MA2011-6

MARINE ACCIDENT
INVESTIGATION REPORT

June 24, 2011

Japan Transport Safety Board

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

Norihiro Goto
Chairman,
Japan Transport Safety Board

Note:

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

MARINE ACCIDENT INVESTIGATION REPORT

Vessel type and name:	Cargo ship RICKMERS JAKARTA
IMO number:	9292010
Gross tonnage:	23,119 tons

Vessel type and name:	Barge SHIN EI-MARU No. 18
Designation number:	Y 0628
Dead weight:	540 tons

Type of accident:	Accident with workers injuries and a fatality
Time of accident:	at around 1005 hours on September 1, 2008
Place of accident:	No.3 pier of Yamashita Wharf in Section 1 of Yokohama Quarter, Keihin Port, Yokohama City, Kanagawa Prefecture, Japan. From Yokohama Bay Bridge Light (P1) on 266° true, approximately 1,400 meters off (Approximate position: 35°27.1'N 139°39.3'E)

June 2, 2011

Adopted by the Japan Transport Safety Board

Chairman	Norihiro Goto
Member	Tetsuo Yokoyama
Member	Tetsuya Yamamoto
Member	Toshiyuki Ishikawa
Member	Mina Nemoto

1. PROCESS AND PROGRESS OF THE INVESTIGATION

1.1 Summary of the Accident

While the cargo ship RICKMERS JAKARTA, alongside with No.3 pier of Yamashita wharf in Section 1 of Yokohama Quarter, Keihin Port, on her starboard side, hoisting cargo using her No. 3 Crane from the hold of the barge SHIN EI-MARU No.18, which was moored on RICKMERS JAKARTA's portside, the hoisting wire rope of the deck Crane broke and the cargo fell into the hold of SHIN EI-MARU No.18 at around 1005 hours on September 1, 2008.

Among a barge crew and stevedores, five stevedores were thrown out by the impact. As a result, one stevedore was dead and three of them suffered bruises. SHIN EI-MARU No.18 sank because holed on her bottom by falling cargo.

1.2 Outline of the Accident Investigation

1.2.1 Setup of the Investigation

The Japan Transport Safety Board (JTSB) took over the investigation of this accident from Yokohama Marine Accident Investigators' Office, and appointed an investigator-in-charge and another regional investigator from the Yokohama Office to investigate this accident on October 1, 2008.

At a later date, the JTSB appointed a marine accident investigator as an investigator-in-charge and another two investigators.

1.2.2 Implementation of the Investigation

September 1 and 2, 2008, and April 13 and 14, 2009 — on-site investigations

September 5 and 24, December 12, 2008, January 14 and 27, 2009, and October 4, 2010 — interviews

December 9, 2008, June 30, August 11, 19, and 20, September 28 and 30, October 7 and 8, 2009. and September 7, 2010 — receipt of the written reply

January 8, June 18, 2009 — interviews and receipt of the written reply to the questionnaire

January 22, 2009 — interviews, receipt of the written reply to the questionnaire and on-site investigations

March 4, 2009 — receipt of the "Investigation report into the Cause of Cargo Freight Falling Accident" prepared by a German investigation and analysis company on request from the ship management company of RICKMERS JAKARTA.

1.2.3 Interim Report

On October 30, 2009, the JTSB submitted an interim report to the Minister of Land, Infrastructure, Transport and Tourism based on the facts found up to that date, and made it available to the public.

1.2.4 Analysis by Other Institutes

In regard to this accident, the National Maritime Research Institute, an independent administrative institution, was commissioned to assess the validity of the report entitled, “Investigation report into the Cause of Cargo Freight Falling Accident,” which was accepted on March 4, 2009.

1.2.5 Opinions of Parties Relevant to the Causes

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

1.2.6 Comments from the Flag State and the Crane Manufacturer

Comments were invited from the flag state and the deck Crane manufacturer.

2 FACTUAL INFORMATION

2.1 Events Leading to the Accident

2.1.1 Movement of Rickmers Jakarta

According to the statement and the written reply from the master of Rickmers Jakarta (hereinafter referred to as “Master A”), the movements of Rickmers Jakarta (hereinafter referred to as “Vessel A”) was as follows.

Vessel A underwent a special survey on its four deck Cranes (hereinafter referred to as “the Crane”) on August 13, 2008, at a dockyard in Shanghai, the People’s Republic of China. This survey was carried out by the classification society[1], Germanischer Lloyd (hereinafter referred to as “GL”), wherein Crane No.2 and No.3 were carried out load test by hoisting a 352-ton load that the load was 1.1 times as heavy weight as the Safe Working Load[2] stipulated by GL rule. Both Cranes successfully passed this test.

On August 25, Vessel A used Crane No.3 to load approximately 227 tons of cargo in the port of Masan, Republic of Korea, and on August 29, Cranes No.2 and No.3 were used in combination to

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[1] “Classification Society” is a nonprofit corporation that establishes standards for the construction of ships and onboard facilities. The organization inspects ships based on the standards and grants ship-class certificates.

[2] “Safe Working Load” is the maximum load a Crane can handle safely. The acronym S.W.L is often used. This value represents the capacity of the Crane in combination with maximum outreach (maximum turning radius that allows hoisting of the S.W.L)

load approximately 321 tons of cargo in Kobe Quarter, Hanshin Port, Kobe City, Japan.

Vessel A, with Master A and 25 crew members onboard, left the Kobe Quarter, Hanshin Port and was berthed alongside with No.3 pier of Yamashita wharf in Section 1 of Yokohama Quarter, Keihin Port, Yokohama City on her starboard side at around 1342 hrs Japan Standard Time (JST: UTC+ 9hr, unless otherwise stated all times are indicated in JST) on August 31. After preparations for cargo-handling, the loading operation except heavy cargo started at around 2154 hrs, and it continued until suspending the loading operation for a break around 0430 hrs on September 1 .

2.1.2 Movements of SHIN EI-MARU No.18

According to the interviews with the person in charge of towing (hereinafter referred to as "Operator B"), the movements of SHINEI-MARU No.18 (hereinafter referred to as "Vessel B") was as follows.

Vessel B loaded the cargo (hereinafter referred to as "the Cargo") at a quay owned by the Electric manufacturer (hereinafter referred to as "the Electric Manufacturer") located in Section 3 of Yokohama Quarter, Keihin port, and waited for Vessel A in harbor located in Section 1 of Yokohama Quarter of the port. After entering into the port of Vessel A, Vessel B with only Operator B on-board was towed out from the harbor by a tug boat at around 0700 hrs on September 1, 2008, and came alongside with portside of Vessel A, in almost the center position between the Crane No.2 and No.3 at around 0800 hrs.

2.1.3 Information of contractual situations for Cargo Handling

According to the written reply from the cargo handling management company (hereinafter referred to as "the Contract Company"), the agent of Vessel A in Japan issued an order for cargo handling operation of Vessel A at No.3 pier of Yamashita Wharf to the Contract Company. The Contract Company issued orders to two companies specialized in cargo handling (hereinafter referred to as "Company C" and "Company D") for loading/unloading the cargo and a company specialized in cargo lashing (hereinafter referred to as "Company E") for the lashing the Cargo loaded onto Vessel A.

2.1.4 Information regarding the Cargo

(1) Outline

According to the cargo planning prepared by the Contract Company and the technical data sheet prepared by the Electric Manufacturer for the Cargo submitted by the ship management company of Vessel A (Rickmers Reederei GmbH & Cie. KG, hereinafter referred to as "Ship Management Company A"), the Cargo was a steam turbine driven generator made by the Electric Manufacturer for a power plant.

The Cargo that size was approximately L× W × H =11.4 m × 5.5 m × 4.6 m and equipped four hoisting metal fittings each on fore/ aft and port/starboard of both sides. The Cargo from Vessel B was scheduled to be loaded onto the portside of No.3 hold[3] of Vessel A while berthed at No.3 pier of Yamashita Wharf and scheduled discharging port of the Cargo was West Palm Beach, Florida, U.S.A.

(2) Weight

(a) According to the technical data sheet of the Cargo, the Cargo weighed 314 tons.

(b) According to the statements of the ordinary seaman who operated Crane No. 3 (hereinafter referred to as "O/S A"), the load meter, equipped on the left side of the front panel in the operator's cabin, indicated around 290 tons when he hoisted the Cargo from Vessel B.

(c) According to the statements of the person in charge of operation of Company C, the Cargo was loaded using a floating crane[4] onto Vessel B at the own quay of the Electric Manufacturer. The measured weight of the Cargo at that time was approximately 300 tons.

2.1.5 Cargo Handling Situation on the Day of the Accident and Development of the Accident

According to the statements of Master A, Operator B, the persons in charge and in charge of cargo handling from the Contract Company, and the persons in charge of personnel management and operation from Company C, the cargo handling situation on the day of the accident and development of the accident were as follows.

The loading operation of the Cargo onto Vessel A started at around 0830 hrs on September 1, 2008. Seven stevedores on board Vessel A (hereinafter referred to as "Stevedore C1, C2, C3, C4, C5, C6, and C7" respectively) and other stevedores hung four hoisting wire ropes (hereinafter the wire ropes for hanging a cargo from a Main Hook Block are referred to as "the Grommets") to the hook block of Crane No. 3 for hoisting a 320-ton load (hereinafter referred to as "the Main Hook Block"). Then the jib[5] was turned toward the portside direction, and the four Grommets were hooked to the four hoisting metal fittings of the Cargo that was in the hold of Vessel B, which was moored alongside Vessel A.

O/S A after receiving signal from Master A, took in slack of the hoisting wire rope (hereinafter referred to as "the Main Wire") and the four Grommets and then started hoisting the Cargo by operating Crane No. 3 at around 0940 hrs. At around 1000 hrs, the Cargo lifted from the

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[3] A "hold" is a confined space in a ship where cargoes are stored.

[4] A "floating crane" is a Crane installed on a specialized floating platform that can travel from place to place as required.

[5] A "jib" is an arm that extends outward from the Crane's driving gear.

hold bottom of Vessel B. When the Cargo reached a level of approximately 7 to 8 meters above the hold bottom at around 1005 hrs, the Main Wire suddenly broke and the Cargo fell onto the hold bottom of Vessel B.

At this time, eight persons, Stevedores C1–C7 and Operator B who moved from Vessel A to Vessel B after completing the operation of hooking the Grommets, were working on board of Vessel B. Three out of the eight stevedores were able to safely move to a barge that was moored to the portside bow of Vessel B, but five stevedores were entered the water. Among the five stevedores entered the water, four were rescued by the vessel and barges that happened to be near the accident site, but Stevedore C1 went missing.

In early evening of the day of the accident, the divers that were searching for Stevedore C1 found him on the sea bottom, and he was confirmed dead. Among the four rescued persons, three were bruised. Vessel B suffered breaking and getting hole at the bottom plate and lead to sank by the falling the Cargo.

The date and time of this accident was around 1005 hrs on September 1, 2008, and the place was approximately to 266° true , 1,400 meters from Yokohama Bay Bridge Light (P1).
(See: Figure 1—Site Map of the Accident, Figure 2—Vessel A General Arrangement, Figure 3—Positioning of Vessel A Crew and Stevedores on Vessel A, Figure 4—Vessel B Position at Time of Accident, Picture 1—Full View of Vessel A (after the accident), Picture 2—Full View of Vessel B)

2.2 The Death or Injuries to Persons

According to the autopsy, the direct cause leading to the death of Stevedore C1 was brain detritions. In addition, an autopsy revealed that he also suffered compound open factures of his skull and facial bones, multiple bone fractures in both sides of his costal bones, and bleeding in both sides of his chest cavities. Besides according to the medical certificate, Stevedores C2, C3, and C4 suffered bruises in their legs and chests that took 5 days to heal.
(See: Figure 4—Vessel B Position at Time of Accident)

2.3 Damage to Vessels

2.3.1 Vessel A

(a) The Main Wire of Crane No.3 broke at a part supported by the 320-ton hoisting sheave[6] (hereinafter referred to as "Main Sheave") at the end of the jib.

[6] A "sheave" is a pulley on which a wire is hanged.

(b) The rightmost Main Sheave which seen from the operator's cabin of Crane No.3 fractured around its entire circumference along the bottom of the wire guide surface (rim's surface where the wire rope hanged on; hereinafter referred to as the "Wire Guide Surface") of its rim.

(c) The Main Hook Block and the Grommets of Crane No.3 submerged, but were salvaged at a later date.

(See: Figure 5—Machine Room Plan: Crane No. 3, Figure 6–Rigging Plan, Figure 7—Jib and Sheave, Picture 3—Sheaves at End of jib (Crane No. 3), Picture 4—Front end of Crane No. 3's jib, Picture 5—Scene of the Accident (after it occurred), Picture 6—the Main Wire at its Break Point)

2.3.2 Vessel B

According to the statements of persons, Master A, Operator B, the person in charge of cargo handling from the Contract Company, persons in charge of labor service and the person in charge of operation from Company C, Vessel B suffered breaking and getting hole at the bottom plate and lead to sank.

(See: Picture 7—Vessel B Salvaged)

2.4 Damage to Other Facilities

The Cargo, submerged due to this accident, was salvaged on October 7, 2008, and took it apart. Then the New Cargo was assembled usable parts and was shipped to original discharging port on June 5, 2009.

(See: Picture 8—The Cargo)

2.5 Crew Information

(1) Gender, Age, and Certificate of Competence

(a) Master A — Male, 52 years old

Nationality — Republic of Poland

Holder of MASTER MARINER CERTIFICATE ON SHIPS OF 3000 GROSS TONNAGE AND MORE issued by the Republic of the Marshall Islands

Date of issue — July 24, 2006

Date of expiry — March 25, 2011

(b) O/S A (Crane operator) — Male, 27 years old

Nationality — Republic of the Philippines

Holder of Crane operator certificate issued by Republic of the Philippines

Date of issue — March 28, 2007

Date of expiry	March 27, 2011

(2) Major Careers of the Crew

(a) Master A

According to the written reply from Master A:

He entered the ocean-going shipping company in 1982, and was on board ocean going cargo vessels and others until 1996. He obtained a master's certificate of competence in 1996, and was on board heavy cargo ships as a chief officer. He came aboard Vessel A on May 16, 2008, as chief officer, and was promoted to master on the day of the accident, 0800 hrs, September 1.

(b) O/S A (Crane operator)

According to the statements of O/S A:

He came aboard a passenger Vessel as ordinary seaman in 2000, and boarded on a cargo ship from 2002. After attending a Crane operator's training course, he was on board a heavy cargo ship, where he operated Cranes. He came aboard Vessel A on May 14, 2008, as an ordinary seaman and Vessel A was second heavy cargo vessel on his seaman's carrier and he operated Crane on Vessel A also.

2.6 Vessels Information

2.6.1 Particulars of Vessel

(1) Vessel A

IMO number	9292010
Port of registry	Majuro (Republic of the Marshall Islands)
Owner	Willric Shipping Co., Ltd. (Republic of the Marshall Islands)
Ship management company	Ship Management Company A (Federal Republic of Germany)
Gross tonnage	23,119 tons
L x B x D	192.99 m × 27.8 m × 15.5 m
Hull material	Steel
Engine	One diesel engine
Output	15,785 kW (maximum continuous)
Propulsion	One fixed-pitch propeller
Date of keel laid	May 29, 2002
Date of launch	November 28, 2003
Classification society	GL

(2) Vessel B

Designation number	Y 0628
Owner	Privately-owned
User	Vessel user F
Dead weight	540 tons
Hull material	Steel

2.6.2 Load condition

(1) Vessel A

According to the written reply from Master A, Vessel A was loaded with 80 containers (approximately 2,057 tons) and approximately 13,700 tons of other cargoes. According to the loading manual[7] of Vessel A, the draft before loading the Cargo was approximately 9.30 m at the bow, and approximately 9.80 m at the stern.

(2) Vessel B

According to the statements of Operator B, draft before loading the Cargo was approximately 0.60 m at the bow and approximately 0.65 m at the stern.

The draft after loading the Cargo was approximately 1.76 m at the bow and approximately 1.81 m at the stern.

2.6.3 Equipment of Vessel A

(1) Arrangement of the Ship

Vessel A was an aft-bridge type heavy cargo ship for international voyages with five holds under upper deck, designated as No.1 hold to No.5 hold from the bow. Vessel A had four Cranes on the upper deck. No.1 Crane and No.4 Crane were located along the center line, and No.2 Crane and No.3 Crane were located on the end of portside of the vessel.

The tally office was located inside the accommodation in backward of No.5 hold, where operating of ballast can be made during the cargo operations.

(See: Figure 2—Vessel A General Arrangement, Picture 1—Full View of Vessel A (after the accident))

(2) Cranes

(a) Particulars of Crane

[7] A "loading manual" is a document that contains a list of information required for the proper stowage of cargoes. Improper placement and arrangement of cargoes and ballasts can impose excessive stress on the ship structure because of their heavy weight.

According to the Class Certificate and the operation manual for the Cranes, submitted by Vessel A, Vessel A was equipped with revolving jib-type hydraulic Cranes, with the jib's pivot located on near of the bottom of the machine rooms. The cargo was slung up/down using a hoisting wire rope that runs through the sheave at the top of the jib. Crane No. 2 and No.3 had a hoisting winch with a capacity of safe working load were 35 tons and 320 tons, a maximum outreach were 35 m and 16 m respectively.

(See: Picture 1—Full view of Vessel A)

(b) Inspection of the Cranes

According to the written reply from GL:

The Cranes were carried out outside inspection and other inspection before shipment from the factory, and a load test was carried out after installation on the ship, in the presence of a surveyor from GL. The GL's "Regulations for the Construction and Survey of Lifting Appliances" stipulates an annual performance test, checks of hoisting gears and their damage and others, as well as a load test every five years, while in operation of the vessel.

Levels of inspection procedures of the Crane parts are classified into three categories (1–3) depending on the importance of the parts concerned. The sheave of the Crane belongs to category 2, and was not inspected during production. (The parts belonging to category 1 are inspected during manufacture).

(3) Crane No.3

Crane No.3 was installed on the end of portside deck between the No.3 and No.4 hold, and its operator's cabin was located in the central front portion of a machine room. The winches, turning gear, hydraulic pumps and others were also equipped for the machine room. According to the detailed plan of the Crane No.3 jib, submitted by Vessel A, the jib length was approximately 35.5 meters.

(See: Figure 2—Vessel A General Arrangement, Figure 5—Machine Room Plan: Crane No.3)

(a) Operator's cabin

The operator's cabin offered a good command of forward-, up/down-, and right/left-views, with the operator seat located in the center and the control consoles on both sides of the seat.

The control console on the left side had such controls as a start/stop button, emergency stop button, and a joystick type control lever that can control luffing and slewing of the jib. The controls on the right console include the control levers for the 35- and 320-ton winches, a wiper switch, and a lighting switch. The digital load meter was installed on the left side of the front panel.

(See: Picture 9—Operator's Cabin of Crane No. 3)

(b) Wire rope hoisting winch and others

The wire rope hoisting winches were installed inside the machine room and they are, from top to bottom, the 35-ton hoisting winch (hereinafter referred to as “the Auxiliary Hoisting Winch”), the luffing winch, and the 320-ton hoisting winch (hereinafter referred to as “the Main Hoisting Winch”). A turning gear was installed on the bottom part of these.

(See: Figure 5—Machine Room Plan: Crane No. 3)

(c) Sheave layout at the end of the jib

At the end of the jib, the following sheaves were installed, from left to right as seen from the operator’s cabin, main sheave B, main sheave A, four luffing sheaves, and main sheave C (rightmost). Two sheaves for 35-ton hoisting were installed at the further end of the jib.

(See: Figure 7—Jib and Sheave, Picture 3—Sheaves at end of jib (Crane No. 3))

(d) Fitted wire ropes

(i) The Main Wire

The Main Wire, nominal diameter[8]: 72 mm, was fixed at one end near main sheave D, located in the upper part of the machine room, and routed by way of main sheave A, at the end of the jib–,and main sheave D, upper part of the machine room, and then hoisted the Main Hook Block through main sheave B, at the end of the jib. It then returned by way of main sheave C, at the end of the jib, and main sheave E, upper part of the machine room, until finally taken up by the drum of the Main Hoisting Winch.

(ii) 35-ton wire rope

The 35-ton wire rope, with its one end fixed near the sheave at the end of the jib, hoisted the 35-ton hook block running through the sheave at the end of the jib. It returned by way of another sheave at the end of the jib and a sheave installed on the upper portion of the machine room, until finally taken up by the drum of the Auxiliary Hoisting Winch.

(iii) Luffing wire rope

This wire rope was fixed at one end near the sheave located in the upper part of the machine room, and traveled round four times between the luffing wire sheave at the end of the jib-and the sheave in the upper part of the machine room before being taken up by the drum of the luffing winch.

(See: Figure 6—Rigging Plan, Figure 7—Jib and Sheave)

[8] “Nominal diameter” is a value that represents a part’s typical diameter. In the case of a wire rope, it represents the diameter of a circumscribing circle. Nominal diameter is used to represent a typical diameter for a part that has different diameters/external radiuses along its length (e.g., screws and nuts).

(e) Maximum load of the Main Wire under operating

According to the Rigging Plan, when Crane No.3 was operated in 320 tons of its Safe Working Load, the main wire was burdened with a load of approximately 172 tons.

(f) Relation between Safe Working Load and Maximum outreach of the Crane

According to the operation manual of the Main Hoisting Winch, the relation between the Safe Working Load for the Main Hoisting Winch and its maximum outreach (distance from the Crane body to the hook) are as follows.

Safe Working Load	Maximum outreach
320 t	6.0–16.0 m
250 t	5.0–20.0 m
200 t	4.5–25.0 m
125 t	4.5–32.0 m
65 t	4.0–32.0 m

(See: Figure 8—Safe Working Load and Maximum Outreach)

2.6.4 Features of Vessel B

According to the statements of Operator B, Vessel B had the following features:

Vessel B had one store at the bow, and one hold in the mid part and a small accommodation space at the stern. The hold dimensions was 28 m (L) × 7.8 m (W) × 3.6 m (H), and hatch-size was 27 m (L) × 6.8 m (W) approximately.

Vessel B's bottom shell was built by steel plates with an approximate thickness of 10 mm and had frames placed on it at intervals of approximate 50 cm. The bottom of the cargo hold was constructed by steel plates, approximate thickness of 8 mm , on above mentioned beams.
(See: Picture 2—Full View of Vessel B)

2.7 Maintenance of Crane No.3

According to the written reply from Ship Management Company A, the maintenance of Crane No. 3 were as follows.

(1) Maintenance by crew on Vessel A

Crew on Vessel A maintain pursuant to the PLANNED MAINTENANCE SYSTEM (hereinafter referred to as "PMS"), a computer management system prepared by Ship Management Company A to control the maintenance status onboard equipment and the period of maintenance. The maintenance includes the greasing of wire ropes and sheaves, and the replacement of gear oil, filters and others. The maintenance history was logged.

PMS provides that the Main Wire be replaced every 60 months.

(2) Maintenance at a dockyard-before accident

In August 2008, five years after Vessel A was inaugurated, maintained the Cranes by dockyard workers and the Crane manufacturer in Shanghai, People's Republic of China. This maintenance included the Main Wire replacement. After completion of this maintenance, a 352-ton load test was carried out according as GL rules in the presence of GL surveyor and the Crane manufacturer.

At this time other tests including safety devices were carried out.

After these tests were completed, visual inspections of the Main Wire were carried out in the presence of the person in charge from the supplier of the Main Wire.

No defects were detected by these Crane tests and visual inspections.

2.8 Operating condition of the Crane before Accident

According to the statements of Master A, crew of Vessel A held the Crane operator certificate issued by the Republic of the Philippines operated the Crane when the cargo was heavier than 100 tons to be hoisted by Vessel A's Cranes. In addition, other crew member adjusted the ballast whenever the load of the Main Wire increased by 20 tons each. After completion of inspections at the dockyard in August 2008, Vessel A loaded 227 tons and 200 tons of cargoes in the port of Masan into the No.4 hold using Crane No. 3, and then loaded approximately 321 tons of cargo using Cranes No.2 together with No.3 into No.3 hold in Hanshin port, Kobe Quarter.

2.9 The Fracture Condition of Main Sheave Immediately after the Accident

According to the pictures taken immediately after the accident, the rim of Main Sheave C was fractured, and rust was observed on the rim's fractured surface on the backside of the wire guide surface.

(See: Picture 3—Sheaves at the end of Jib (Crane No. 3), Picture 4—Front End of Crane No. 3's Jib, Picture 10—Fractured Main Sheave C and Rust Formation)

2.10 The Results of Investigation and Analysis

According to the report "Investigation report into the Cause of Cargo Freight Falling Accident" (hereinafter referred to as "Analysis Report") prepared by an investigation and analysis company located in the Federal Republic of Germany (hereinafter referred to as the "Investigation & Analysis Company") at the request of Ship Management Company A, the Main Wire including the broken portion, fractured Main Sheave C, and Main Sheave E, not fractured, were removed from Vessel A and sent to the Investigation & Analysis Company on September 22, 2008, and then carried out investigation for finding the cause of the break and fracture.

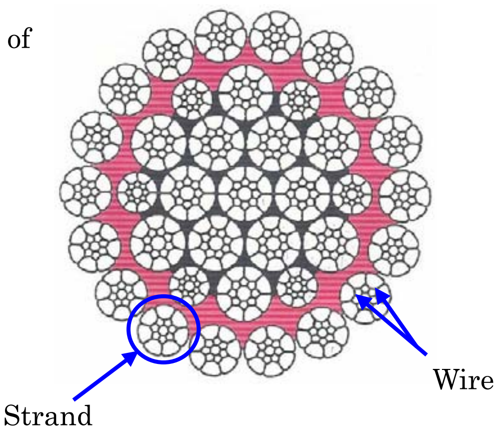
For a comparative analysis with fractured Main Sheave C, the following items were also sent to the Investigation & Analysis Company: a Main Sheave of the same type as Main Sheave C, removed from sister ship of Vessel A, under the supervision of Ship Management Company A, and an unused Main Sheave. Unprocessed L-shaped angle steel[9], from which the sheave rim was manufactured, was also shipped to the Investigation & Analysis Company from the sheave manufacturer.

According to the Analysis Report, the results obtained were as follows:

2.10.1 The Main Wire

(1) Construction

The Main Wire consists of four layers of helically wrapped strands around a central straight strand[10]: the center strand has six equally spaced strands twisted around it, then this composite strand has another twelve strands (6 strands each of two different thicknesses) wrapped around it in a helical fashion, then this has the outermost eighteen strands wrapped around it in a helical fashion. The surface of each strand is galvanized to prevent rust formation.



Main Wire Cross Section

(2) Strength

According to the inspection certificate issued by GL, a breaking load[11] of the Main Wire was approximately 655 tons.

2.10.2 The Main Sheave

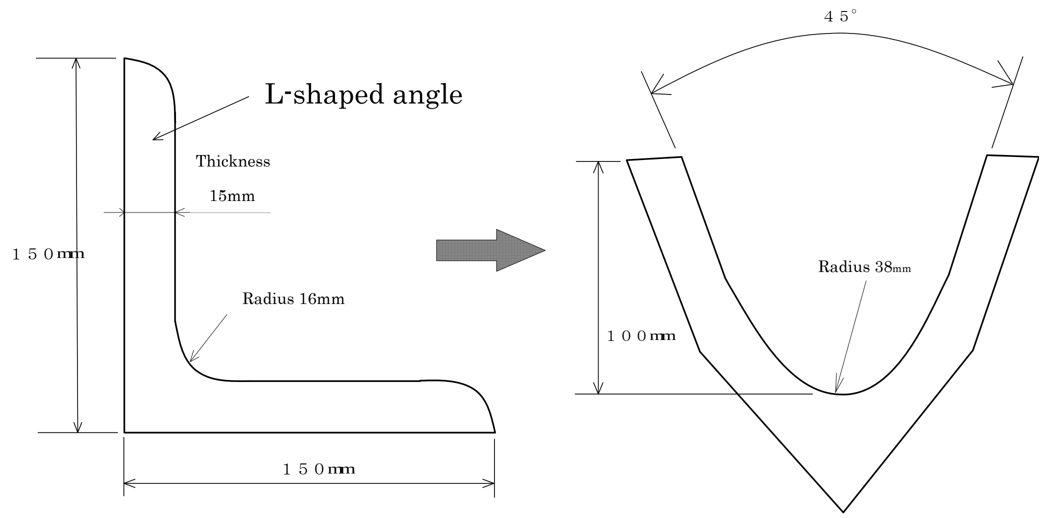
The Main Sheave was composed of a rim, a hub and two webs. A rim provides a wire guide surface, a hub contained a shaft bearing, and two webs connected the two former elements. Two web plates connected the rim with the hub. The rim had the following approximate dimensions: up

[9] A “angle steel” is a steel material of L-form, T-form and others in cross section.
[10] A “strand” is a bundle consisting of multiple wires (e.g., thin steel wire) stranded or twisted together.
[11] A “breaking load” is the maximum load applied to a test piece in a tensile test before the test piece ruptures.

to the bottom of the wire guide surface: 1,450 mm; up to the outer circumference: 1,650 mm, and width: 156 mm. Other dimensions include: a hub width of approximately 160 mm, a rim thickness of approximately 15 mm, a web thickness of approximately 18 mm, and a radius of the bottom of the wire guide surface of approximately 38 mm.
(See: Figure 7—Jib and Sheave)

2.10.3 The Rim of Main Sheave

The rim was manufactured from L-shaped angle steel material (DIN[12] S355J2G3[13], width of 150 mm and thickness of 15 mm, cross-section inner radius of 16 mm) through bending and shaping using a cold forming technique[14] to form it into a rim with a minimum groove radius of 38 mm (at the bottom of the wire guide surface) and a groove angle of 45°.



Manufacture of the Rim

2.10.4 The Broken Main Wire

(1) Visual Inspection

Any lacks of lubrication of the Main Wire were not found by visual inspection, except around the broken part, and the twisting condition of strands were normal. The surface of the Main Wire was smooth, without any breaks in the outermost wires, and no evidence of rust formation was found.

But then at the broken part and in its vicinity, the plastic coating covering the core strands

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[12] "DIN" is the abbreviation used to represent the standards of the Federal Republic of Germany. The standards are established by "Deutsches Institut für Normung e.V."

[13] "S355J2G3" is a type of steel corresponding to JIS standard SM50. It has the tensile strength of 490 N/mm^2 (the maximum tensile stress a test piece can endure before it ruptures when it is applied with a tensile load).

[14] "Cold forming" is a method of processing materials at normal temperatures. In contrast to hot forming, which is performed at elevated temperatures, cold forming provides better precision and the merit of increased hardness (work hardening). On the other hand, it allows a lesser degree of processing because of poor ductility as compared to hot forming, and it tends to allow residual stress. Additional heat treatment is performed if enhanced ductility is required.

were destroyed, and found damages of the outer wires and strands.

(2) Comparative Shape Inspection

The Main Wire and a new wire rope were compared in terms of the following items, and no difference was detected.

(a) Visual review of the wire rope construction in general

(b) Review of the manufacturing process

(c) Review of the number and arrangement of the wire ropes, the strands and the plastic coating of the core rope

(d) Gauging the diameters of the wires, the strands, and the wire rope

(e) Review of the lay direction of the strands and the strand layers

(f) Gauging the lay lengths or lay angles of the strands and the rope

(g) Evaluation of the pre-forming by gauging the radial height of the wires and the strands

(h) Evaluation of the compaction by gauging the diameters of the strands

(3) Material Strength Test

The wire tensile test was carried out on 149 wires in total 593 wires (approximately 25% of all wires). The aggregate breaking force was approximately 607 tons calculated by means of extrapolation. Aggregate breaking force according to the Certification was approximately 655 tons. The difference in the aggregate breaking force was probably caused by the compacting of the strands.

From the findings described above, it could be concluded that the broken Main Wire neither had defects in terms of strength nor any problems in terms of quality. The accident was the result of secondary damage by the impact load.

2.10.5 The Fractured Main Sheave

(1) Main Sheave C

Results of investigation and analysis were as follows.

(a) Appearance of fractured surface

(i) The Rim of Main Sheave C was totally broken and rust was observed in some parts of the fractured surface located on the backside of the wire guide surface. The appearance of a brittle Cleavage fracture[15] at most part of fractured surface could be seen, but hardly to find any

[15] "Cleavage fracture" is a mode of brittle fracture that accompanies very little plastic deformation (i.e., the material is irreversibly deformed and will not regain its original shape even after the removal of external force), and it progresses along the cleavage surface (e.g., in crystal structure, cleavage occurs in a crystallographic plane where inter-atomic binding force is weak).
In brittle fracture, no apparent stretching or squeezing takes place before fracture (fracture of glasses is an example of brittle fracture).

contraction in the through-thickness direction (typically observed in ductile fractures[16]) was observed.

(ii) Ductile dimple[17] fractures were observed in a part of present near the outer surface of the rim.

(iii) Any fatigue-fracture surfaces[18] were not found in the fractured surface.

(See: Picture 11—Inspection by Electron Microscope, Picture 12—State of rim fracture)

(b) Results of chemical analysis

The chemical analysis of the rim conducted to that the base materials, both webs and the rim, fulfill the requirements of a S355J2G3, as described in the mill sheet[19] at the time of manufacture.

(c) Results of mechanical characteristics measurement

Tensile and impact tests on the rim were carried out. The characteristic values of the tensile test fulfilled the requirements. In addition the Charpy values[20] from the impact tests carried out at -20℃ did not fulfill the requirements (min.27 J) for the specimens, located at the 'edge of the angle' (average 22 J) and the values deriving from the specimens 'base of the angle' were even lower (average 10 J).

Comparing with the mill sheet, tensile strength was higher and the values from the impact tests were lower than these results on the mill sheet.

(d) Observation of welded parts

According to the observation of welded parts between the rim and web, the crack propagation path did not pass through the root of the welding[21] and could not find the sign of cause of the fracture although the welding have no complete penetration.

(See: Picture 13—Backside of Wire Guide Surface (cracks found in Main Sheave C))

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[16] "Ductile fracture" is a type of fracture caused by an application of tensional force, and accompanies plastic deformation such as stretching and squeezing.

[17] A "dimple" is a dent found in a fractured surface. Inside a metallic material under external force, microvoids emerge as the material undergoes deformation. Increased external force induces coalescence of these microvoids and finally leads to fracture, leaving the remnants of these voids, which are called dimples because of their appearances.

[18] "Fatigue fracture surface" is characterized by a succession of striped patterns that indicate stepwise progression of fracture due to fatigue caused by repeated application of varying stress. Fatigue is a term that represents a phenomenon in which the strength of a material decreases by repeated application of stress that exceeds its fatigue limit.

[19] A "mill sheet" is a data sheet that explains the quality of a steel material. It is called a "mill sheet" because the mill (factory or manufacturing site) issues the sheet.

[20] "Charpy value" provides a measure of a material's toughness, and it is the energy required to break a notched test piece using a hammer impact divided by its cross-section area. The higher this value the tougher the material.

[21] A "root of the welding" is a point in the cross-section of welding material where the weld faces of each member face each other.

(e) Results of hardness measurements

Hardness measurements were carried out over the low deformed area (face side of wire guide) of the rim and the high deformed area (backside of wire guide) of the rim. As the result of the measurement, the hardness of low deformed area was 230 Hv[22], but the hardness of the high deformed area increasing to 284 Hv, and the tensile strength exceeded the strength of original materials.

The findings from (a) through (e) could be summarized as follows.

No irregular chemical composition was found in welded parts between the rim and web.

As for Mechanical-Technological Characteristic, compare the data of rim on mill sheet with the data of measurement, could find as follows.

The Charpy value and the elongation were lower than data of mill sheet and the data of tensile test exceeded the data of mill sheet.

Although welded parts have no complete penetration at the root of the welding, this was not considered to be the cause of the fracture, and as for hardness, there were no abnormality except the higher hardness of the rim.

(2) Microscopic Observation of Metallographic Structure

Investigation on Main Sheave C, as well as on unfractured Main Sheave E for comparison, was carried out. The results obtained are as follows.

(a) Main Sheave C

Microscopic observation[23] of the rim revealed, on the backside of the wire guide surface, small crack-like overlapping and rolled-in scale[24] that occur in the rolling[25] process of material production were found. These cracks had depths of 75–113 μm and were filled with oxidized scale. Although the wire guide surface showed a normal metallic structure, the micro structure of the backside of the wire guide surface was stretched significantly and squeezed due to high deformation and, in addition, the micro hardness increase and the tenacity reduce.
(See: Picture 13—Backside of Wire Guide Surface (cracks found in Main Sheave C))

(b) Main Sheave E

As is the case with fractured Main Sheave C, microscopic observation of Main Sheave E

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[22] "Hv" is the unit of Vickers hardness; the larger number means the harder. Hv is derived from the indentation left in the surface of the test material after removal of pyramidal indenter.

[23] "Microscopic observation" denotes methods of microscopic texture observation beyond the reach of the naked eye.

[24] "Scale" is an oxide film that grows on a metallic surface.

[25] "Rolling" is a method used for shaping and processing metallic material, in which the work piece runs through between multiple rotating rolls.

showed, on the backside of the wire guide surface, small crack-like overlapping that occur in the manufacturing process of the angle steel and rolled-in scale that occur in the rolling process of material production were present. These cracks had depths of 62–117 μm and were filled with oxidized scale.

Although the wire guide surface showed a normal metallic structure, on the contrary the micro structure of the backside of the wire guide surface was stretched significantly and squeezed due to high deformation.

(See: Picture 14–Backside of Wire Guide Surface (cracks found in then non-fractured sheave E))

According to the above, small cracks occurred by overlapping in the manufacturing process of the angle steel and occurred by rolled-in scales in the rolling process of material productions were present, and high deformation carried out under the cold forming at the manufacturing process of the rim caused to increasing the hardness of the surface.

(3) The Sheaves Sampled from Sister Ship of Vessel A, Unused Sheave, and Unprocessed L-shape Angle Steel

(a) Sheave from sister ship

Sheaves sampled from Cranes No.2 and No.3 of sister ship were examined. Large cracks were present on the backside of the wire guide surfaces of these sheaves and small crack-like overlapping and rolled-in scale that occurred in the rolling process of material production were present.

Note that no fatigue-fracture surfaces were found in these large cracks.

(b) Unused sheave

In the examination of the unused sheave, cracks that run from the backside of the wire guide reach to near of the wire guide surface were present, and elastic deformation[26] was observed relating to these cracks, indicating the persistence of residual stress[27] that possibly occurred in the cold forming process during the rim manufacture and the welding between the rim and web. Residual stress was not completely removed from the sheave.

(c) Unprocessed L-shaped angle steel

Examination of a cut surface of the unprocessed L-shaped angle steel revealed the existence of the notched surface by formation of crack-like overlapping.

(See: Picture 15—Sheave of a sister ship, Picture 16—Cracks found in Unused Sheave)

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[26] “Elastic deformation” is a reversible alteration of the form of a material under an external force. Once the force is removed, the material regains its original shape.

[27] “Residual stress” represents stress that persists inside a metallic material as a result of rapid and inhomogeneous deformations caused by rolling, forging, thermal process, or welding.

(4) Conclusion

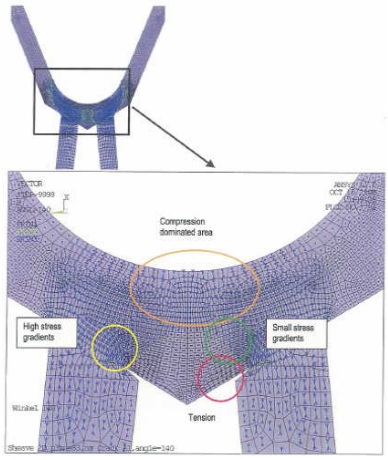
Judging from (1), (2) and (3), the manufacturing process of the angle steel which was the material for the rim resulted in small crack-like overlapping and rolled-in scales on the rim surface which was located inside of the rope sheave. In addition a high deformation of the inner rim surface was present and the micro structure was stretched and squeezed in this area of the rim. Besides, this led to hardness in this area. The high deformation of the rim led to concentration of stress at the small crack-like overlapping and caused the materials to become brittle, thus finally leading to fracture of the rim. Stress during normal operation could have lead to the fracture of the rim.

2.10.6 Results of Finite Element Method (FEM)[28] Calculation

FEM analysis of the backside area of the wire guide surface was made assuming three different situations as following, (1) no cracks, (2) 8 mm depth crack in the vicinity of the web, and (3) 1 mm depth crack in the vicinity of the web. In these calculations, a 320-ton load was applied to each of the models.

(1) No Cracks

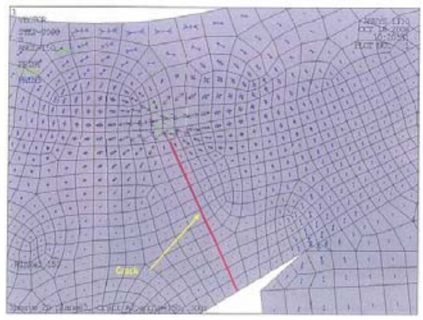
High stress gradients were obtained close to the welded parts of the rim and the web. The crack started not at the welding part.



FEM Vector plot of principal Stress (without crack)

(2) 8 mm depth crack in the vicinity of the web

The results as vector plots of the principal stress (8mm crack) shown that highest stress gradients occurred at the end point of the crack.

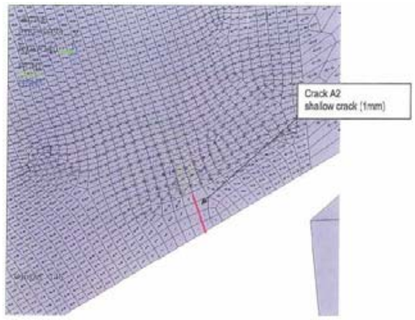


FEM Vector plot of principal Stress (8 mm crack)

[28] The "Finite Element Method (FEM)" is a numerical analysis technique in which an object of complicated shape is divided into an aggregate of simple, manageable chunks and a numerical method is applied to each of them, and the results are added up to gain an overall approximate solution.

(3) 1 mm depth crack in the vicinity of the web

The results as vector plots of the principal stress (1mm crack) shown that highest stress gradients occurred at the end-point of the crack.



FEM Vector plot of principal Stress (1 mm depth crack)

2.10.7 Point in Time of Brittle Fracture Occurrence

In this accident, it was considered probable that the Main Wire to drop into the gap created by the fracture in the rim of Main Sheave C. The Main Wire dropped into the gap was forcefully extended when it dropped into the hub, whereby a huge dynamic load was imposed upon the Main Wire, thus resulting in the breaking of the Main Wire. Therefore, it was considered probable that a brittle fracture took place prior to the breaking of the Main Wire.

2.10.8 Results of Fracture Mechanics Analysis

Fracture mechanics analyses were usually used for the evaluation of the conditions of cracked structures. In the following subsection the assessment according to BS7910[29] was briefly explained.

(1) Results of Analysis: with a 8 mm depth crack

A fracture would not occur if the sheave has a Charpy value higher than 27 J. The stress intensity factor[30] would become larger (i.e., become more fracture-prone) as the inter-web distance becomes larger and the hub width becomes wider and then it is easily destroyed.

(2) Results of Analysis: with a 1 mm depth crack

The cracks did not lead to unstable crack (brittle and ductile fracture mixed), however, it growth could be possible.

(3) Effect of Secondary Stress

As the magnitude of the secondary stress was unknown the effect of the residual stress was

29 "BS7910" stands for British Standard 7910, which provides a guideline for making an allowance evaluation regarding the effect a defect, such as a crack, can exert on a welded structure.

30 "Stress intensity factor" is a value used to represent the intensity of stress distribution gradient (stress state) near the tip of a crack. It is often used as a reference to predict an occurrence of brittle fracture.

analyzed under the assumption of 50% of the yield point[31] as additional stresses. Assuming a shallow crack 1 mm depth the addition of residual stress would lead to a stable condition. For the deep crack of 8 mm depth the additional residual stress causes a stress intensity factor higher than the Charpy value of 27J. This would lead to an unstable condition.

(4) Possibility of Fatigue Fracture

Results of detailed investigations showed that the location of the fracture coincided neither with the welding root face nor thermally affected areas, and observation of the fractured surface did not reveal any fatigue-fracture surface. These findings showed clearly that fatigue was not an issue in this accident.

(5) Summary

A comparative investigation of the stress intensity factor at the end point of a crack and of the material toughness value[32] of the material was carried out, whereby the crack depth was a parameter. The results indicated that the stress intensity factor becomes larger as the depth of a crack increases.

If we assume that the residual stress at welding parts was approximately 50% of the yield point, this level of residual stress could have the effect of triggering fracture propagation if the crack had a depth of 8 mm, even if the material has the Charpy value of 27 J. In contrast, fracture propagation would not occur if the crack depth was small, even in materials with the Charpy value as low as 6 J, because of the small stress intensity factor.

From these findings, the possibility of fatigue damage or occurrence of fatigue crack propagation due to prolonged use of Main Sheave C could be considered remote. On the other hand, the stress intensity factor, which becomes larger as cracks deepen and the inter-web distance became wider, could trigger brittle fracture even in materials with high Charpy values.

2.11 Validity Evaluation of this Analysis Report by National Maritime Research Institute

JTSB entrusted the validity evaluation of the following items in this Analysis Report with the National Maritime Research Institute (an independent administrative agency; hereinafter referred to as "NMRI").

(1) Sequence of events leading to the break of the wire rope

(2) Validity of descriptions put forward in this Analysis Report regarding the effect of cold

[31] A "yield point" is the stress at which a material being stretched by increasing external force begins to deform rapidly without further increase of stress.

[32] "Fracture toughness value" is an index that represents the strength of a material containing a cutout.

forming on angle steel parts in the manufacture of Main Sheave C. The validity of the description regarding material defects was also examined.

(3) Validity of stress evaluation based on the results of FEM analysis.

(4) Further elucidation of the time point when brittle fracture occurred in Main Sheave C, and the validity of the fracture mechanics analysis described in this Analysis Report.

NMRI's evaluations were as follows.

2.11.1 Verification of Possible Causes that Resulted in the Break of Wire Rope

The approach taken in the strength test of the wire rope materials could be highly regarded as it started from basic wire tests and calculated the break load as an arithmetic sum, and also provided a good accumulation of experimental data. The results from the investigation on the broken wire and the analysis of the wire test were correct and the interpretation thereof was rational.

2.11.2 Examination of Manufacturing Processes of Main Sheave C and Material Defects: with Consideration Given to the Effect of Cold Forming and Others

The conclusion that a cleavage failure occurred is considered appropriate, based on the following findings obtained from an examination of the fractured surface: there was very little contraction in the through-thickness direction, and almost no roughness or formation of steps in the fractured surface.

The results from investigation and analysis on chemical components, mechanical properties, the welded parts and hardness of Main Sheave C were quite appropriate. In particular, the analysis of welded parts led to the conclusion that denied a direct causal link between the fracture and the incomplete penetration parts that remained in some of the welded parts. This was an important analysis based on the fact that the root of fracture propagation did not coincide with the root of welding.

The tests showed the following properties of the test sample: a lower Charpy value and less stretching than those listed in the mill sheet, high values in tensile tests, and extra hardening found in the highly deformed area of the rim. The analysis linked these findings to work hardening, which is considered quite accurate.

The following interpretation is highly evaluated: the surface metallic structure of Main Sheave C had surface scars, and these scars developed into small crack-like during the manufacturing process of the angle steel.

In conclusion, the Analysis Report deduced the factors leading to the fracture as follows.

Small crack-like were created during the manufacture of the angle steel, and the surface of the rim suffered significant hardening during its manufacturing processes (e.g., bending and shaping through cold forming), providing stress focusing points that led to the occurrence of fracture. This analysis is firmly based on actual experiences in steel processing and welding, and is considered correct from a technical point of view.

2.11.3 Validity of FEM Analysis: Stress Evaluation on the Rim of Main Sheave

The FEM analysis lacks an exact calculation of maximum stress, despite such calculation being necessary for brittle fracture analysis. The Analysis Report presented instead the stress distribution of the fractured surface region where stress gradient takes maximum values (see "FEM stress distribution (without cracks)). However, in view of the fact that Main Sheave C functions while it is rolling, the values in this distribution have to be accepted only as an approximation.

On the other hand, the stress ratio of two different points within the fractured surface can be read from the chart. From these values, it is considered appropriate to estimate stress that acts on the surface cracks in the backside of the wire guide surface in the following fashion.

From the "FEM stress distribution (without cracks)," the compression stress acting on the web (σh) and the normal surface stress on the backside of the wire guide surface (σs : parallel to wire guide surface and normal to fracture surface) have the following relation: σh ranges from −1/4 to −1/3 of σs (the negative sign indicates compression).

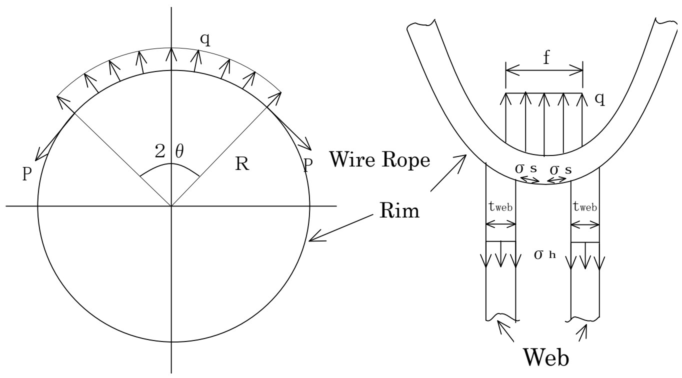
From chart (a) below, $q \cdot 2R\theta \cdot f = 2P \cdot \sin\theta$

From chart (b) below, $q \cdot f = \sigma h \cdot 2t_{web}$

As θ approaches zero, 2 sinθ can be approximated by 2θ. Substituting this into the equation above, we obtain the following approximate formula representing the relation between normal surface stress of Main Sheave C (σs) and wire rope tension P.

$\sigma s = (1/4 \sim 1/3) \cdot \sigma h$

$= (1/4 \sim 1/3) \cdot P/(2R \cdot t_{web})$



(a) Balance between wire tension P and rim pressure q

(b) balance between rim pressure q and web axial stress σ h

Balance among the wire rope, rim, and web

2.11.4 Clarification of Time Point and Validity of Fracture Mechanics Analysis for the Rim of Main Sheave C

(1) Clarification of time point of fracture occurrence

The Analysis Report indicated deductively the following sequence of events as the results of the causal investigation: (1) surface defects (occurred in the manufacturing process of Main Sheave C) → (2) fracture in the rim of Main Sheave C → (3) impact load on the Main Wire → (4) break of the Main Wire.

However, this deduction is not based on material evidence.

As brittle fracture propagates inside steel material at the speed of a surface wave (i.e., the speed at which a surface impact that triggered tiny undulation propagates: approximately 2,000 m/sec), the conclusion that the fracture propagated across the whole circumference of the rim of Main Sheave C in a very short period of time is considered appropriate. The tension of the Main Wire and the contact pressure upon the rim maintained dynamic equilibrium, but, at the moment brittle fracture occurred, a precipitous reduction of the contact pressure took place, pulling the Main Wire into the crack gap between the two rim members separated by the fracture. Therefore, the conclusion that this instantaneous movement of the Main Wire caused a sudden change in the tension of the Main Wire, imposing a huge overload and impact on the Main Wire, is considered appropriate.

If we assume that the Main Wire broke prior to the fracture of rim of the Main Sheave C, it is almost impossible to specify the origin of the force that led to the Main Wire's break.

(2) Validity of Fracture Mechanics Analysis

It is considered appropriate that the Analysis Report used fracture mechanics analysis to evaluate the stability of the parts containing cracks, and employed BS7910 as a reference.

When stress is applied to a material that contains crack defects, brittle fracture may be triggered if the stress around the tip of the crack becomes larger than the strength of material. Namely, brittle fracture can take place when $K \geqq K_{mat}$, where,

K: stress intensity factor

K_{mat}: fracture toughness

According to Fracture Mechanics, when stress σs is applied to a part with plate width b and with a crack of depth a in it, the stress intensity factor becomes:

$K = \sigma s \sqrt{\pi a} F$ (F is a factor determined by a/b)

According to The Stress Analysis of Cracks Handbook (Hiroshi Tada, Paul C. Paris, George Rankine Irwin, Del Research Corporation, Hellertown, Pennsylvania, 1973), when the plate width is sufficiently larger than the crack depth (i.e., a/b=0), F becomes approximately 1.12. Thus

$K \fallingdotseq 1.12\sigma s\sqrt{\pi a}$

Using the equations presented in clause 2.11.3, calculations were made assuming three levels of rope tension (P = 100, 150, and 200 tons). Results obtained assuming 150 tons of rope tension are as follows:

Surface normal stress $\sigma s \fallingdotseq P/3 \cdot 2 \cdot R \cdot t_{web}$

$= 150 \cdot 9.8 \cdot 1000/ (3 \cdot 2 \cdot 725 \cdot 18)$

$= 18.8\ N/mm^2$

Therefore, assuming a crack depth of 8 mm, the stress intensity factor can be calculated as:

(a) Without residual stress

$K = 1.12 \cdot \sigma s \cdot \sqrt{\pi \cdot a}$

$= 1.12 \cdot 18.8 \cdot \sqrt{\pi \cdot 8}$

$= 105.5\ N/mm^{1.5}$

(b) Assuming $15.0 kgf/mm^2$ ($147 N/mm^2$) of residual stress

$K = 1.12 \cdot \sigma s \cdot \sqrt{\pi \cdot a}$

$= 1.12 \cdot (18.8 + 147) \cdot \sqrt{\pi \cdot 8}$

$= 930.7\ N/mm^{1.5}$

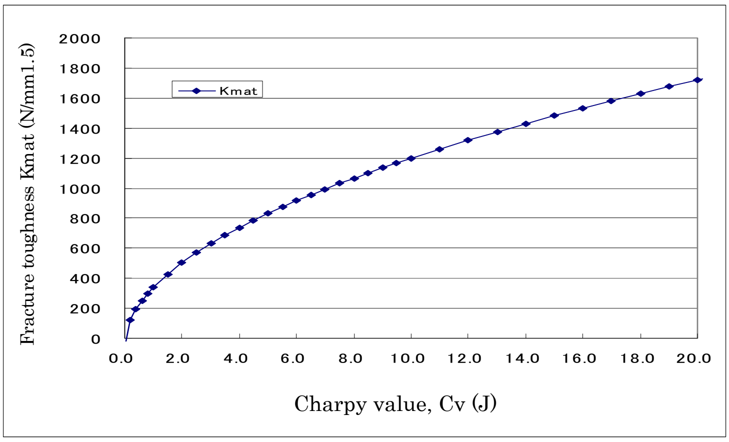
According to the correlation chart of BS7910, fracture toughness K_{mat} can be expressed using the following equation:

$K_{mat} = (820 \cdot \sqrt{Cv} - 1420) / B^{0.25} + 630$

Cv: Charpy value (J)

B: material thickness (mm)

This equation is represented graphically as follows (B is assumed to be 15 mm).



Charpy value vs. Fracture toughness

If Cv = 6 J is used in the graph, we obtain K_{mat} = 916N/mm$^{1.5}$ Substituting P = 150, a = 8 mm, residual stress = 15.0kgf/mm^2 (147N/mm^2) into the equating gives K = 930.7N/mm$^{1.5}$ > Kmat =916N/mm$^{1.5}$, satisfying the required condition of brittle fracture. Therefore, we concluded that a brittle fracture could have occurred.

2.12 Information on the Main Sheaves Installed on the Same Type of Cranes: Sister Ships under the Control of Ship Management Company A

2.12.1 Information Surrounding the Same Type Sheave

According to the written reply to the questionnaire from the Crane Manufacture, information surrounding the same type sheave was as followings: The basic design of the sheaves in question (a cold rolled rim made of angle steel, two web plates and a hub) was generally used since in the 1960s in Germany. The Sheave Manufacture has been manufacturing sheaves of the design for 40 years and has been supplier of the Crane Manufacture for about 30 years. In all these years the Crane Manufacture has never heard of a problem or a damage like this. The Sheave Manufacture has an approval certificate for the manufacturing of this type of welded rope sheaves and under continuous surveillance by many classification societies such as DNV (Det Norske Veritas)and GL.

2.12.2 Inspection of the Main Sheave

According to the written reply to the questionnaire from the Ship Management Company A, and from interviews and the written reply to the questionnaire from the person in charge of labor service of the Contract Company, the Ship Management Company A has under its control eight sister ships of Vessel A, each of which calls at Keihin port, Yokohama Quarter. Each of them has four Cranes, and with a few exceptions, all were manufactured by the Manufacturer of Vessel A's Cranes. After the accident, an examination of the Main Sheaves was carried out by means of ultrasonic flaw detection[33] by engineers from a company specialized in this technique, with the person in charge of the Ship Management Company A in attendance. This examination revealed that 37 out of 90 sheaves had hidden fault (each Crane has five sheaves, thus one ship has ten sheaves). All the faulty sheaves were subsequently replaced.

2.13 Information on Regulations of classification society on Weld Construction Sheaves

GL regulations (Regulations for the Construction and Survey of Lifting Appliances) contain

[33] "Ultrasonic flaw detection" is a nondestructive test technique used to detect hidden internal defects in materials such as steel stock. This technique takes advantage of the characteristic of ultrasonic waves in that they are reflected in the interface between dissimilar materials.

no stipulations on weld construction sheaves.

2.14 Information Surrounding the Fall of the Cargo

2.14.1 Operation of Crane No.3 during the Hoisting Operation of the Cargo

According to the interviews with Master A, O/S A, and the person in charge of labor service and the person in charge of operation of Company C, the hoisting operation proceeded as follows. From the mounting of the Grommets hung from the Hook Block of the Crane No.3 onto the Cargo until the Cargo cleared the bottom of the hold, the hoisting operation was suspended temporarily upon every increase of approximately 20 tons of load according to the meter readings in the operator's cabin for ballast adjustment. After the Cargo left the bottom of hold of Vessel B, the load meter reading remained at about 290 tons, and the hoisting operation proceeded smoothly at a constant speed without any arresting.

According to the written reply to the questionnaire from Master A, the actual operation radius from Crane No.3 to the Main Hook Block was 12 m or less (maximum outreach: 16m).

2.14.2 Positioning of Vessel A Crew and Stevedores

According to the interviews with Master A, O/S A, the person in charge of cargo handling of the Contract Company, the person in charge of labor service and the person in charge of operation of Company C, and the person in charge of the operation of Company D, the positioning of the persons involved were as follows:

Master A was on the portside bow, the third officer of Vessel A was on the portside stern, and the person in charge of the Contract Company was on the center rear; all were above the hatch cover of hold No.3. O/S A was positioned in the operator seat of Crane No.3. Three men were positioned on the portside of the upper deck, from the bow to stern side: a stevedore from Company D, the person in charge of operation and the person in charge of labor service of Company C.

(See: Figure 3—Positioning of Vessel A Crew and Stevedores on Vessel A)

2.14.3 Positioning of Vessel B and Workers when the Accident Occurred

According to the interviews with operator B and Stevedores C2, C3, C5, C6 and C7, the positioning of Vessel B were as follows:

(1) Positioning of workers

Operator B was positioned on the bow of Vessel B, and stevedores were positioned as follows: Stevedore C6 toward the starboard bow, Stevedore C7 toward the portside bow, Stevedore C3 toward portside stern, Stevedore C5 near stern, Stevedore C1 toward the starboard stern, and Stevedore C2 and C4 were positioned inside the hold (starboard and portside respectively).

(See: Figure 4—Vessel B Position at the Time of Accident)

(2) Situation of the Stevedores Immediately after the Accident

(a) Operator B

Operator B was standing on the bow deck watching the Cargo being hoisted up, when the Cargo dropped. Operator B immediately moved to the barge on the left.

(b) Stevedore C1

After the Cargo went up and passed through the opening of the hold of Vessel B, Stevedore C2 saw Stevedore C1 walk from the back to the front portion inside the hold, go upstairs to the deck, and then walk on Vessel B's starboard deck toward the bow. This was the last moment he saw Stevedore C1.

Just before the Cargo fell, Stevedore C5 saw Stevedore C1 positioned on the starboard stern deck (away 1-2m from Stevedore C1) of Vessel B (i.e., broadside of Vessel B that was in contact with the portside outer shell of the Vessel A), but he did not see Stevedore C1 after the Cargo fell.

(c) Stevedore C2

While Stevedore C2 was cleaning up inside the hold (rear starboard side), Stevedore C2 heard a cry and at the same time the Cargo fell down, crashing through the bottom of the hold, and sea water began bursting into the hold. While Stevedore C2 was trying to escape, Stevedore C2 fell down and was engulfed by the bursting sea water. As Vessel B started to sink, Stevedore C2 caught the hold edge of the opening of the hold, and then pulled himself onto an object floating nearby.

(d) Stevedore C3

The Cargo fell while Stevedore C3 was moving on the portside deck in the direction of the bow to stern. Stevedore C3 fell down because of the impact. While Stevedore C3 was trying to stand up, Vessel B started to sink and Stevedore C3 entered the water.

(e) Stevedore C4

Stevedore C2 saw Stevedore C4 cleaning up the portside of the hold and being engulfed by the bursting sea water by the impact of the fall of the Cargo.

(f) Stevedore C5

When Stevedore C5 was moving on the deck from portside rear further toward the rear, Stevedore C5 heard a noise that sounded like that of the rope breaking. At the moment Stevedore C5 looked up at the Cargo, the falling Cargo crashed through the bottom of the hold and sea water began bursting into the hold. Then Stevedore C5 realized that he was under the sea.

(g) Stevedore C6

When Stevedore C6 was watching the Cargo being hoisted up, it fell into the hold, smashing through the bottom, and Stevedore C6 felt an impact. As Stevedore C6 could hardly stay on feet alone, Stevedore C6 caught hold of the bitt to avoid falling down, and moved to the barge moored on the portside. When Stevedore C6 moved to the barge, the Person in Charge of Operation B and Stevedore C7 had already moved to the same barge.

(h) Stevedore C7

When Stevedore C7, positioned on the portside deck, was watching the Cargo being hoisted up, Stevedore C7 heard a voice from above, and immediately after, Stevedore C7 heard a noise that sounded like a wire rope breaking, followed by the crash caused by the falling Cargo. To withstand the heavy shaking of Vessel B, Stevedore C7 clung to the edge of the hold opening, and then Stevedore C7 moved to the barge moored on the portside.

(3) Situation of Vessel B

After the Cargo fell, Vessel B started to turn round leftward slowly. As a result, the portside stern came free from the barge that was in contact with Vessel B, and the portside bow came near to it.

2.14.4 Situation Surrounding the Fall of the Cargo

According to the interview with the person in charge of operation of Company D, he was positioned in the portside of the upper deck. While he was watching the Cargo being hoisted slowly past in front of him, the Cargo suddenly dropped about 50 cm and stopped temporarily, and then it started to fall into the hold of Vessel B.

2.14.5 Information on the Sound Produced at the Time of the Fall of the Cargo

According to the interviews with Stevedores C5 and C7, and the worker of Company E, they heard a noise like that of a dong when the Cargo, which was being hoisted up slowly, reached a height of about 7 or 8 meters from the bottom of the hold of Vessel B. The sound like that of a dong came from the sheave at the tip of the jib of the Crane No.3, or from somewhere around it, accompanied by quieter hissing noises that sounded like the strands of the wire rope were breaking. A few seconds later, the Main Wire broke with a “dong” and the Cargo fell into the hold of Vessel B.

2.14.6 Situation of Vessel B after the Cargo Fell

According to the interviews with Operator B, and Stevedores C2, C3, C5, C6, C7, the situation of Vessel B immediately after the Cargo fell was as follows.

The Cargo fell into the hold of Vessel B, smashing through and creating a hole in the bottom of the hold, and sea water came bursting through the hole. Vessel B sank nearly to the upper end of its side due to the impact, came afloat for a moment, and then went under water.

2.15 Safety Management of the Contract Company and Company C

According to the interview with the person in charge of the Contract Company, and the person in charge of labor service and the person in charge of operation of Company C, and according to the guideline document (safety instructions and operation references) submitted by Company C, the safety management on site was as follows.

In regard to the operation of handling the Cargo, the person in charge of the Contract Company explained the operation procedures to the stevedore before the commencement of actual cargo handling, whereby he made sure that they wore helmets and safety shoes, and instructed them to never work directly under the Cargo.

Onboard Vessel A, the person in charge of the Contract Company had a meeting with the crew about the cargo handling procedures. He checked also the operational status of the Crane and wire, and he confirmed that there were no irregularities.

During the cargo handling operation, an on-site safety patrol was conducted by the person in charge of labor service of Company C.

According to interviews with the person in charge of labor service of Company C, there were no stevedores working directly under the Cargo when the accident occurred.

2.16 Meteorological Conditions

2.16.1 Weather Data

On the day of the accident, the recorded data and figures on weather observation at Yokohama Local Meteorological Observatory, which is located about 1,230 m south of the site of the accident were as shown below.

10:00 Weather Clear, Wind direction: East, Wind speed: 2.1 m/s, Temperature: 28.5°C

11:00 Weather Clear, Wind direction: Southeast, Wind speed: 2.4 m/s, Temperature: 28.4°C

2.16.2 Weather Observed by the Crew

According the log book of Vessel A, the local weather in the vicinity of Vessel A was as follows.

06:00 Wind direction: East, Wind speed: 1.1 m/s, Temperature: 24°C

12:00 Temperature: 30°C

3 ANALYSIS

3.1 Situation of the Accident Occurrence

3.1.1 Events Leading to the Accident

Judging from clauses 2.1, 2.2, 2.3, and 2.14, the process leading to the accident was as follows.

On September 1, at around 0830 hours, Vessel A was hoisting the Cargo from Vessel B, which was moored on Vessel A's portside, using Crane No.3, when the rim of Main Sheave C fractured and caused the Main Wire to break. Because of the Main Wire break, the Cargo, along with the Main Hook Block and the Grommets fell onto Vessel B; as the result five stevedores entered the water. Stevedore C1 was killed and three of the other four were bruised.

At the same time, the falling Cargo created a hole on the bottom of Vessel B, causing it to sink.

3.1.2 Analysis of the Weight of the Cargo, and the Height from where it Fell

Judging from clauses 2.1, 2.6.2, 2.14.4, and the general arrangement of Vessel A, the actual weight of Cargo was about 290 – 300 tons, and it was being hoisted from Vessel B by one of Vessel A's Cranes. At the time of the accident, the Cargo's bottom side was estimated to be at the height of approximately 8 meters from the hold bottom of Vessel B.

3.1.3 Time and Site of the Accident

Judging from clause 2.1, it is considered probable that this accident occurred at around 1005 hrs on September 1, 2008, at the site approximately 1,400 m from Yokohama Bay Bridge Light (P1) to 266° true.

3.1.4 Meteorological Conditions

Judging from clause 2.16, it is considered probable that the weather at the time of accident was fair, with an east wind of an approximate velocity of 2 m/s.

3.2 Analysis of Crew and Vessels

3.2.1 Conditions of crew and vessels

(1) Conditions of Vessel A crew

Judging from clause 2.5(1), Master A held a legal and valid Certificate of Competency.

(2) Conditions of Vessel (Vessel A)

(a) Usage condition of Crane No.3

Judging from clauses 2.6.3(2)(a), 2.8, and 2.14.1, Crane No.3 had 35-ton hoist gear and

320-ton hoist gear. It is considered probable that the Crane used the 320-ton hoist gear when hoisting a cargo heavier than 35 tons.

It is considered probable that, when hoisting a cargo heavier than 100 tons, the member of Vessel A's crew who holds a Crane operator certificate (issued by the Republic of the Philippines) operated the Crane. In addition, other crew member adjusted the ballast each time the Main Wire load increased by 20 tons.

Therefore, at the time of hoisting the Cargo, it is considered probable that O/S A operated the 320-ton hoisting gear of the Crane, and other crew member was adjusting the ballast of Vessel A as the load increased in increments of approximately 20 tons.

(b) Maintenance status of Crane No.3 by Vessel A crew

Judging from clause 2.7(1), it is considered probable that the crew of Vessel A performed maintenance according to the PMS provided by Company A.

(c) Inspection status of Crane No.3

Judging from clauses 2.1.1 and 2.7(2), it is considered probable that, after having been in service for five years, the Main Wire of Crane No.3 was replaced on August 2008 in a dockyard in Shanghai ,People's Republic of China, and subsequently passed the load test according to the GL rules, whereby 1.1 times the nominal load (i.e., 352 tons) was applied.

(d) Usage status of Crane No.3 after the inspection

Judging from clause 2.8, it is considered probable that, after the inspection, Vessel A loaded two cargoes (approximately 227 and 200 tons) into the No.4 hold in Masan port, Republic of Korea using Crane No.3, and then a cargo of approximately 321 tons into No.3 hold in Hanshin port, Kobe Quarter using Cranes No.2 and No.3 in combination, wherein Crane No.3 showed no abnormal behavior or irregularities.

(3) Condition of Vessel (Vessel B)

Judging from clauses 2.6.4 and 2.14.3, Vessel B was a barge with its hold located in the center of its hull, and it is considered probable that the personnel were positioned as follows: Operator B at the bow, Stevedore C6 at the starboard side of the bow, Stevedore C7 at the portside of the bow, Stevedore C3 at the portside of stern, Stevedore C5 near the center of stern, Stevedore C1 on the starboard side of the deck, and Stevedore C2 on the starboard side of the stern and C4 on the portside of the stern inside the hold.

3.2.2 The Position where the Cargo Fell in Vessel B

Judging from clauses 2.1 and 2.3.2, and from the fact that the hole was created nearly at the center of the bottom of Vessel B's hold, it is considered probable that the Cargo fell and hit Vessel B's hold, near the center.

3.2.3 Background of the Accident

(1) Hoisting Load and Outreach of Crane No.3 at Time of Loading the Cargo

Judging from clauses 2.1.4, 2.6.3(2), and 2.14.1, it is considered probable that the Crane was hoisting the Cargo at a constant speed (load meter indicated about 290 tons) from Vessel B's hold without excessive load variation until the accident occurred. Therefore, it is considered probable that the hoisted load never exceeded the Safe Working Load.

It is also considered probable that Crane No.3 was used within the maximum outreach through all the hoisting procedures of the Cargo.

(2) Condition of the Main Wire

Judging from clauses 2.10.4(1) and (2), it is considered probable that there were no irregularities in terms of the quality of the Main Wire, as exemplified by the visual inspection, shape inspection, and actual measurements performed after the accident.

(3) Strength of the Main Wire and Load during Actual Usage

Judging from clauses 2.10.1(2) and 2.10.4, it is considered probable that the breaking load of the Main Wire was approximately 607 tons, based on a strand strength test (sum of strengths of all strands), and approximately 655 tons, based on the GL inspection certificate. In the strand strength test, 25% of strands are actually tested and the breaking load of a wire is calculated by summing up the contributions from all strands. Therefore, it is considered probable that the discrepancy in these values is caused by the strength variation of each strand. The maximum load imposed on the Main Wire of Crane No.3 was approximately 172 tons or less, assuming that it was operated under its Safe Working Load condition or below. Therefore, it is considered probable that the load imposed on the Main Wire was below its breaking load.

(4) Safety Control at Time of Accident: the Contract Company and Company C

Judging from clause 2.15, it is considered probable that, at the time of the accident, both the Contract Company and Company C provided safety instructions to the stevedores before they started their work. These instructions were based on the safety instruction documents and work standards, and included information on the Cargo, on the necessity of a helmet and safety shoes, and on the avoidance of activities directly under the Cargo.

It is also considered probable that safety precautions were taken on the ship. These include: a crew meeting on the cargo-handling method, a safety check of the Crane (operational status of the Crane, check for wire irregularities), and a safety patrol during the loading operations by the person in charge of labor safety from Company C.

3.3 Matters Contributing to Determination of the Cause of the Accident

3.3.1 Rim Fracture in Main Sheave C

(1) Processing Method of the Main Sheave

(a) Processing of the rim

Judging from clauses 2.10.2, 2.10.3, and 2.11.2, it is considered probable that the rim was manufactured from a narrow angle side of an L-shaped angle steel material (radius 16 mm). The material was bent and shaped through cold forming so that its wire-guiding surface has a 38 mm groove radius.

(b) Material components and mechanical characteristics of the rim

Judging from clauses 2.10.5(1)(b),2.10.5(2), 2.10.5(4), and 2.11.2, it is considered probable that, through the elongation and narrowing down processes during the rim production, the surface of the rim underwent substantial hardening, and this caused significant ductility reduction. Although component analysis indicated that the rim satisfied the requirements listed in the mill sheet at the time of manufacture, an impact test revealed that some portions of it had Charpy values much lower than those required by DIN.

(c) Back side of wire-guide surface

Judging from clauses 2.10.5 (1)(e), 2.10.5 (2), and 2.11.2, both in Main Sheave C (fractured) and Main Sheave E (un-fractured), it is certain that there were small crack-like overlappings and rolled-in scale on the backside of the wire-guide surfaces, caused by metal rolling. The same types of cracks were also found in the unprocessed L-shaped angle steel and they were filled with oxidized scale. Consequently, it is considered probable that the cracks were formed during the production of L-shaped angle steel.

(d) Residual stress inside the rim

Judging from clause 2.10.5(3), unremoved residual stress remained in the rim, which was caused by the cold forming during its production process and web welding process. Therefore, it is considered probable that unremoved residual stress remained in the rim of Main Sheave C as well.

(e) Manufacturing process of the Main Sheave

Judging from clauses 2.10.5 and 2.12, it is considered probable that the hardness of the rim surface increased by the cold forming of the sheaves and the manufacturing process of the Main Sheave had some faults because 37 out of 90 Main Sheaves sampled from Vessel A and its sister ships were confirmed to have faults (all ships are under the management of the Ship Management Company A).

In the meanwhile, judging from clause 2.12.1, it is considered that the Crane Manufacture has constructed the Crane using the same type sheaves of Vessel A, however the Crane Manufacture has never heard of a problem or a damage like this, and the Sheave Manufacture has an approval certificate for the manufacturing of this type of sheaves and are under continuous surveillance by many classification societies such as GL.

(2) Circumstances Surrounding Fracture of Main Sheave C

(a) Fractured surfaces

Judging from clauses 2.10.5(1) and 2.11.2, the fracture took place around the entire circumference, and a cleavage fracture was observed in many of the fractured surfaces. Although dimples were observed in some of the fractured surfaces that faced the wire guide surface, fatigue breakdown was not observed. Therefore, it is considered probable that brittle fracture took place in the rim.

(b) Situation of Welded Parts between the Rim and Web

Judging from clauses 2.10.5(1)(c) and 2.11.2, although some incomplete penetration parts were found in the welded parts between the rim and web, it is considered probable that these incomplete penetration parts were not the direct cause of the rim fracture, because the crack propagation root face did not pass through the welded root.

(c) Cracks on backside of Wire Guide Surface

Judging from clause 2.9, the inspection immediately after the accident indicated the existence of rust on the rim fracture surfaces of the backside of the wire guide surface. Therefore, it is considered probable that some cracks already existed even before the accident.

(3) Progress of Rim Fracture

Judging from clauses 2.10.5 and 2.11.2, it is considered probable that the origin of this accident can be attributed to the following factors. The rim had small cracks in its backside portion of the wire guide surface (the cracks were originally created in the manufacturing process of the angle steel from which the rim was produced) and its surface was hardened due to the cold forming used in its manufacture, resulting in ductility reduction. In addition, residual stress was not completely removed from the rim. As a heavy cargo weighing approximately as much as the Safe Working Load was hoisted, conditions that allow brittle fracture were created inside the rim, and stress was concentrated at the pointed tips of the cracks already existing in the rim (distributed in the backside portion of the wire guide surface), thus finally resulting in brittle fracture along the cleavage surface.

3.3.2 Analysis of Fracture in Main Sheave C Based on FEM Measurements

Judging from clause 2.11.4, it is considered somewhat likely that the combination of the following factors could occur in the rim during the use of Crane No.3, leading to brittle fracture: tension P on the Main Wire due to the Cargo, stress σ_s acting on the surface cracks in the backside of the rim's wire guide surface, the depth of the cracks, the strength of Charpy value Cv, and residual stress.

3.4 Causal Factors of the Accident

3.4.1 Break in the Main Wire

(1) Situation of the Main Wire at Time of Accident

Judging from clauses 2.10.4 and 2.11.1, it is considered probable that there were no defects in the Main Wire in terms of quality, and it was used in conditions below its breaking load.

(2) Cause of the Main Wire Break

Judging from clauses 2.10.5(1), 2.10.5(2), 2.10.7, 2.11.2, 2.11.4(1), 2.14.4, 2.14.5, and 3.3.1(3), it is considered probable that the following factors caused the break:

(a) When the conditions for brittle fracture were met, the fracture propagated instantaneously around the entire circumference of the rim of Main Sheave C.

(b) Tension on the Main Wire was sharply reduced due to the fracture of the entire circumference of the rim, and then the Main Wire dropped into the gap caused by the fracture and came to a stop on the hub, when a jolting overload larger than its break load was inflicted on the wire, leading to a break.

3.4.2 Situation Leading to the Death of Stevedore C1

Judging from clauses 2.1, 2.2, 2.3.1, and 2.14.3, it is considered somewhat likely that, at the time the Cargo fell, Stevedore C1 fell overboard due to being hit either by a Main Hook Block or a Grommet that fell concurrently with the Cargo. However, it could not be determined what the details of the situation were.

It is considered probable that Stevedore C1 was found on the sea bottom by the divers who were searching for him and confirmed dead in early evening of the day of the accident.

3.4.3 Situation Leading to Injuries of Stevedore C2–C7 and Operator B

Judging from clause 2.14.3, it is considered probable that three Stevedores (C2–C4) were bruised when the Cargo fell into the hold of Vessel B either by the impact or when thrown overboard. In addition to these three, Stevedore C5 was also thrown overboard. It is considered probable that all these four were rescued by the vessel that were near the accident location.

It is considered probable that the other three persons who were posted on the bow (Stevedores C6, C7, and the Operator B) were able to move to the barge that came alongside (portside) Vessel B. Immediately after the Cargo fell, Vessel B turned its head leftward and its portside bow came into contact with the barge to its immediate portside, thus enabling the three persons to escape.

3.4.4 Results of Main Sheave Inspections: Cranes No.2 and No.3 of Vessel A's Sister Ships

Judging from clause 2.12, it is considered probable that Main Sheaves containing cracks were also used on ships other than Vessel A: after the accident, investigation was conducted of the Main Sheaves of Cranes No.2 and No.3 onboard the other sister ships of Vessel A, and many cases were found, in addition to the case of Vessel A's Crane No.3, where the Main Sheaves had been replaced.

4 CONCLUSIONS

4.1 Findings

(1) It is considered probable that this accident occurred while Vessel A was hoisting the Cargo using onboard Crane No.3 from Vessel B at No.3 pier of Yamashita wharf in Section 1 of Yokohama Quarter, Keihin port, rim fracture in Main Sheave C caused the Main Wire to break and the Cargo fell along with the Main Hook Block and grommet onto Vessel B, as a result, one stevedore was killed and three of them suffered bruises.

(2) It is considered somewhat likely that, at the time the Cargo fell, Stevedore C1 who wore a helmet and safety shoes on the starboard side of the deck was hit either by a Main Hook Block or a Grommet that fell concurrently with the Cargo.

It is considered probable that, at the time the Cargo fell, Stevedore C2 in the starboard stern side of the hold, Stevedore C3 on the portside stern of the deck and Stevedore C4 in the port stern side of the hold who wore helmets and safety shoes suffered bruises by the impact when the Cargo fell into the hold of Vessel B or they entered the water.

(3) It is considered probable that tension on the Main Wire was sharply reduced due to the fracture of the entire circumference of the rim, and then the Main Wire dropped into the gap caused by the fracture and came to a stop on the hub, when a jolting overload larger than its break load was inflicted on the wire, leading to a break.

(4) It is considered probable that : the rim had small cracks in its backside portion of the wire guide surface (the crack were originally created in the manufacturing process of the angle steel from which the rim was produced) and its surface was hardened due to the cold forming used in its manufacture, resulting in ductility reduction. In addition, residual stress was not completely removed from the rim. As a heavy cargo weighing approximately as much as the Safe Working Load was hoisted, conditions that allow brittle fracture were created inside the rim while Crane No.3 was in operation, thus finally resulting in the break.

(5) It is considered probable that, through bending and shaping the material by cold forming and the elongation and narrowing down process during the rim production, the surface of the rim underwent substantial hardening, and caused significant ductility reduction.

4.2 Probable Causes

It is considered somewhat likely that :

This accident occurred while Vessel A was hoisting the Cargo, using onboard Crane No.3, from Vessel B at No.3 pier of Yamashita wharf in Section 1 of Yokohama Quarter, Keihin port. The Main Wire broke while hoisting the Cargo, and it fell along with the Main Hook Block and Grommet onto Vessel B. Stevedore C1 was hit by either the falling Main Hook Block or Grommet, and three of the other stevedores entered the water by the impact when the Cargo fell into the hold of Vessel B. It is considered somewhat likely that this accident was caused by the fracture of Main Sheave C that occurred in the hoisting operation, during which the Main Wire dropped into the fracture gap of the rim causing the wire to break.

It is considered probable that the fracture in Main Sheave C was caused by the following factors: existence of small crack-like in the backside of the wire guide surface (possibly created in the manufacturing process of the angle steel, from which the rim was produced), significant surface hardening that occurred during the rim manufacturing that caused ductility reduction, unremoved residual stress, and the hoisting of the Cargo, which was almost of a weight equal to the Safe Working Load. It is considered that all these factors combined created a brittle fracture condition while Crane No.3 was in operation.

It is considered probable that the following steps finally led to the breaking of the Main Wire: a fracture occurred in Main Sheave C at the front end of the jib, and when the Main Wire dropped into the gap caused by the fracture and came to a stop at the hub, the Main Wire was impacted by a jolting overload that exceeded its breaking load.

5 SAFETY RECOMMENDATIONS

The Japan Transport Safety Board, based on the result of the accident investigation, recommend as follows to Crane manufacturers in order to prevent the recurrence of similar casualties.

It is considered somewhat likely that this accident was caused in the following sequence. While Crane No.3 of RICKMERS JAKARTA was hoisting the Cargo, the rim of Main Sheave C at the extremity of the jib fractured, causing the Main Wire's precipitous drop into the gap caused by fracture. This caused a break in the Main Wire, and also, finally, the fall of the Cargo, Main Hook Block, and grommet onto SHIN EI- MARU No.18.

This accident occurred in spite of the fact that Crane No.3 passed a load test three weeks earlier, and later investigation revealed the occurrence of brittle fracture on the fractured surface of Main Sheave C and various sized cracks were observed on Main Sheave E's surface. In the face of these findings, Crane manufacturers should, when they produce a rim that requires strong bending and shaping processes as a part of a weld construction sheave, perform proper control of manufacturing processes, including the selection of materials.

6 ACTIONS TAKEN

6.1 Actions taken by Vessel A and Ship Management Company A

According to the written reply to the questionnaire from Ship Management Company A, the following actions were taken.

6.1.1 Actions taken by Ship Management Company A

(1) Inspection and Replacement of Main Sheave C

Immediately after this accident occurred, Ship Management Company A notified the occurrence of the accident to the Crane Manufacturer and GL, and imposed a ban on the use of the 320-ton hoisting winches of Cranes No.2 and No.3 onboard Vessel A and its eight sister ships until the Main Sheave was thoroughly examined and the problem was resolved.

Subsequently, a detailed inspection on the Main Sheave was carried out, and all Main Sheaves within which a crack was detected were replaced. Ship Management Company A lifted the ban on the condition that a thorough check of the Main Sheave be carried out prior to the start of cargo handling operation.

In addition, Ship Management Company A and the Crane Manufacturer investigated the cause of the accident, and manufactured an improved type of Main Sheave. Improvements included the change of rim material to S355J+M, which features enhanced ductility, and the re-engineering of production procedures. All 90 Main Sheaves onboard the Vessel A and its eight sister ships were replaced with the improved sheaves under the supervision of inspectors from the Crane Manufacturer and GL.

(2) Guideline Document

Ship Management Company A prepared a guideline document, intended for use on Vessel A, that lists usage instructions and maintenance/inspection procedures and also requires the visual inspection of sheaves and reporting every six months. Ship Management Company A distributed this document to all of its ships as a means of stricter guidance.

6.1.2 Actions Taken by Vessel A

Under the guidance of Ship Management Company A, the crew of Vessel A ensured thorough undergoing of inspections prior to the start of cargo handling operations and maintenance/service procedures pursuant to PMS.

6.2 Actions Taken by the Crane Manufacturer

According to the written reply to the questionnaire from the Crane Manufacture, the Sheave Manufacture carried out the following measures and the Crane Manufacture accepted the measures.

(1) Additional material test for the angle profiles used for the cold forming of rims and if found necessary, another test prior to the cold forming.

(2) A hand grinding process of the inside of the rim in the area between the web plates has been added to remove possible small crack-like overlapping and rolled in scales.

6.3 Actions Taken by the Contract Company and Company C

According to the interviews and the written reply to the questionnaire from the person in charge of the Contract Company, the Contract Company accepted job safety instructions from the Labor Standards Inspection Office on December 5, 2008. In response to this, the Contract

Company and Company C prepared a remedial action plan as of December 25, 2008, and submitted it to the Labour Standards Inspection Office, Kanagawa Labour Bureau, Ministry of Health, Labour and Welfare.

Remedial actions are summarized below, and the Contract Company and Company C implemented these actions immediately.

(1) Safety of Workers Onboard a Barge while a Cargo is Being Hoisted

(a) When a person in charge of cargo handling draws up cargo handling procedures, he/she must incorporate due consideration to the area for worker evacuation in the plan.

(b) In the case of heavy cargo handling, the person in charge of cargo handling must share previously gained knowledge about the heavy cargo at the pre-work meeting.

(c) While the cargo handling is underway, the person in charge of cargo handling must make rounds of the work area, making sure that workers are handling cargoes while incorporating evacuation actions.

(2) Wearing of a Life Jacket during Operations Onboard a Barge

It is absolutely necessary for workers to put on a life jacket when they move to a barge. Workers are recommended to keep wearing the life jacket through their operations onboard a barge as long as possible.

(3) Checking of Operational Status Log of Cargo Handling Equipment

(a) An inspection certificate must be obtained from the ship when it arrives in port, and it must be checked thoroughly prior to the start of cargo handling

(b) Relevant documents (e.g., Crane's inspection certificate) from the ship must be copied and filed.

6.4 Actions Taken by GL

Based on the preliminary results at the early stage of this accident investigation, GL released a circular to GL-registered ship owners and ship management companies that recommends inspection of the sheaves that support a thick wire rope (diameter ≧ 28 mm) using a reliable instrument (e.g., ultrasonic testing) in addition to conventional visual inspection. Although sheaves are manufactured according to approved industrial standards, and therefore do not need approval from a classification society, GL assessed it appropriate that a larger sheave incorporated in a weld construction sheave of onboard decks receive enhanced inspection.

In regard to the Crane Manufacturer, GL approved the materials and manufacturing processes used to produce improved Main Sheaves, and administered an examination of the final product. With regard to the Main Sheave Manufacturer, GL administered an examination of the improved sheave and granted a manufacturing certificate.

Figure 1 – Site Map of the Accident

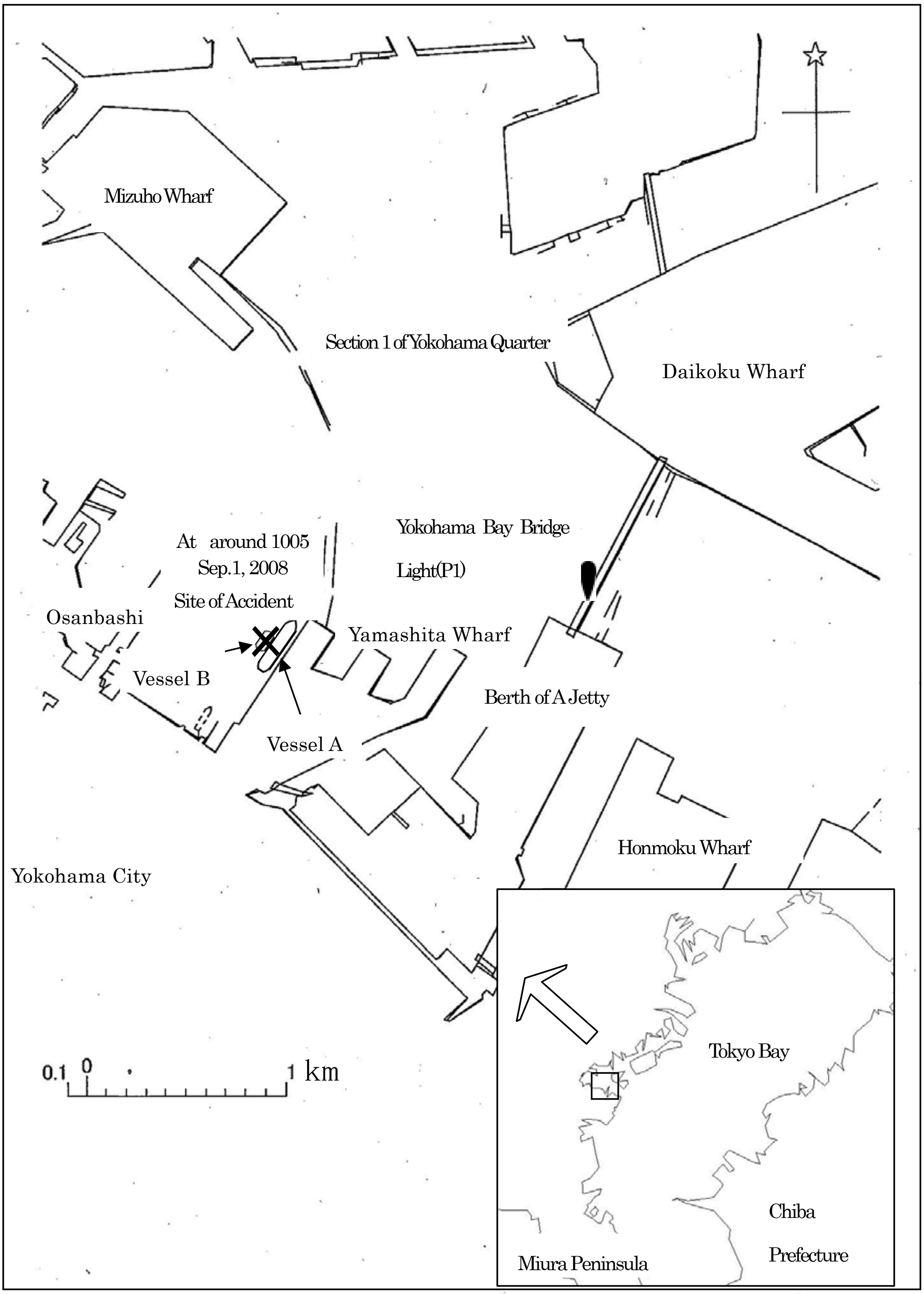


Figure 2—Vessel A General Arrangement

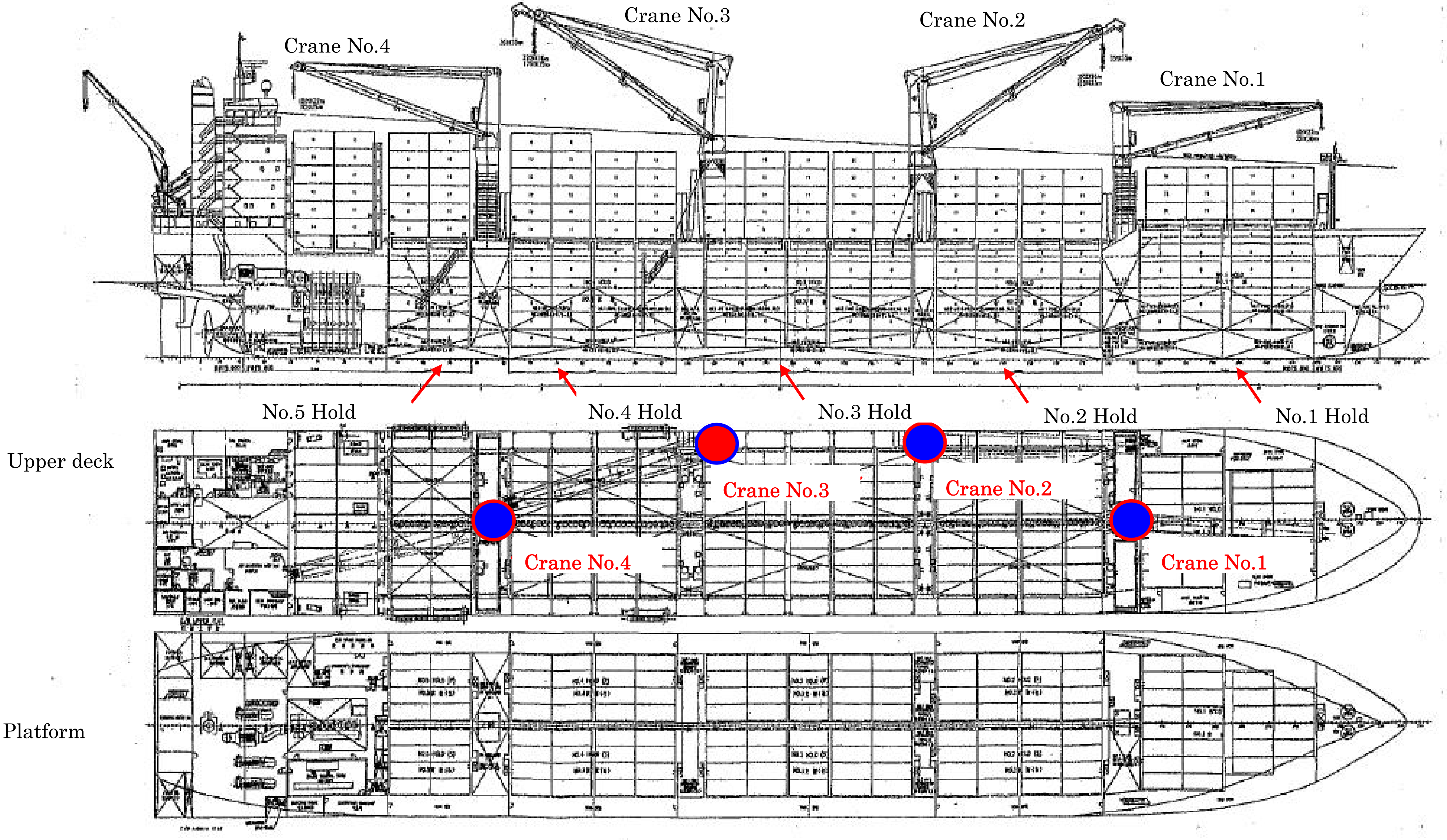
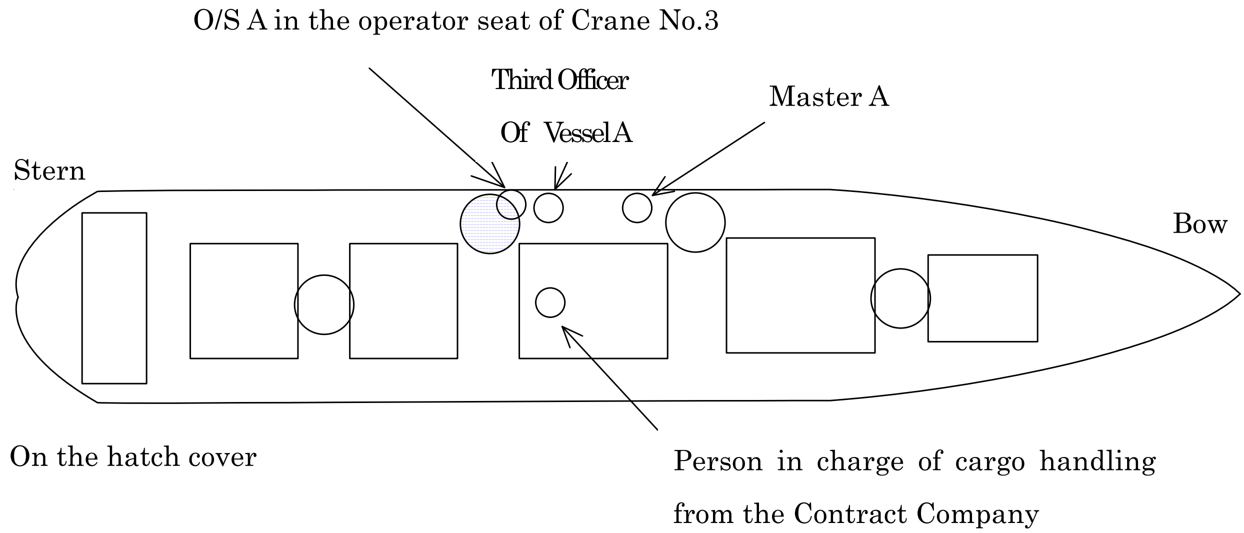


Figure 3—Positioning of Vessel A Crew and Stevedores on Vessel A



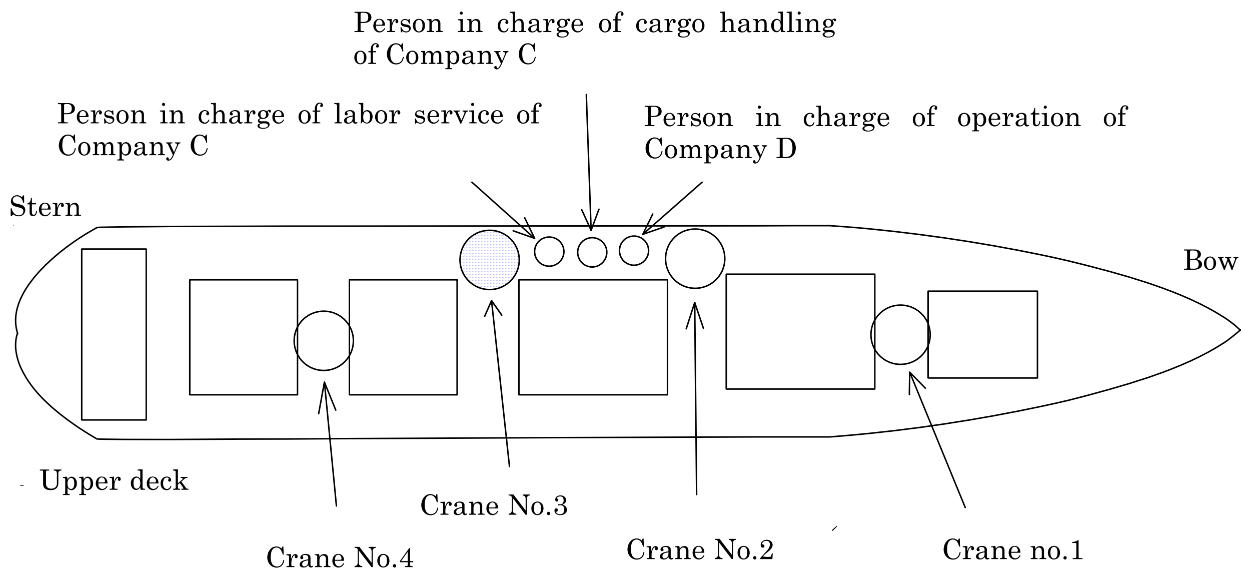
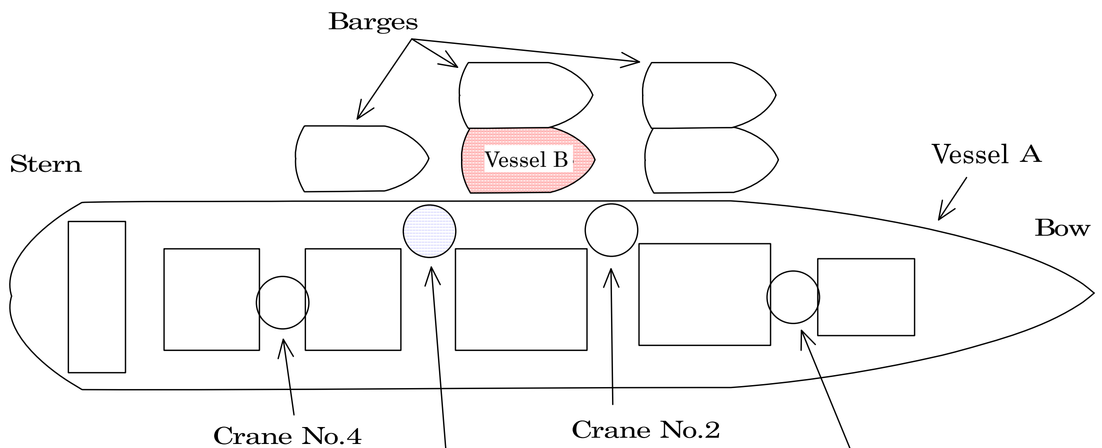


Figure 4—Vessel B Position at Time of Accident

a Vessel B Position



b Position of Stevedores and Person in Charge of Operation B on Vessel B

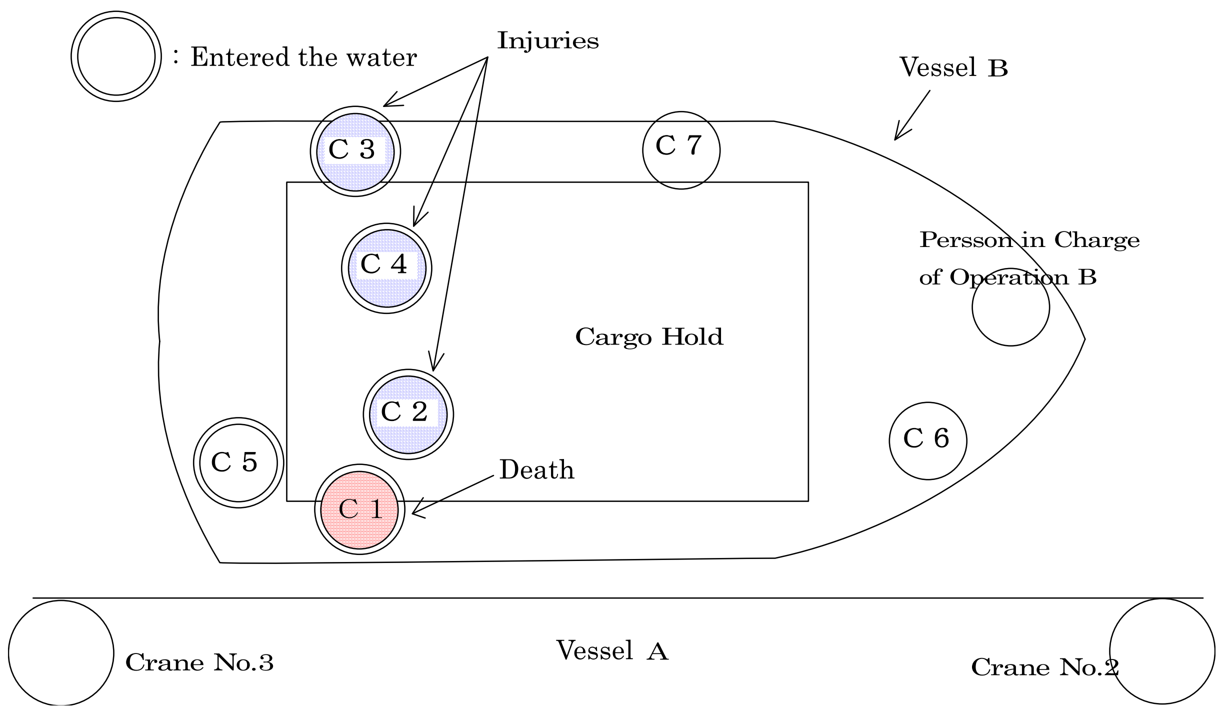


Figure 5—Machine Room Plan: Crane No.3

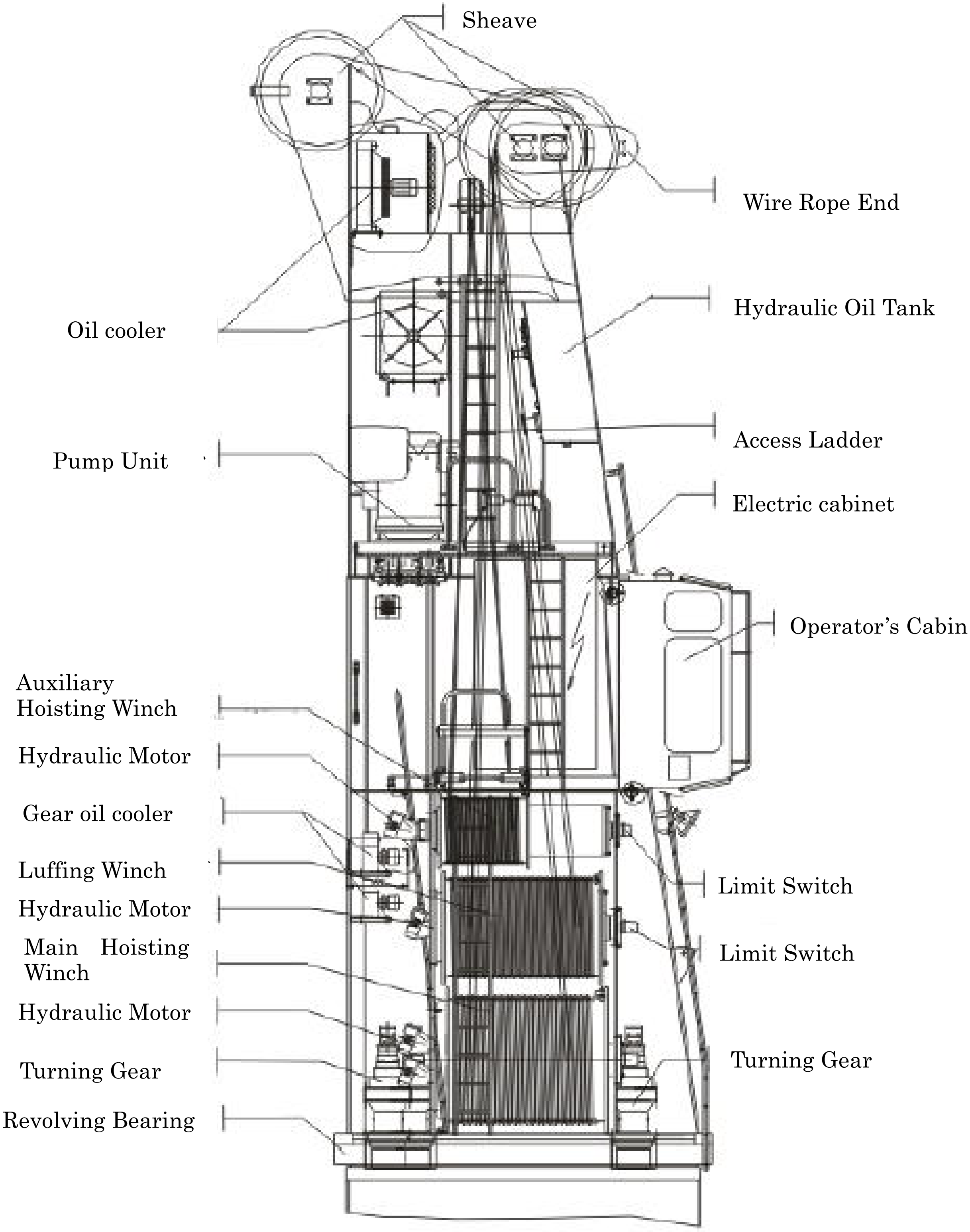


Figure 6—Rigging Plan

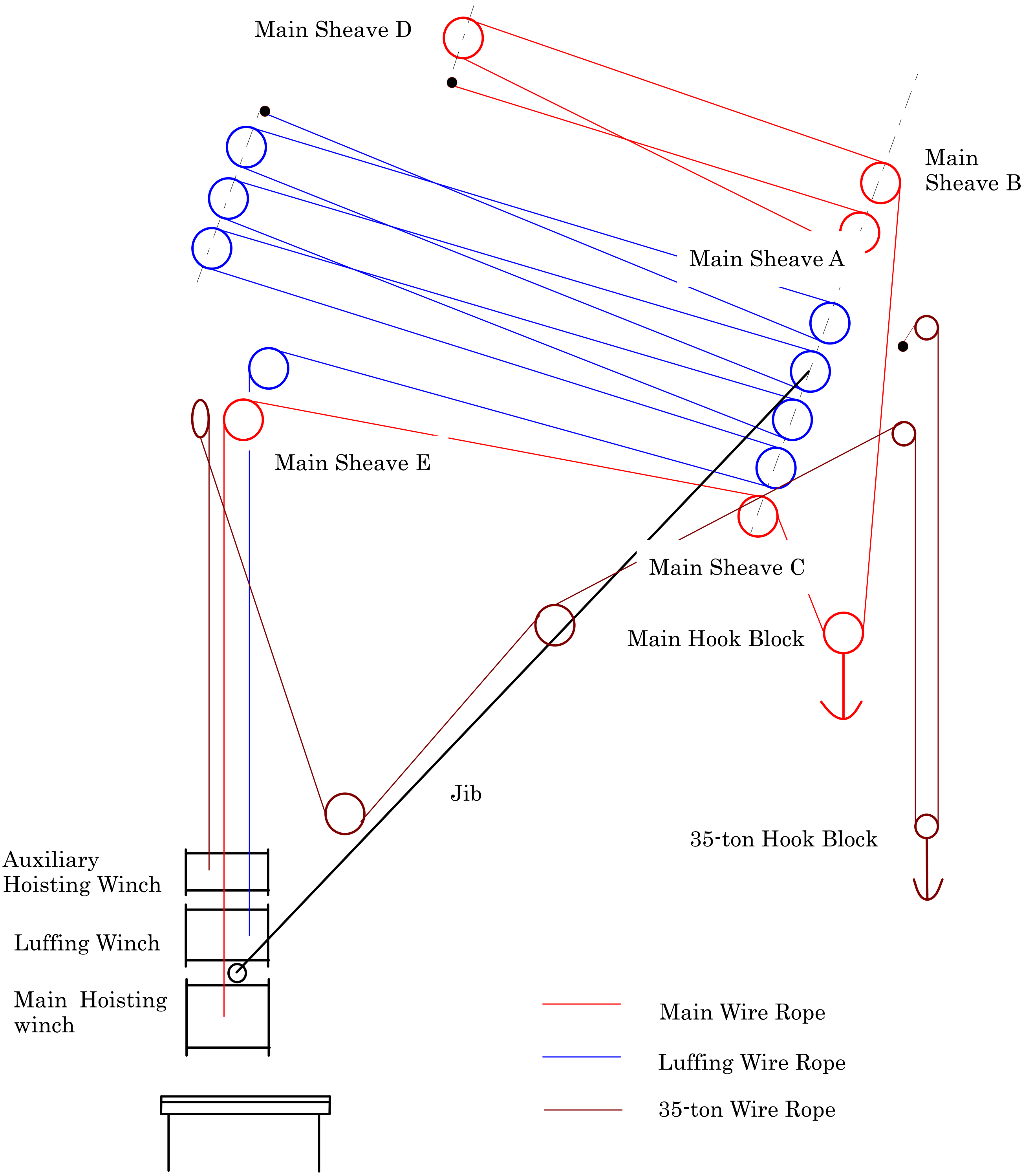


Figure 7—Jib and Sheave

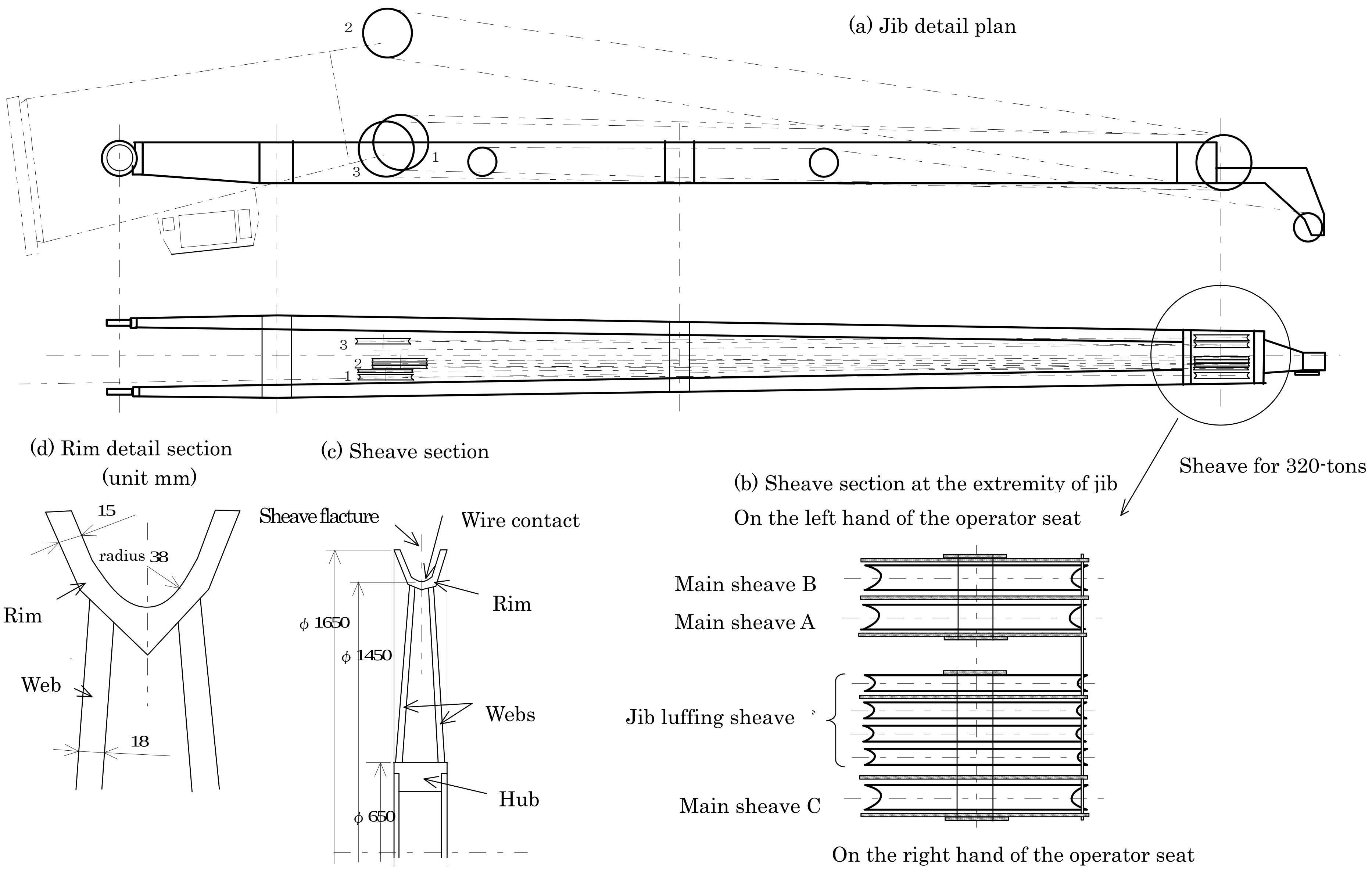
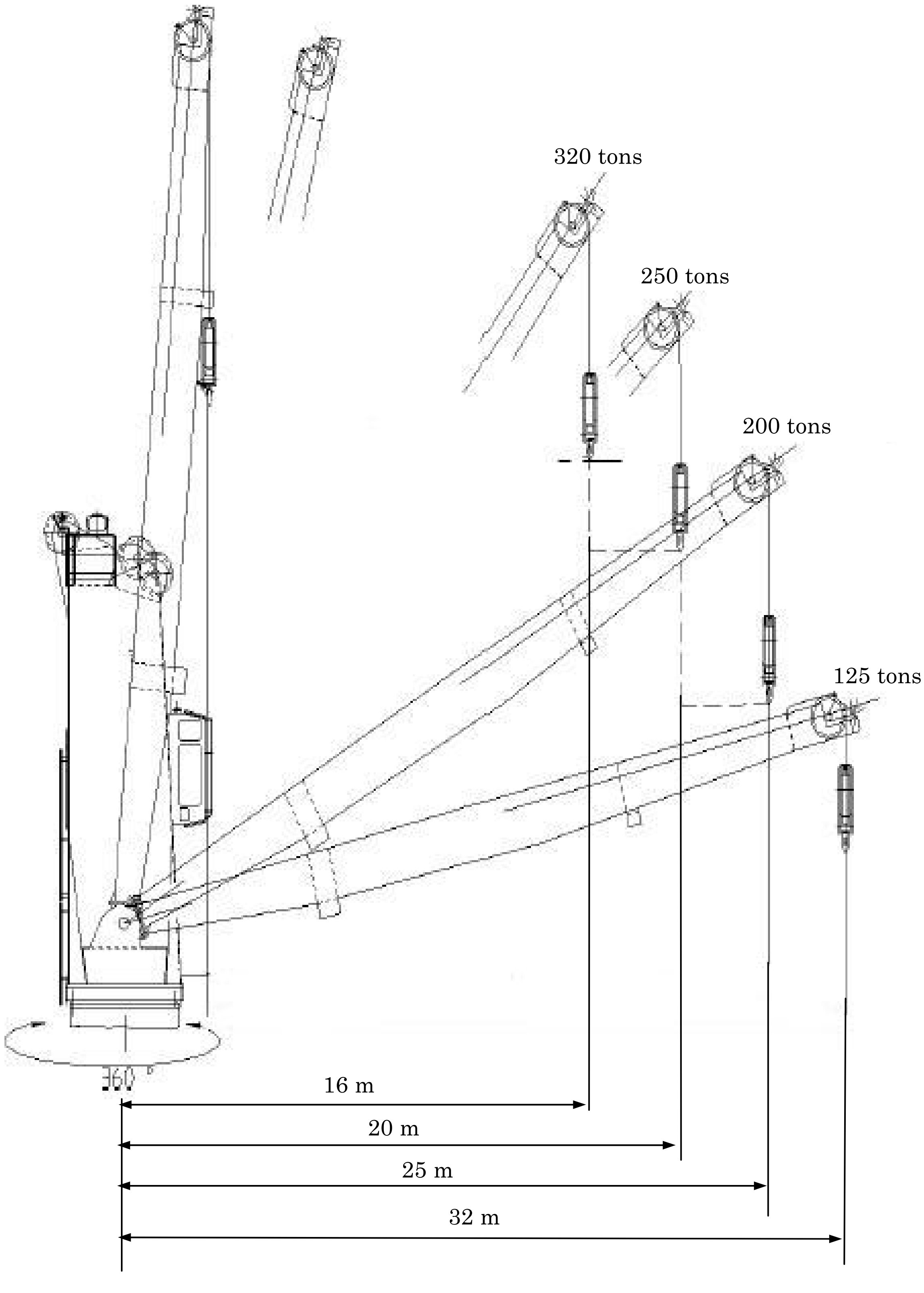


Figure 8—Safe Working Load and Maximum Outreach

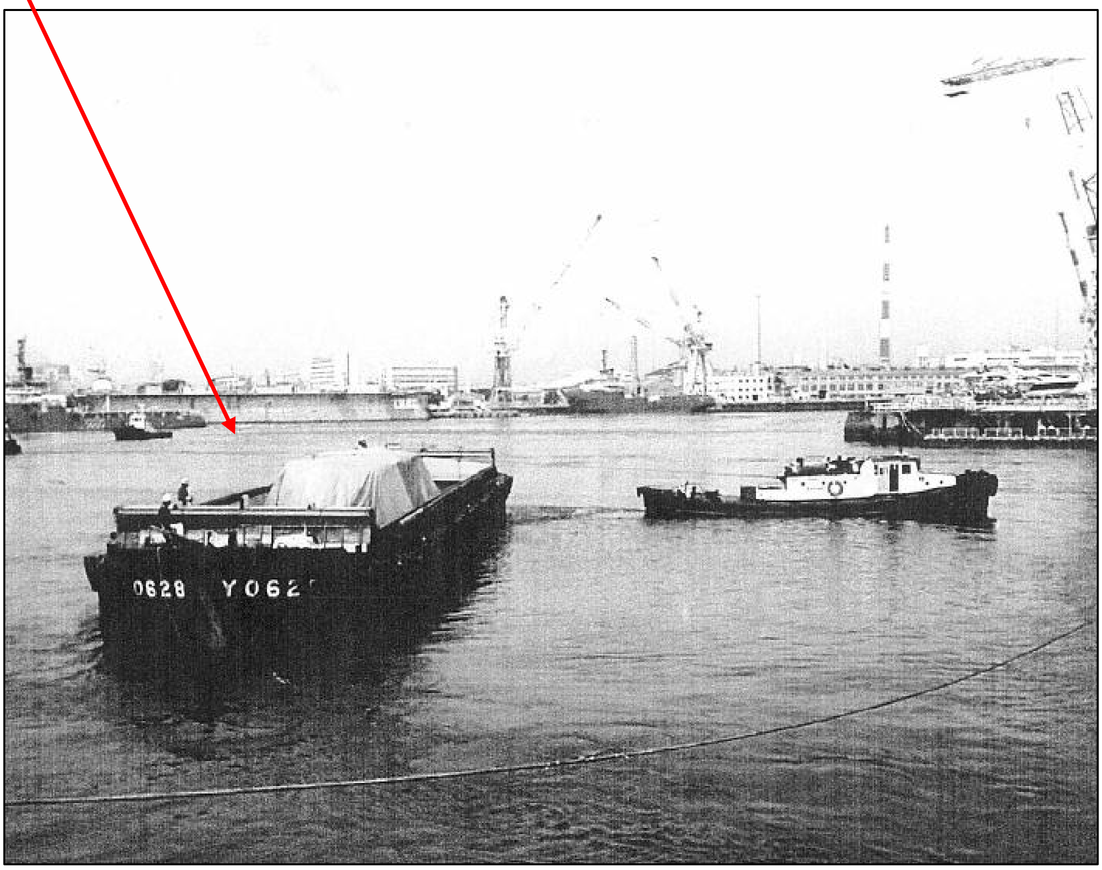


Picture 1—Full View of Vessel A (after the accident)

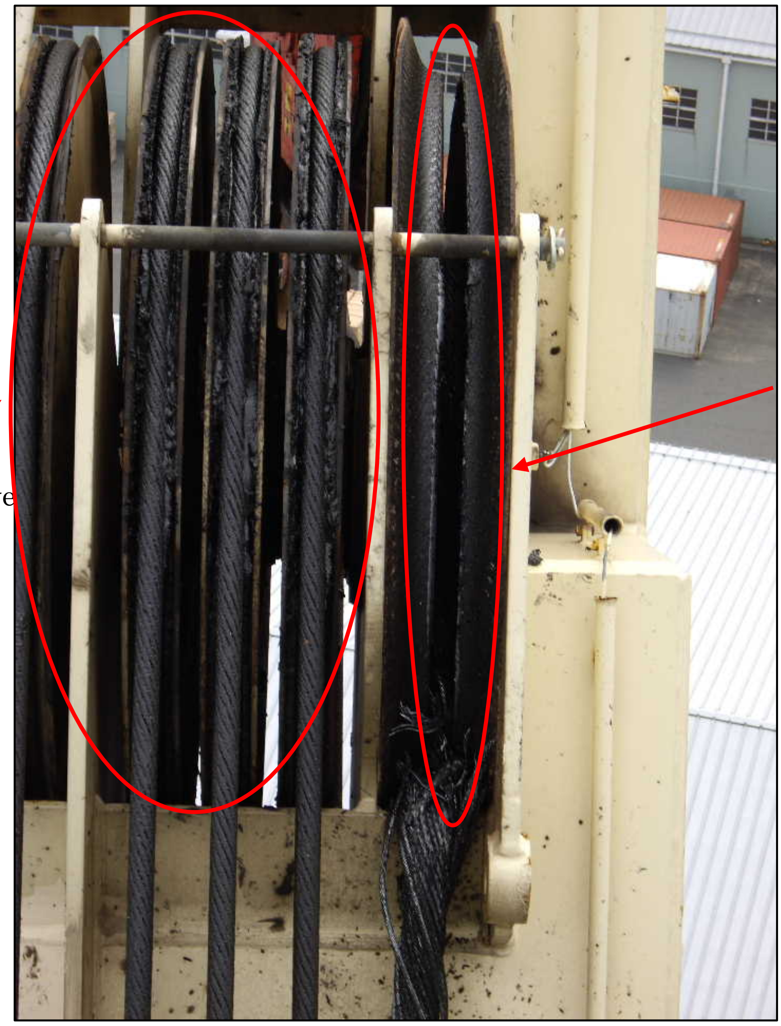
Crane No.1 Crane No.2 Crane No.3 Crane No.4

Vessel B

Picture 2—Full View of Vessel B (before the accident)

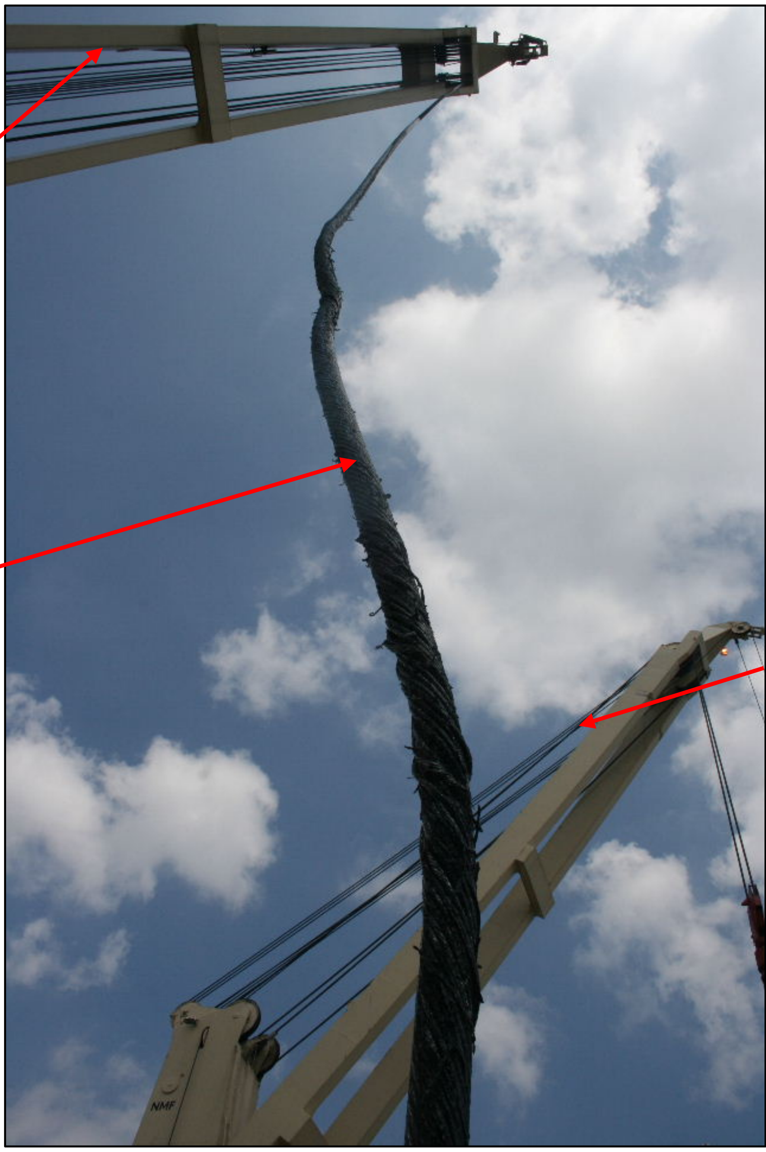


Picture 3—Sheaves at the end of Jib (Crane No.3)



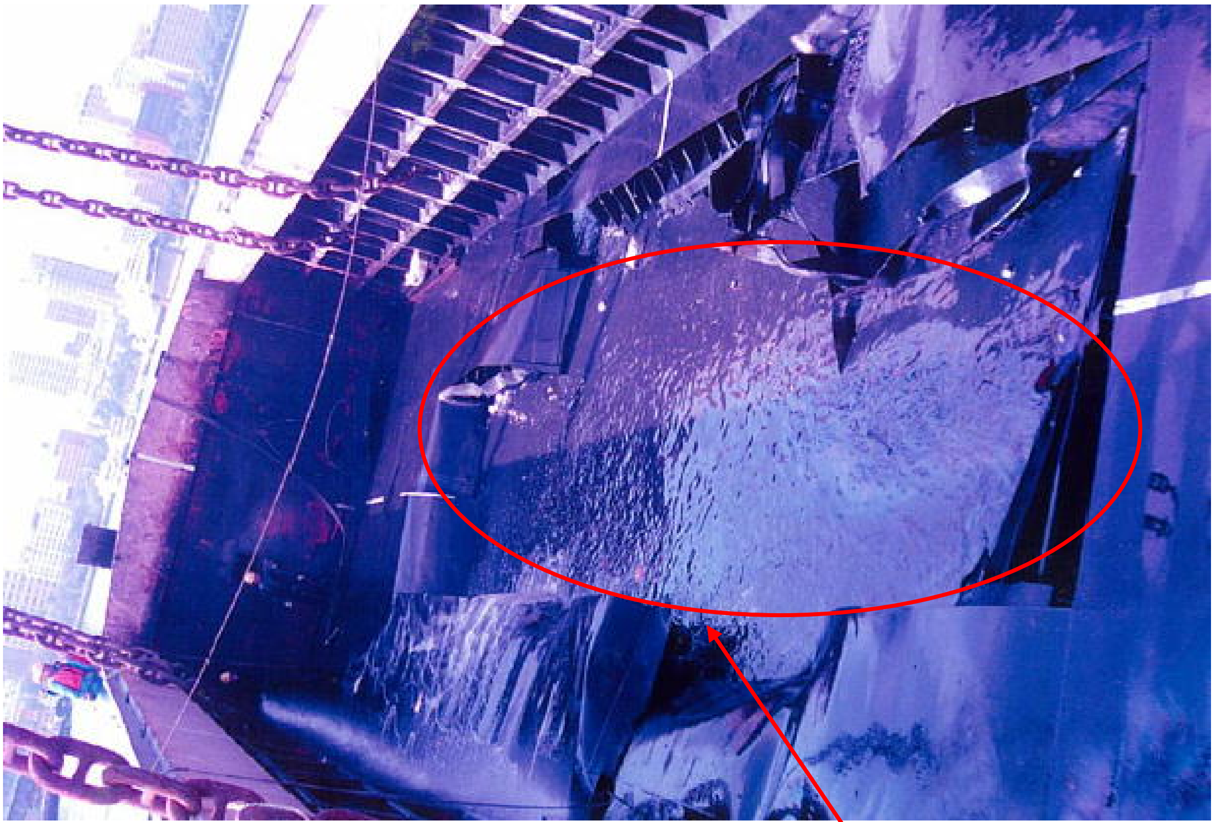
Picture 4—Front End of Crane No.3's Jib

Picture 5—Scene of the Accident (after it occurred)



Picture 6—the Main Wire at its Break Point

Picture 7—Vessel B Salvaged



Hole created by the accident

Picture 8—The Cargo

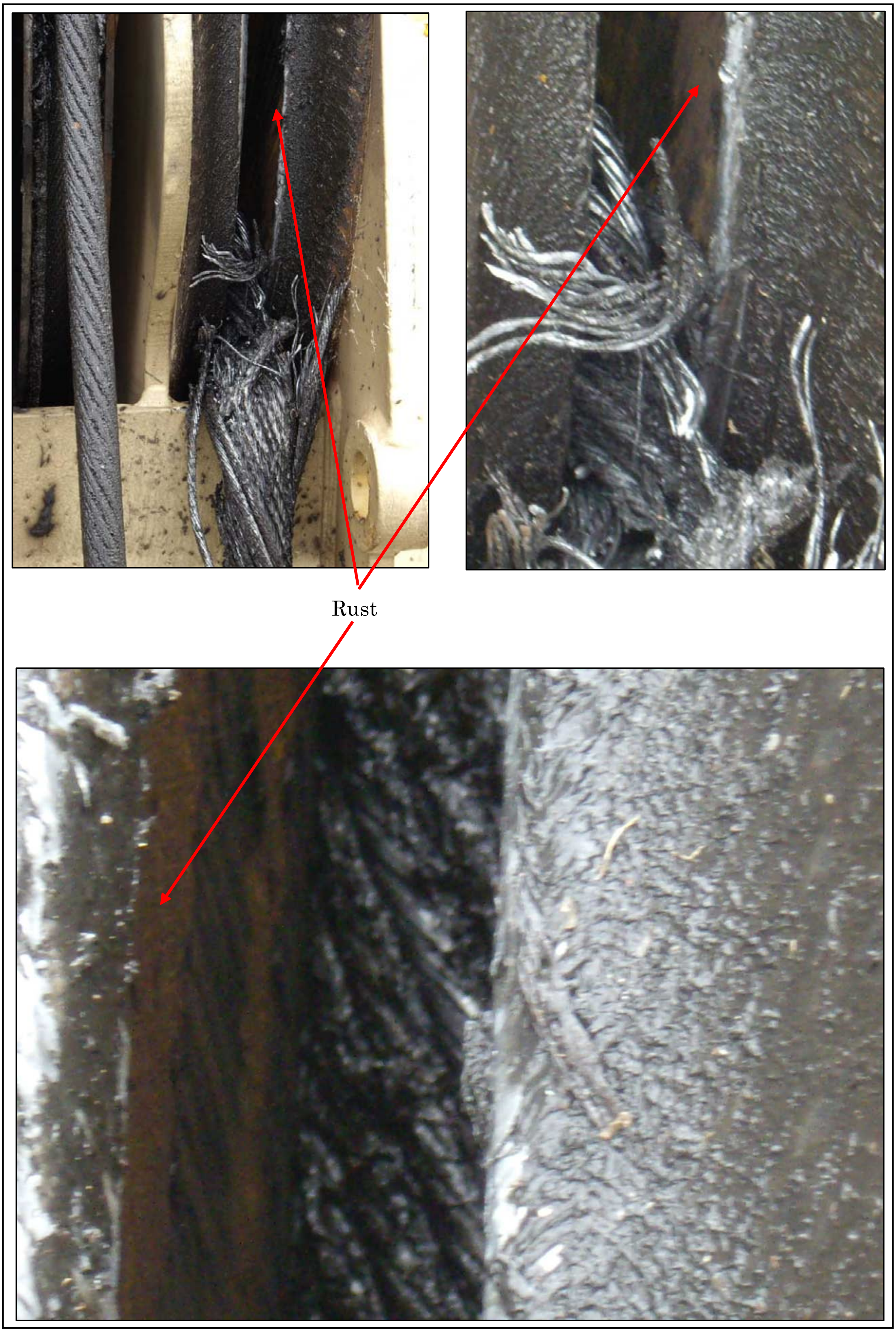
Hoisting attachment Grommet

Loading Operation (immediately before the accident)

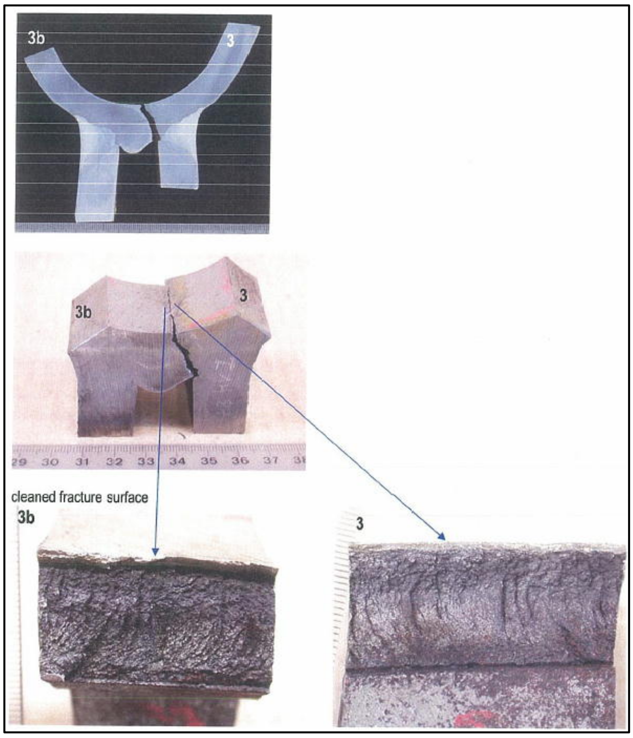
Salvage operation of the submerged cargo

Picture 9—Operator’s Cabin of Crane No.3

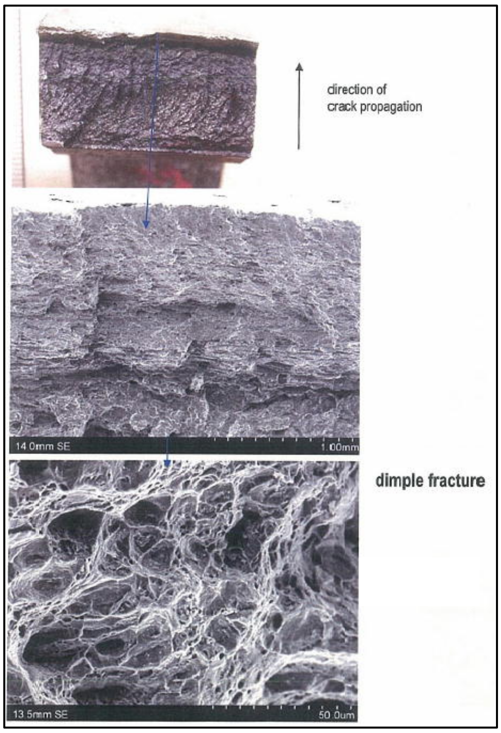
Picture 10—Fractured Main Sheave C and Rust Formation



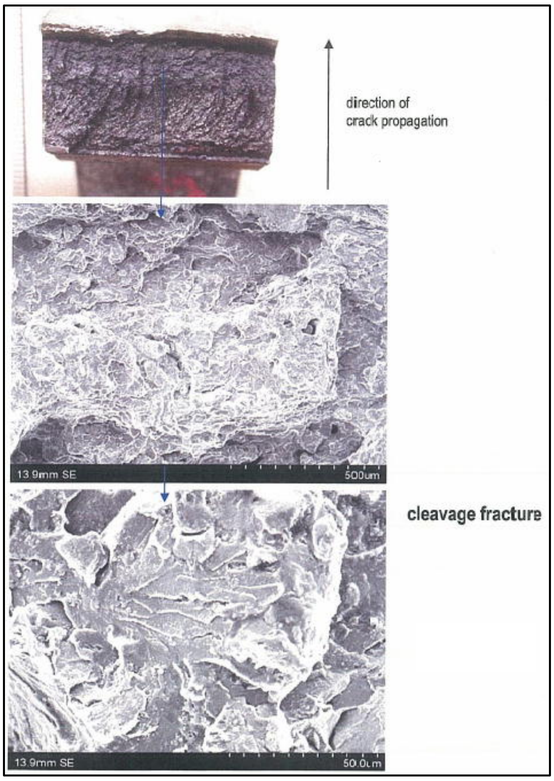
Picture 11—Inspection by Electron Microscope



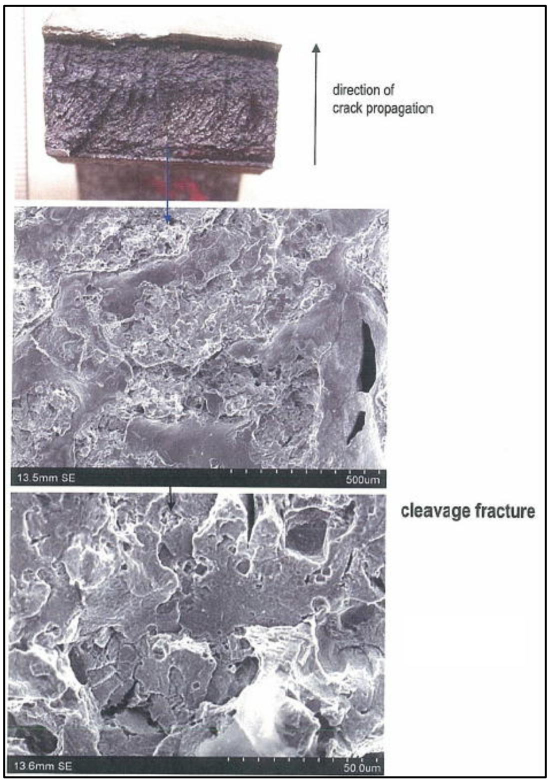
a Situation of rim's fractured surface



b Vicinity of wire contact surface

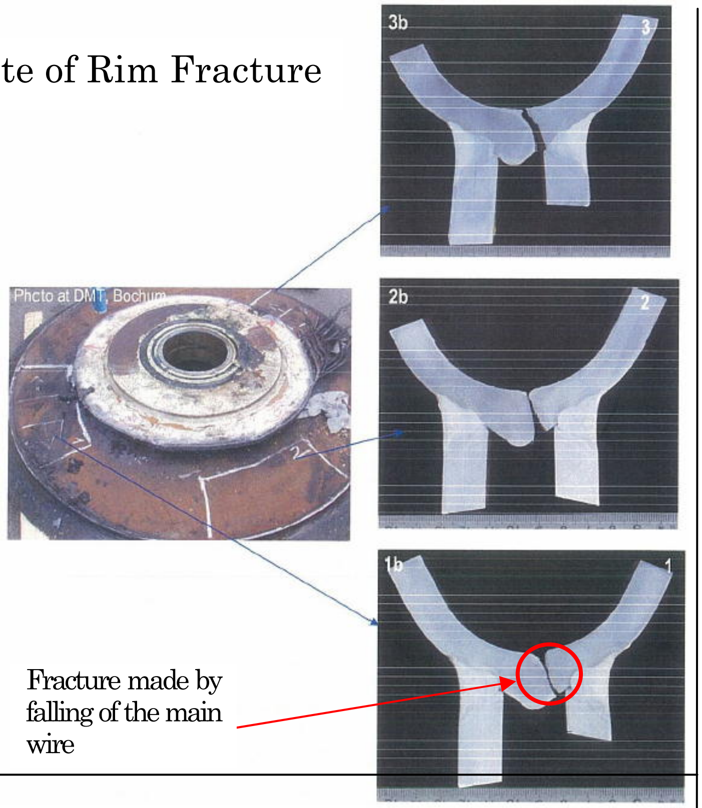


c Rim's fractured surface

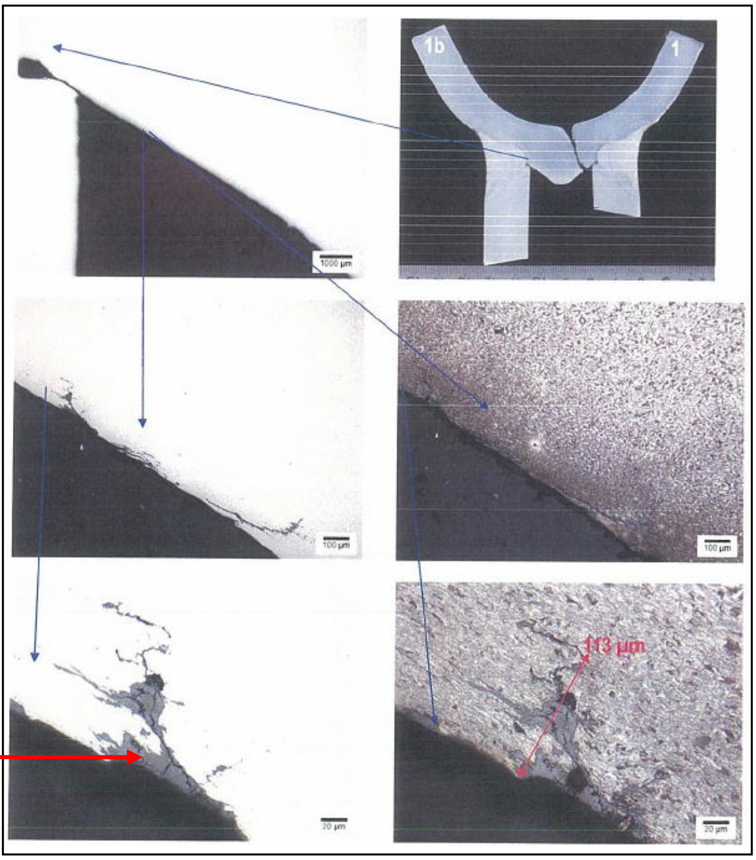


d Rim's fractured surface

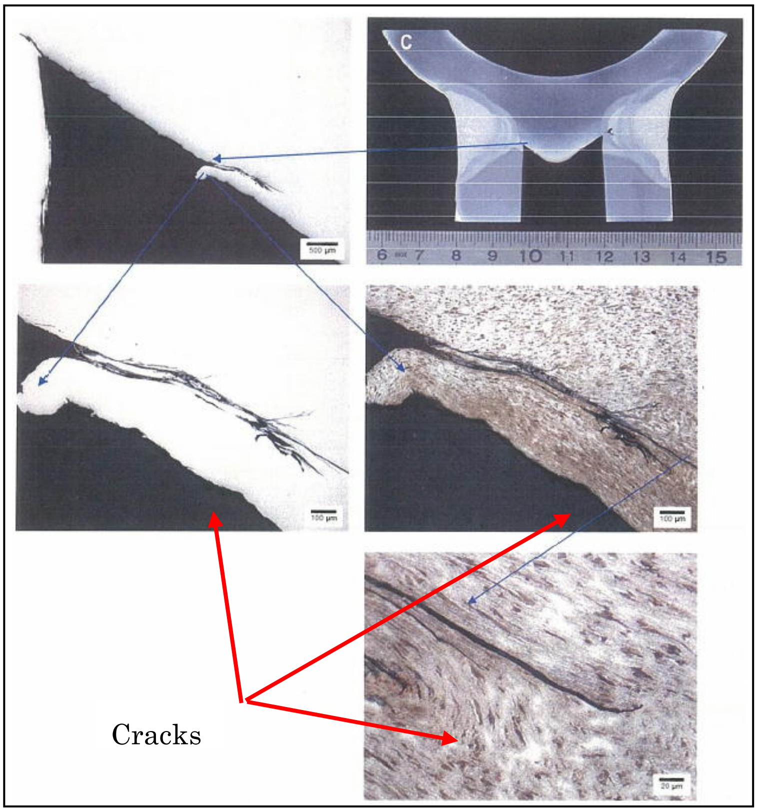
Picture 12—State of Rim Fracture

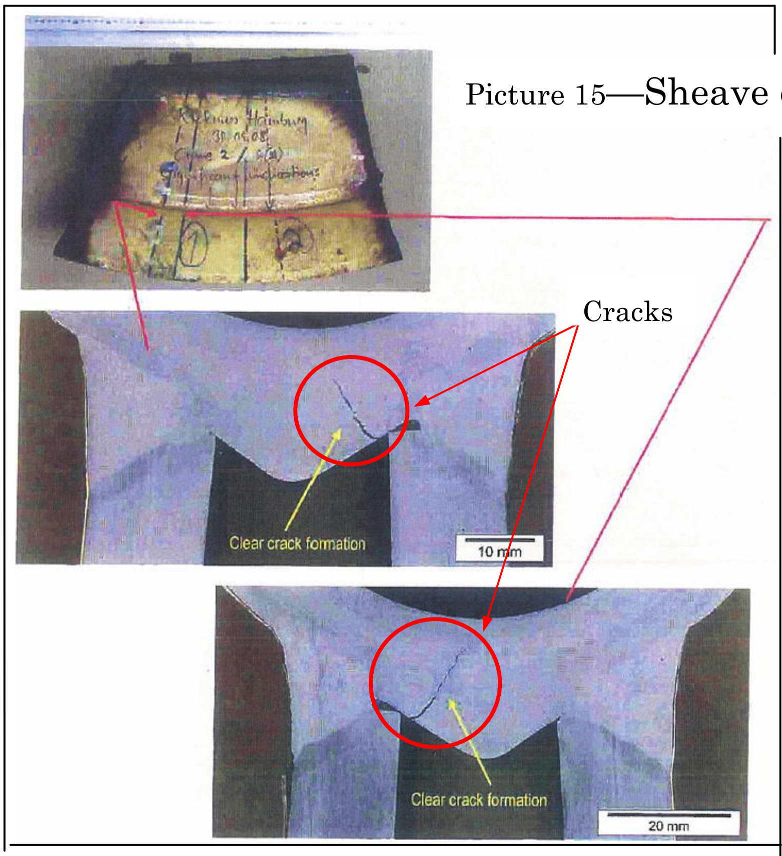


Picture 13—Backside of Wire Guide Surface (cracks found in Main Sheave C)



Picture 14—Backside of Wire Guide Surface (cracks found in unfractured Sheave E)





Picture 15—Sheave of a sister ship

Picture 16—Cracks found in Unused Sheave