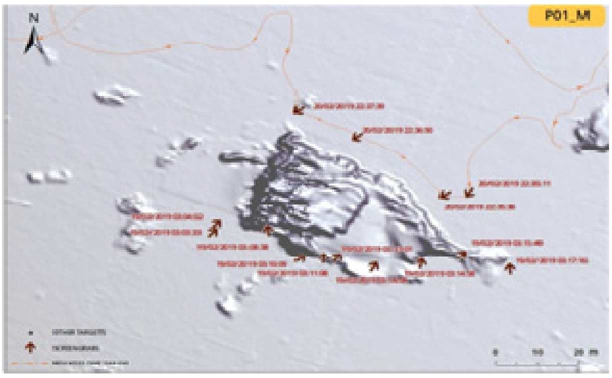
The objects are severely torn and crushed. They are not certain but presumed to be part of the stiffened plate structures inside the hull fitted with frames.



40. P01_M

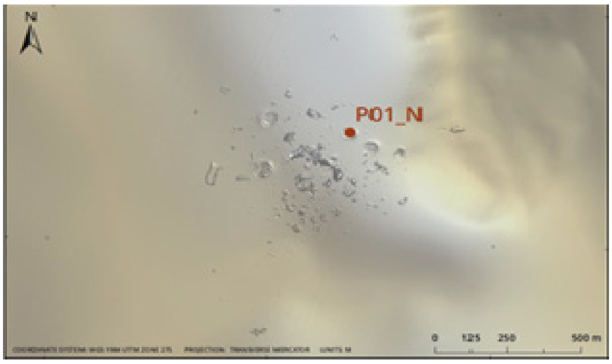
The part of the hull from where these dented stiffened plate structures came cannot be easily identified, but they are presumed to be internal structures attached with many frames.

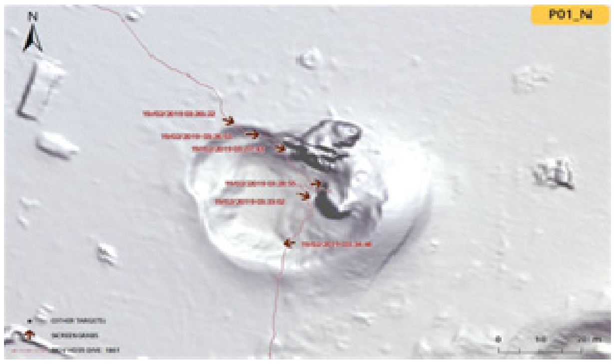




41. P01_N

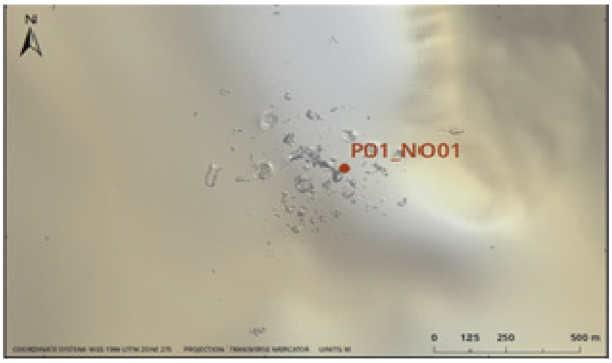
Solid objects presumed to be iron ore and debris of many structures were observed. They are difficult to determine with precision but presumed to be from inside the hull in way of the cargo holds.

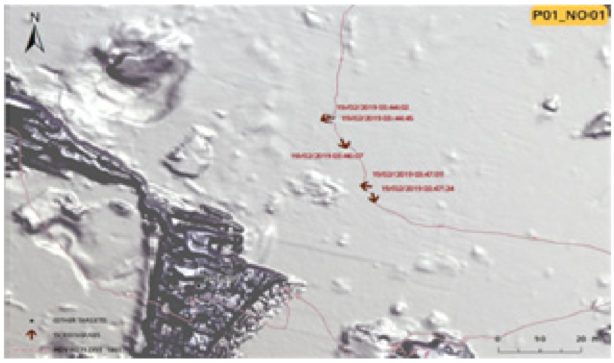




42. P01_N01

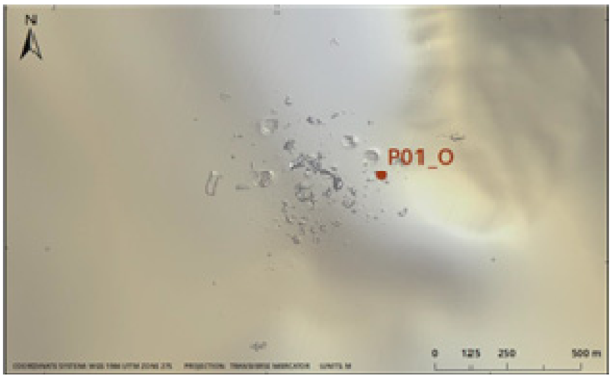
Seen here are numerous small pieces of debris presumed to be part of the bar-typed structure; cables; pipes; and other devices and torn and crushed stiffened plate structures. They are presumed to be part of the hull's internal structures.

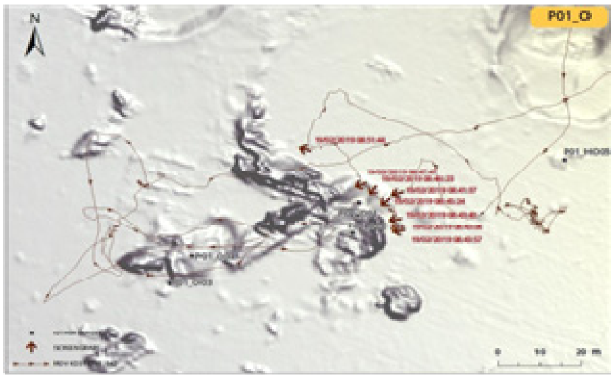




43. P01_O

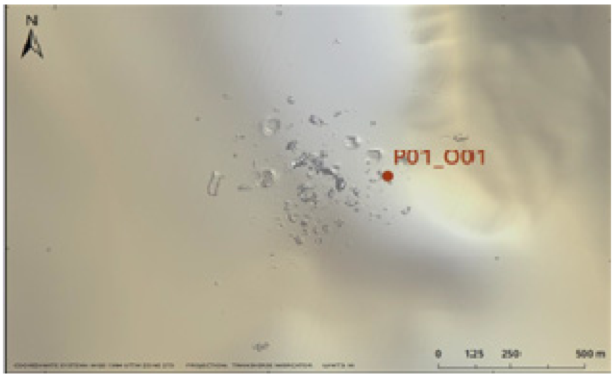
Given that frames with some openings are torn and crushed, they are presumed to be the shell plating structures.

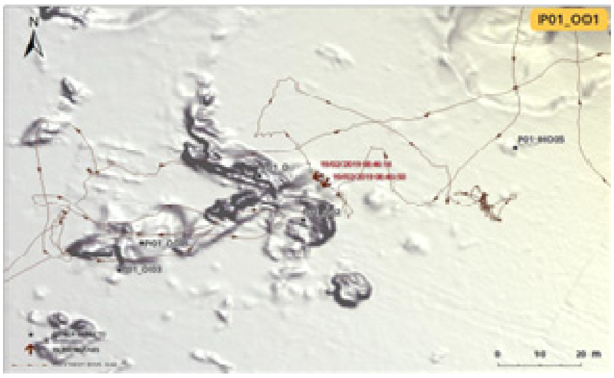




44. P01_001

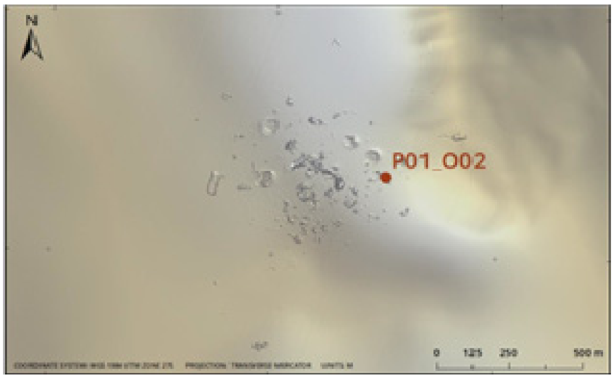
The pieces of yellow debris are mostly identified as stiffened plate structures attached with stiffeners. They are uncertain but presumed to be part of the hull's internal structures.

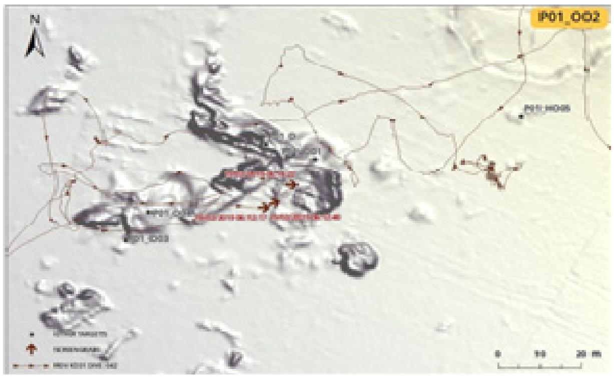




45. P01_002

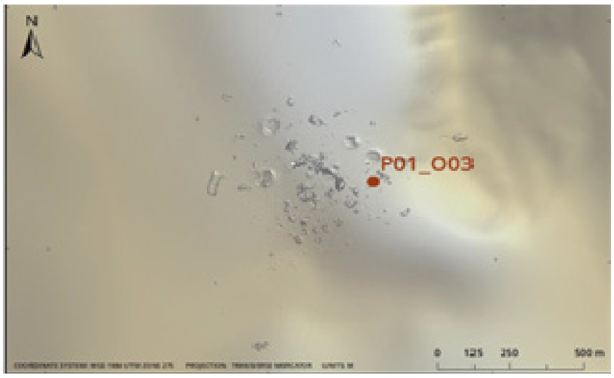
The stiffened plate structures attached with stiffeners are torn and dented. They are presumed to be part of the hull's internal structures.





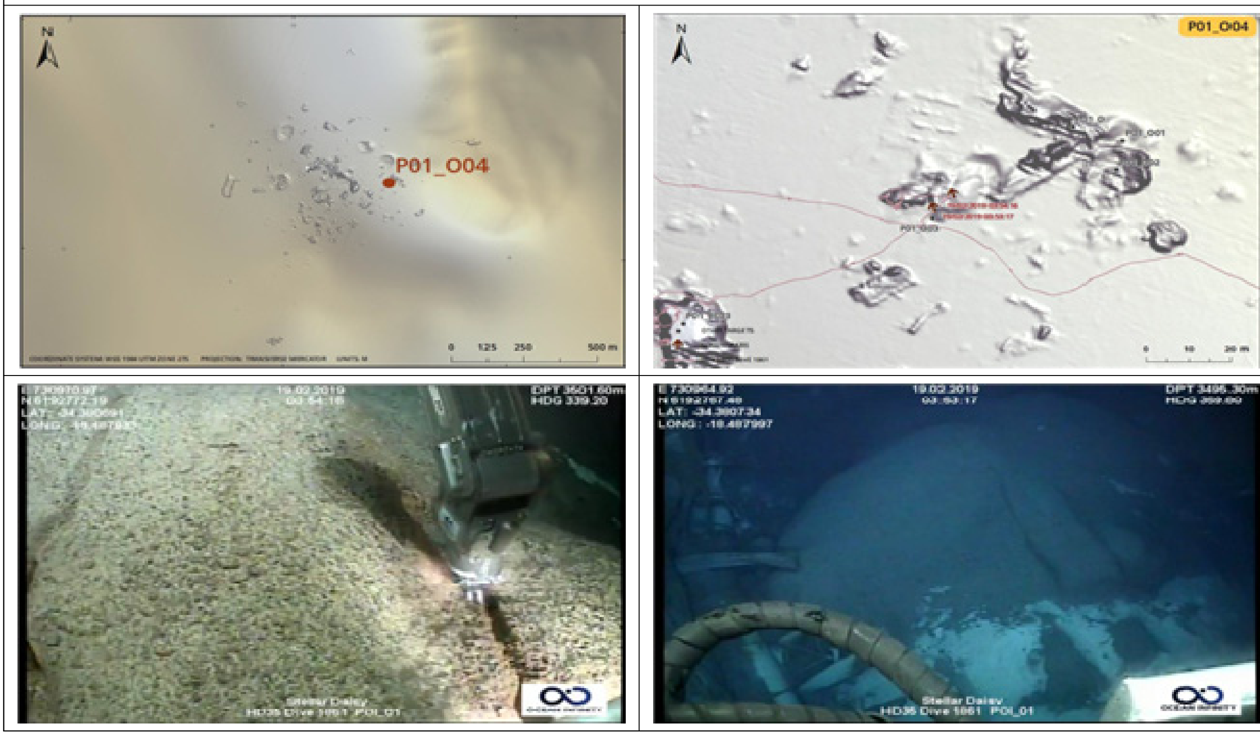
46. P01_003

The objects were identified as part of the mast structures of Stellar Daisy.



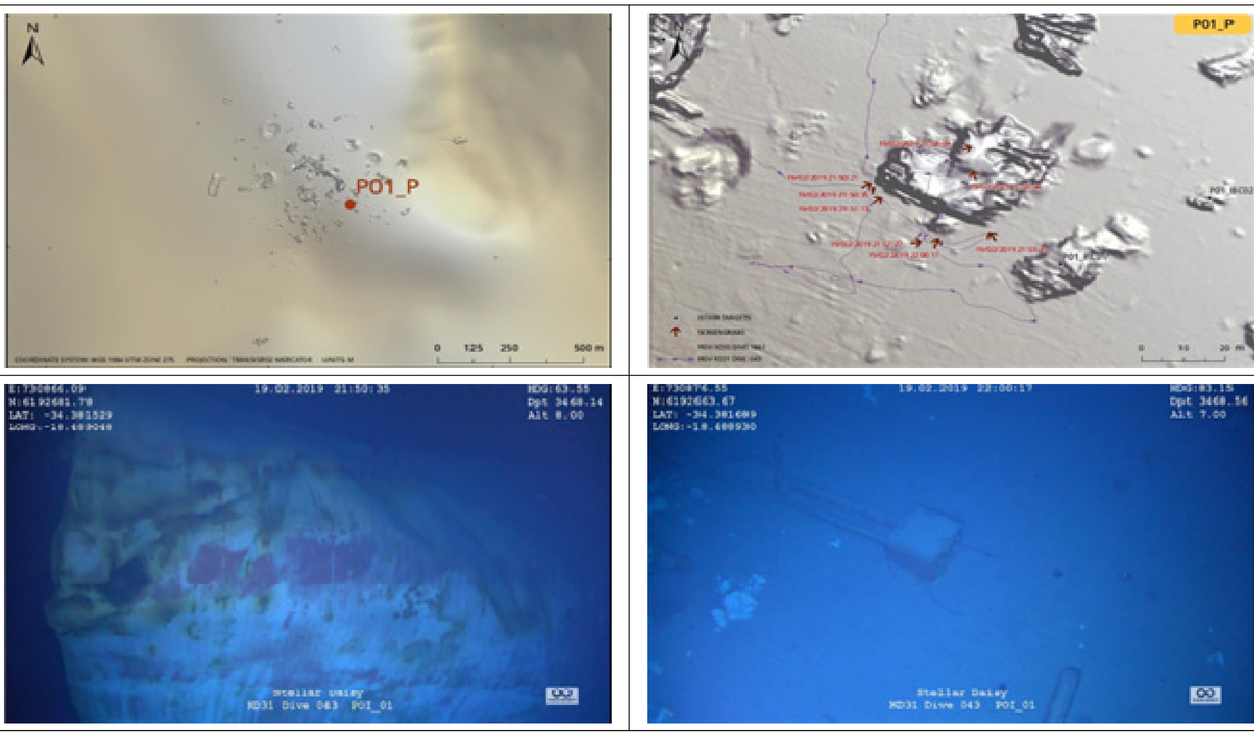
47. P01_004

There are solid objects of iron ore and crumpled stiffened plate structures, presumed to be part of the internal structures of cargo holds.



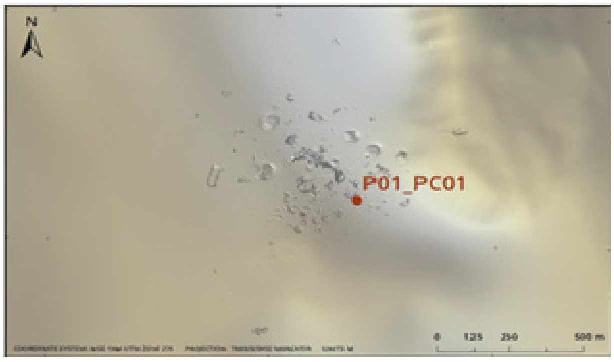
48. P01_P

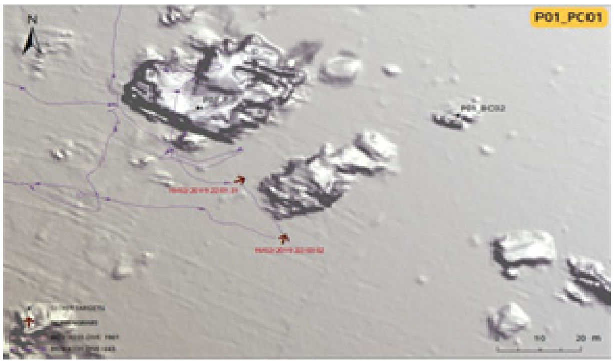
Numerous small stiffened plate structures are seen torn and crushed, and debris of the bollard and control panel (electric cabinet) are in the way. They are presumed to be structures from near the accommodation area.



49. P01_PC01

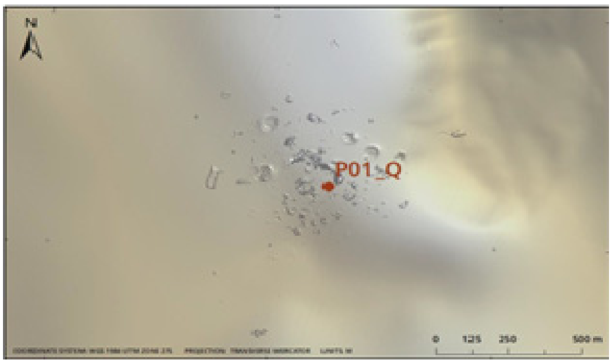
There are torn and dented stiffened plate structures attached with frames where stiffeners passed through. They are presumed to be part of the hull's internal structures.

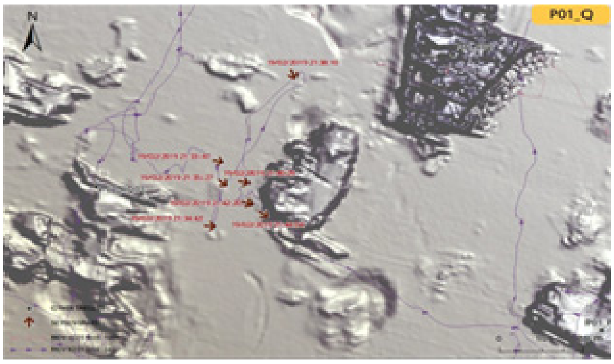




50. P01_Q

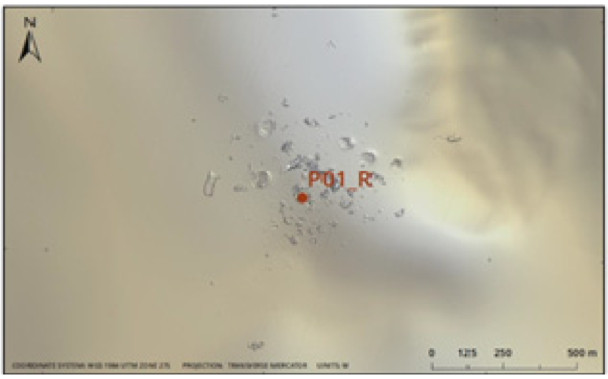
There are severely torn structures that could be either the shell plating or deck plating. Also, debris of the adjacent ladder structure was sighted.

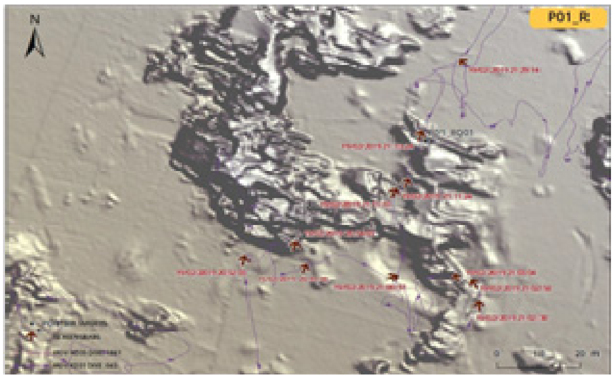




51. P01_R

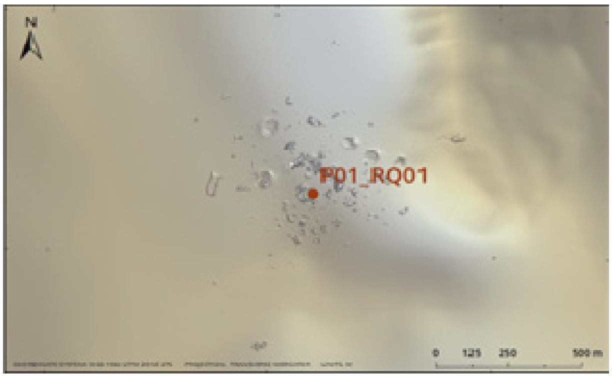
Seen here are debris of cables and many small stiffened plate structures, which are torn and dented. They are presumed to be part of the hull's internal structures.

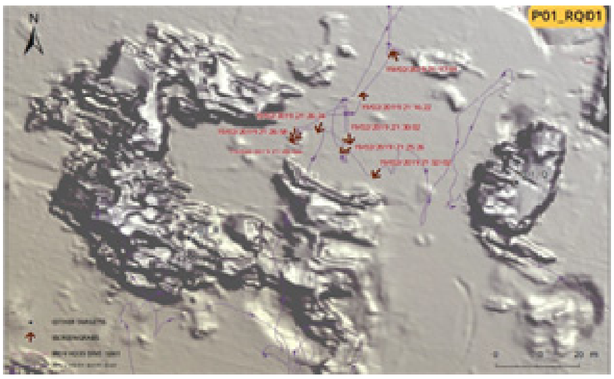


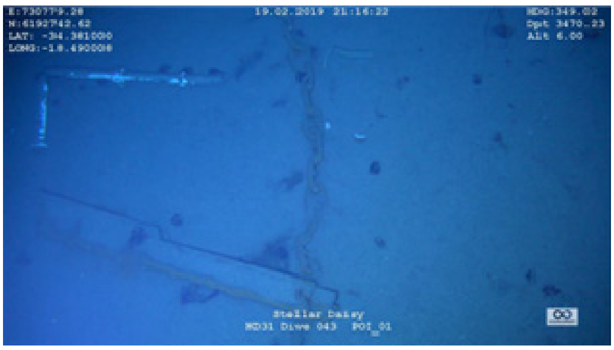


52. P01_RQ01

The point of interest was identified as the bow area based on the indications, such as the ship's name, mooring chains, and the draft mark.

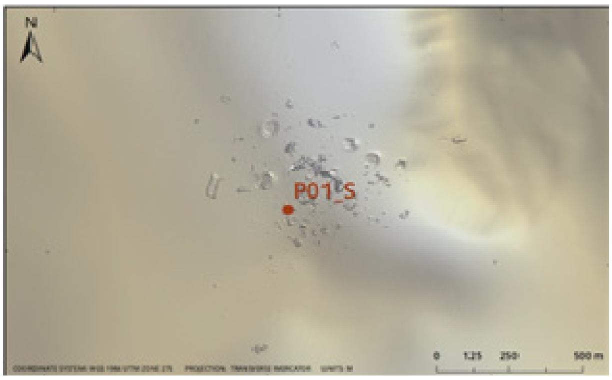


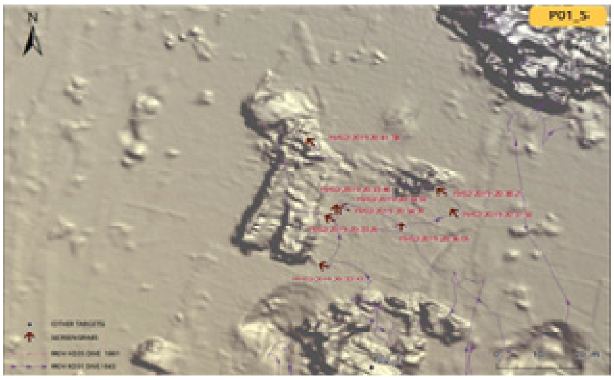




53. P01_S

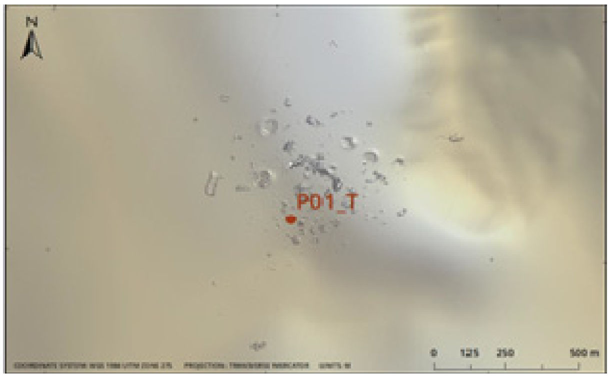
The objects were identified as cargo hold hatch cover No. 4.

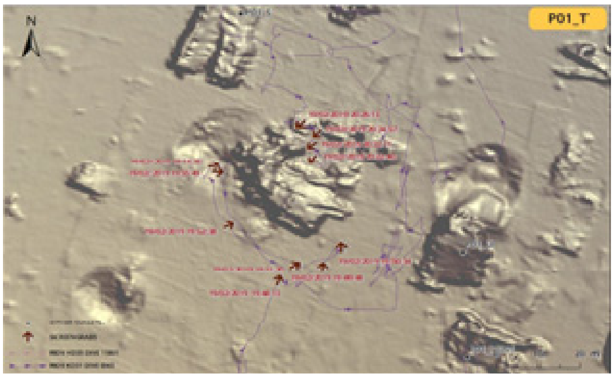


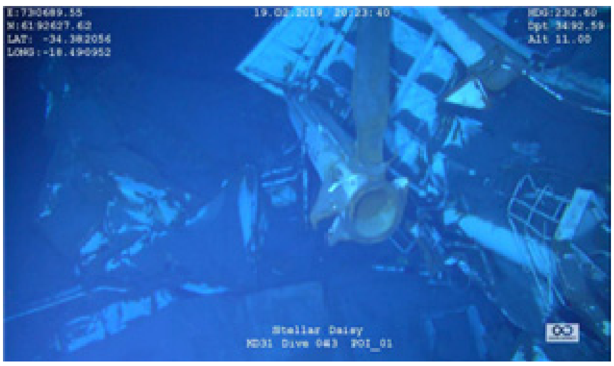


54. P01_T

There are debris mixed up with handrail and pillar structures, mast steps, and cables. They are presumed to be part of structures in the accommodation area.

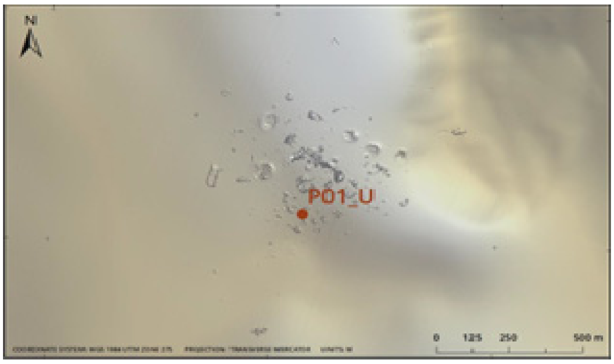


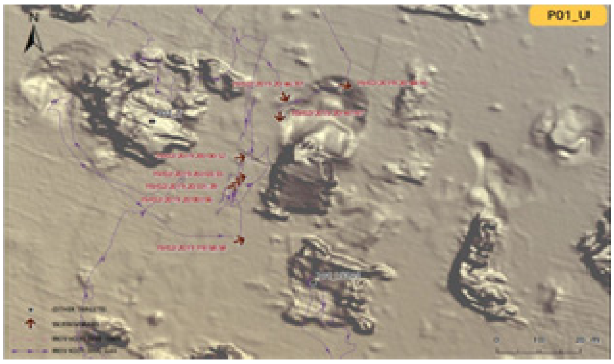




55. P01_U

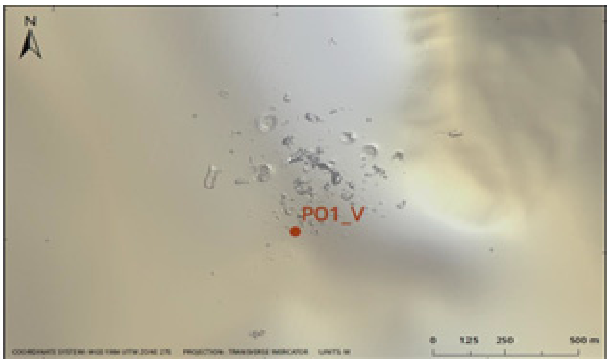
The objects include debris considered to be an electrical control cabinet, wires, and cables. Also seen are dented stiffened plate structures, indicating that may be debris from inside the hull compartments.

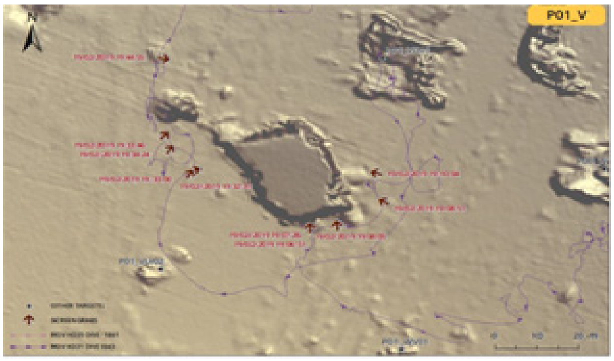




56. P01_V

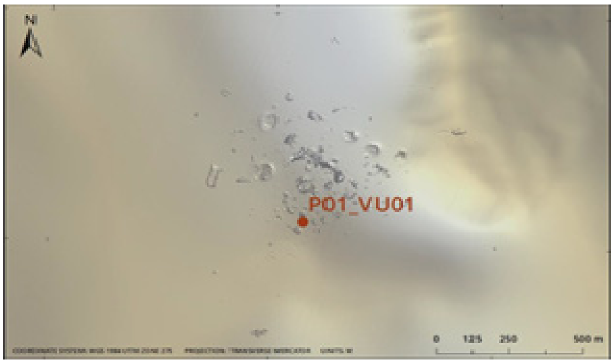
There are torn and severely dented frames where pipes passed through, and a bollard. They are presumed to be part of the deck or shell plating.

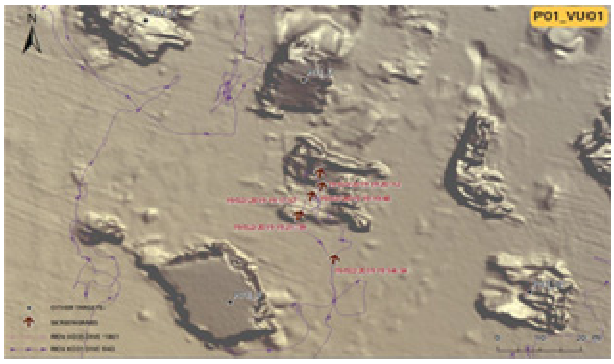




57. P01_VU01

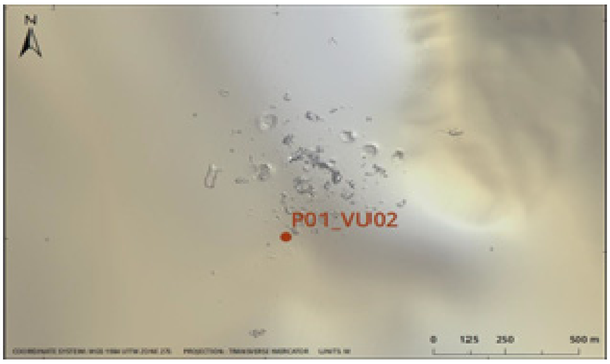
There are metal fragments of ladders or pipes, debris of rope cables, bollards attached to the hull structures, and a stiffened plate structure where pipes passed through. They are presumed to be detached from the deck area.

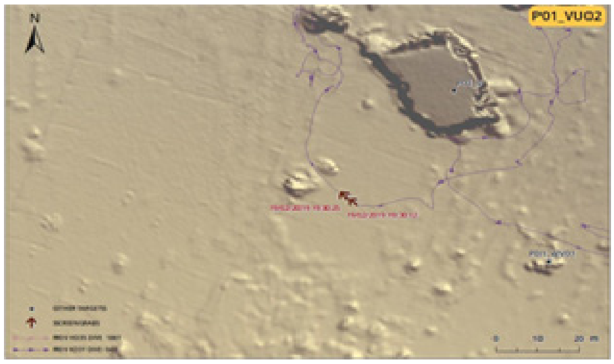





58. P01_VU02

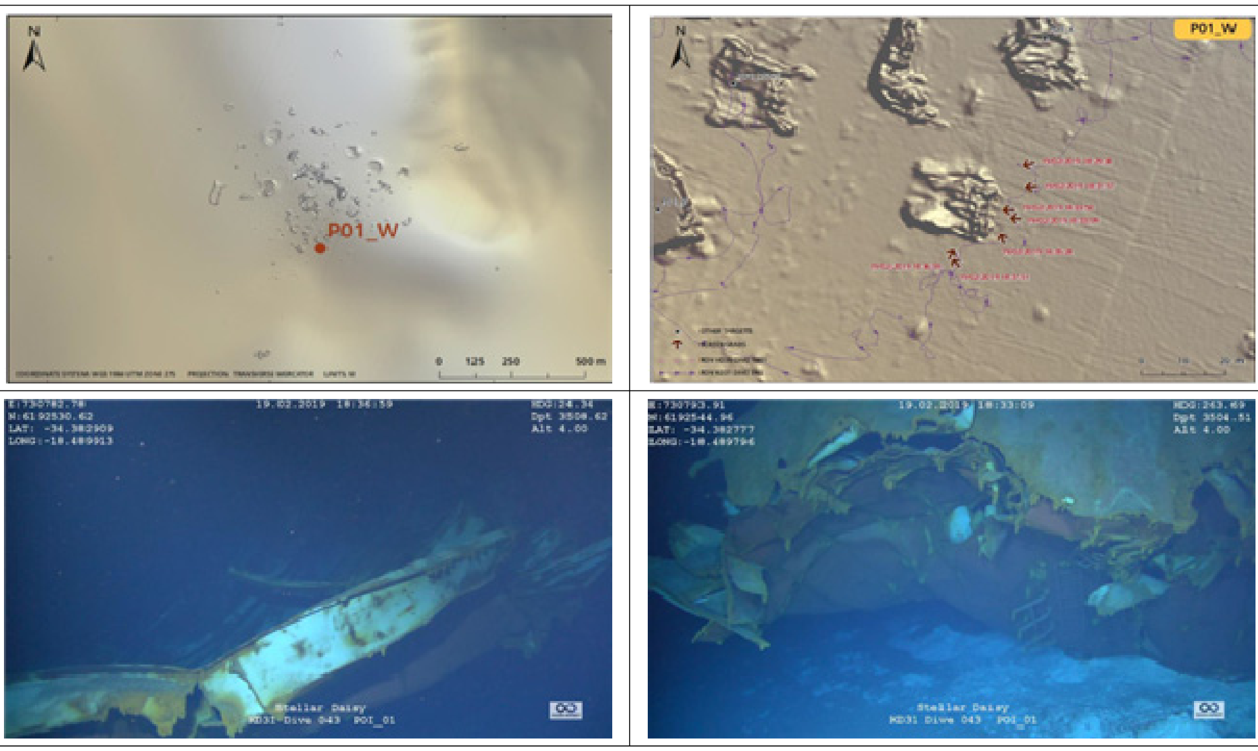
The objects are torn and dented stiffened plate structures presumed to be part of the hull's internal structures.





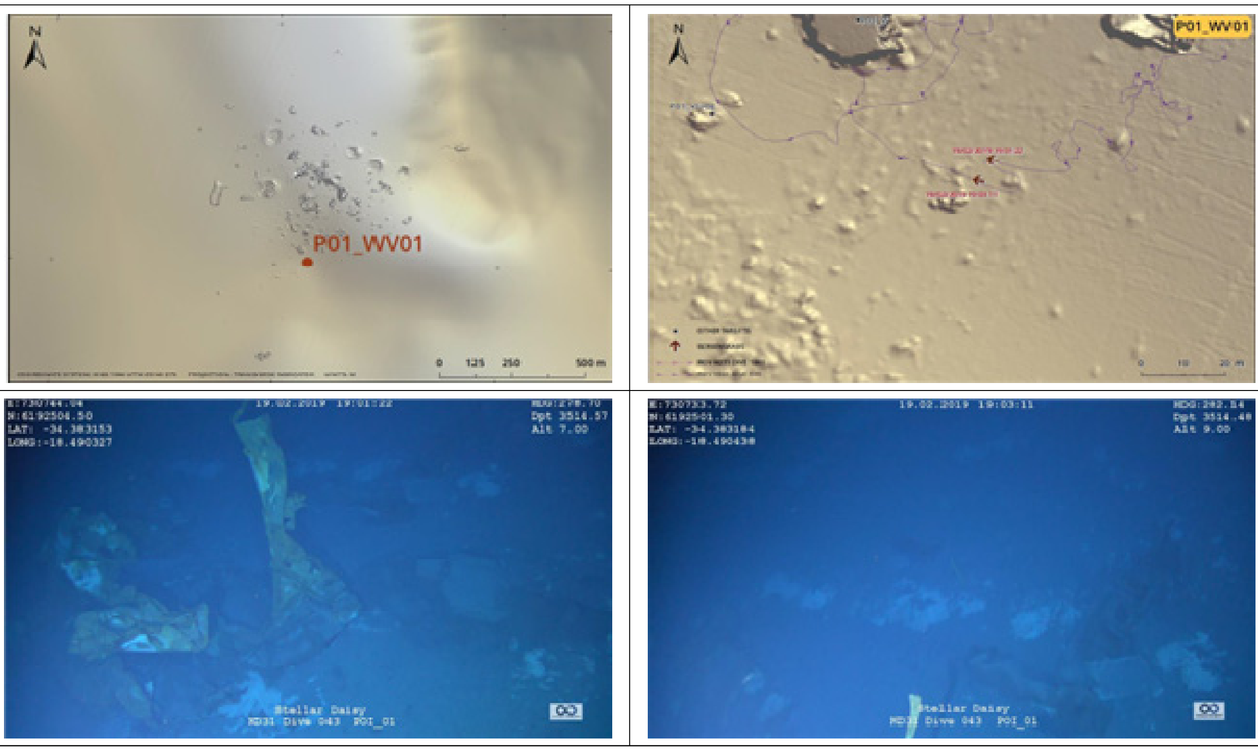

59. P01_W

Torn and crushed stiffened plate structures are piled up. Their identity is very much uncertain, but they are believed to be outfitting structures of the hull.



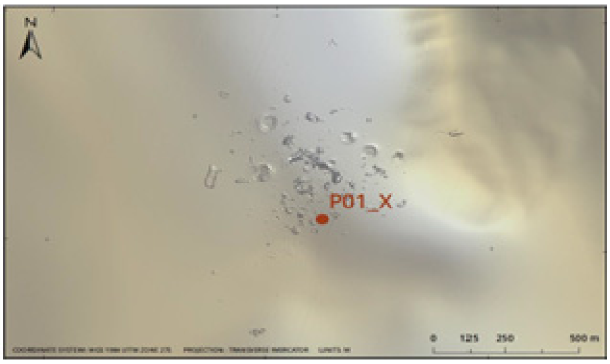
60. P01_WV01

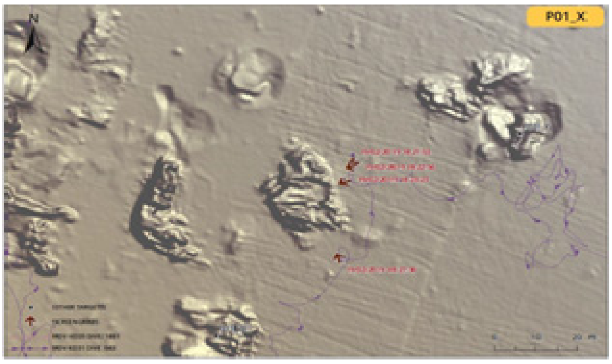
The objects are part of the stiffened plate structures crushed and torn into two to three pieces. It is not easy to identify which part of the ship they came from.



61. P01_X

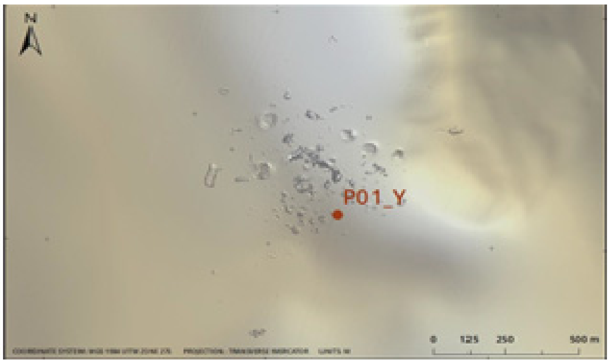
There are several torn and crushed stiffened plate structures discovered. They are presumed to be debris of the structure where the edge of the deck meets the area above the draft on the shell plating.

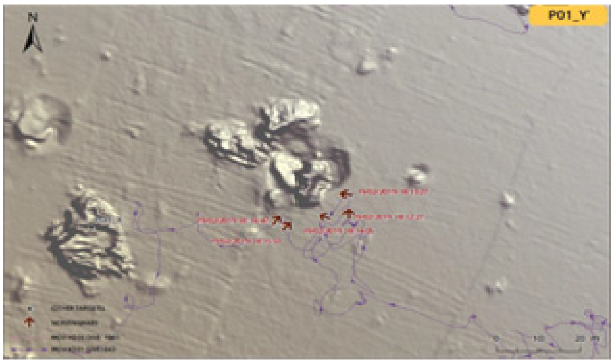


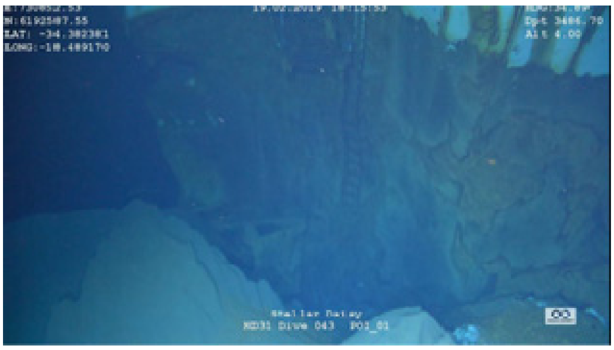


62. P01_Y

The objects are torn and crushed stiffened plate structures. They are presumed to be the bulkhead structures inside cargo holds or the hull.

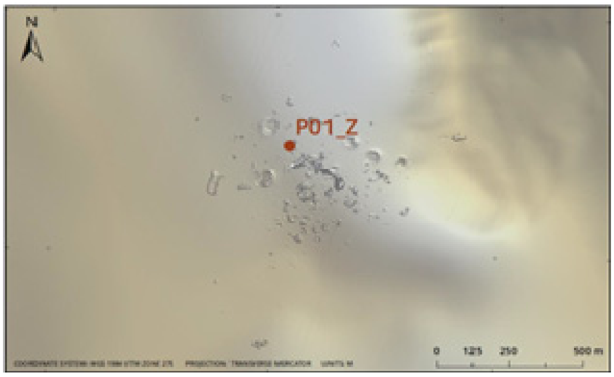


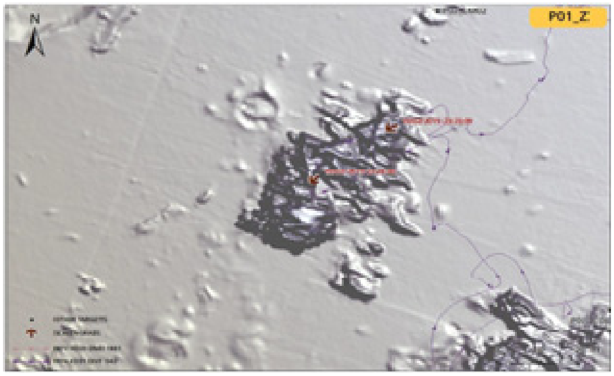




63. P01_Z

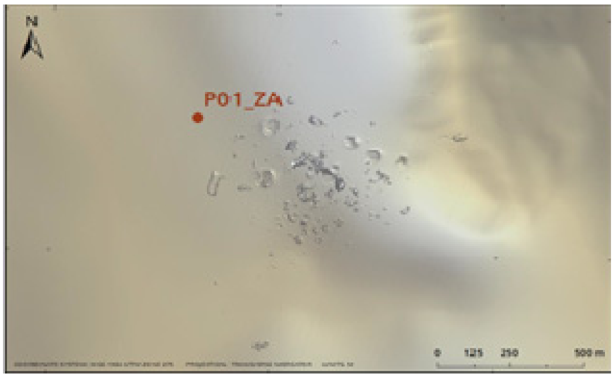
The objects are torn and crushed stiffened plate structures. They are unidentifiable but presumed to be the structures from cargo holds or the bulkhead inside the hull.

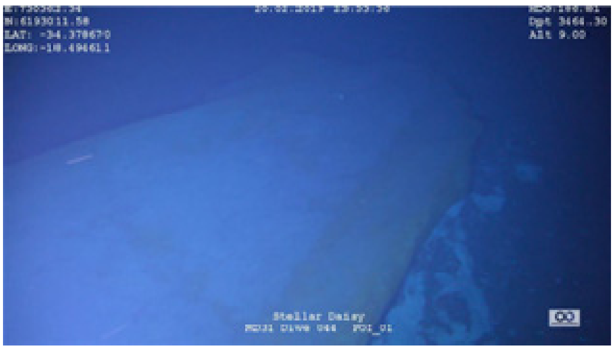




64. P01_ZA

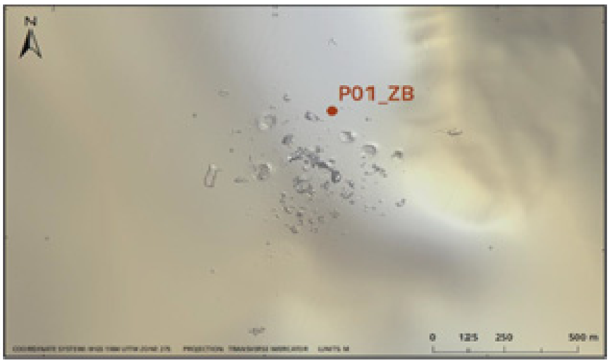
The objects are torn and dented stiffened plate structures. Given that the structures are red, they are presumed to be an area below the deck or the draft.

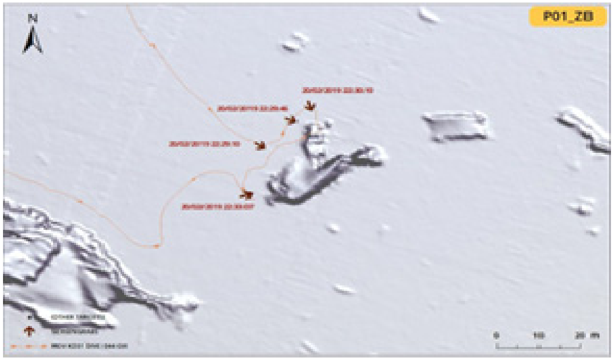




65. P01_ZB

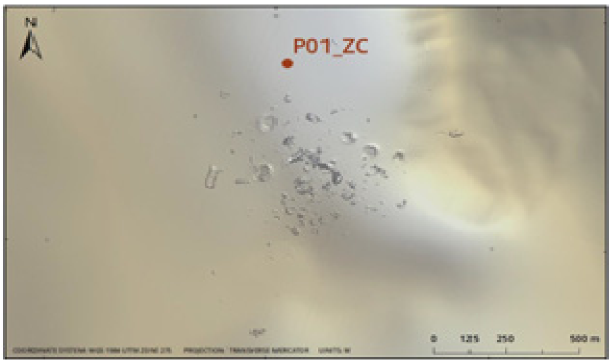
The objects are ripped and dented stiffened plate structures. One of the sides is colored gray while the other side is black. This suggests they are from the area above the draft on the shell plating.

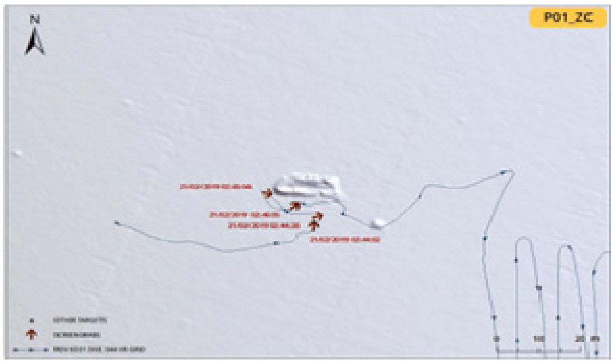


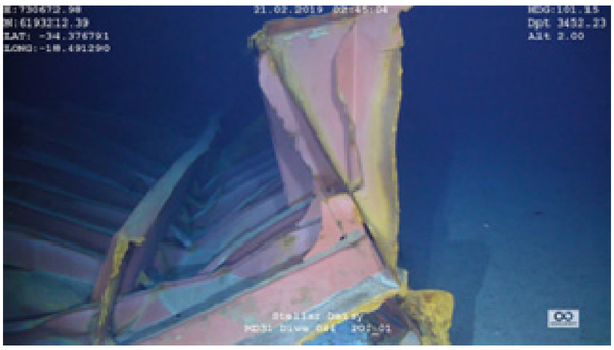


66. P01_ZC

The objects are structures with equally spaced openings. They are presumed to be part of the hatch coaming.







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Figures