Marine Safety Investigation Unit

Transport Malta

MARINE SAFETY INVESTIGATION REPORT

Failure of an overhead monorail crane wire rope, resulting in fatal injuries to a crew member on the deck of the Maltese-registered container vessel,

***CMA CGM MANTA RAY*,**

in the port of Laem Chabang, Thailand, on 07 November 2022

202211/008

MARINE SAFETY INVESTIGATION REPORT NO. 16/2023

FINAL

Investigations into marine casualties are conducted under the provisions of the Merchant Shipping (Accident and Incident Safety Investigation) Regulations, 2011 and therefore in accordance with Regulation XI-I/6 of the International Convention for the Safety of Life at Sea (SOLAS), and Directive 2009/18/EC of the European Parliament and of the Council of 23 April 2009, establishing the fundamental principles governing the investigation of accidents in the maritime transport sector and amending Council Directive 1999/35/EC and Directive 2002/59/EC of the European Parliament and of the Council.

This safety investigation report is not written, in terms of content and style, with litigation in mind and pursuant to Regulation 13(7) of the Merchant Shipping (Accident and Incident Safety Investigation) Regulations, 2011, shall be inadmissible in any judicial proceedings whose purpose or one of whose purposes is to attribute or apportion liability or blame, unless, under prescribed conditions, a Court determines otherwise.

The objective of this safety investigation report is precautionary and seeks to avoid a repeat occurrence through an understanding of the events of 07 November 2022. Its sole purpose is confined to the promulgation of safety lessons and therefore may be misleading if used for other purposes.

The findings of the safety investigation are not binding on any party and the conclusions reached and recommendations made shall in no case create a presumption of liability (criminal and/or civil) or blame. It should be therefore noted that the content of this safety investigation report does not constitute legal advice in any way and should not be construed as such.

MARINE SAFETY INVESTIGATION UNIT
A3 Towers
Triq l-Arkata
Paola PLA 1212
Malta

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LIST OF REFERENCES AND SOURCES OF INFORMATION

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IMO. (2020). *International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978* (Consolidated ed.). London: Author.

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Interviews with the crew members of *CMA CGM Manta Ray*.

CMA CGM Manta Ray's documents and logbooks.

Site Assessment and Failure Analysis Reports, carried out by an accredited and neutral testing facility in Singapore, and provided by CMA CGM International Shipping Co. Pte. Ltd.

GLOSSARY OF TERMS AND ABBREVIATIONS

°	Degree
°C	Degree Celsius
3D	Three-dimensional
A	Ampere
AB	Able seafarer – deck
ABS	American Bureau of Shipping
ASTM	American Society for Testing and Materials
D-Time	Delay time
DPA	Designated person ashore
ECR	Engine control room
EDX	Energy dispersive X-ray
GA plan	General Arrangement plan
GMDSS	Global Maritime Distress and Safety System
gt	Gross tonnage
H-Load	High load
HV	Vickers Pyramid Number
ISM Code	International Safety Management Code
kgf	Kilogram-force
kN	Kilo Newton
knot	Nautical mile per hour
kW	Kilowatt
L-Load	Low load
LT	Local time
m	Metres
MARINA	Maritime Industry Authority, the Philippines
min	Minute
MLC, 2006	Maritime Labour Convention, 2006
$mmin^{-1}$	Metres per minutes
mm	Millimetre
MPa	Mega Pascal
MSIU	Marine Safety Investigation Unit
mt	Metric tonne
nm	Nautical mile
O-Time	Overload reaction time
P&I	Protection & Indemnity

PA system	Public address system
rpm	Revolution per minute
s	Second
SOLAS	International Convention for the Safety of Life at Sea, 1974, as amended
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978, as amended
STCW Code	Seafarers' Training, Certification and Watchkeeping Code
SWL	Safe Working Load
TEU	Twenty-foot equivalent unit
UMS	Unmanned machinery space
UTC	Coordinated universal time
WSC	Wire strand core

SUMMARY

CMA CGM Manta Ray was engaged in cargo operations at the port of Laem Chabang, Thailand. In the morning of 07 November 2022, an oiler and the two wipers were assigned to transfer heavy scrap from the engine-room workshop to the port side of the external 'A' deck of the accommodation. The metal items had remained on board following the vessel's recent dry dock works. The port side arm of the vessel's overhead monorail crane on deck was used to hoist the drum-full of the scrap metal and place it on the external 'A' deck.

After the drum was placed in the intended location, the oiler hoisted the crane's block, using the wireless remote controller to park the port side arm in its securing position. At one point, the crane's wire rope parted, and the block fell onto the oiler, who was standing directly below it, on the external 'A' deck. The oiler suffered fatal injuries due to this occurrence.

Site assessments and laboratory analysis conducted on various components of the monorail crane, revealed that the hoist limit switch of the port side arm of the monorail crane was inoperative, since its drive chain had disengaged from one of its sprockets. Furthermore, the overload limit switches of the monorail crane were not designed to prevent over-hoisting of the crane's blocks. Subsequently, the port side block of the monorail crane was hoisted beyond its limit, and the wire rope parted when subjected to overloading.

The Marine Safety Investigation Unit has made six recommendations, intended to address the safe operation of the deck monorail cranes.

1 FACTUAL INFORMATION

1.1 Vessel, Voyage and Marine Casualty Particulars

Name	*CMA CGM Manta Ray*
Flag	Malta
Classification Society	American Bureau of Shipping
IMO Number	9322499
Type	Container vessel
Registered Owner	CMA CGM S.A., The French Line
Managers	CMA CGM International Shipping Co. Pte. Ltd., Singapore
Construction	Steel (double bottom)
Length overall	294.05 m
Registered Length	283.54 m
Gross Tonnage	54,152
Minimum Safe Manning	15
Authorised Cargo	General cargo in containers
Port of Departure	Singapore
Port of Arrival	Laem Chabang, Thailand
Type of Voyage	International
Cargo Information	30,339 mt (2,554 TEU) of containerized cargo
Manning	26
Date and Time	07 November 2022, at 10:09 (LT)
Type of Marine Casualty	Very Serious Marine Casualty
Location of Occurrence	Laem Chabang, Thailand
Place on Board	Accommodation – external deck
Injuries/Fatalities	One fatally injured crew member
Damage/Environmental Impact	Damages to the overhead monorail crane wire and block
Ship Operation	Moored; Cargo unloading – ship to shore
Voyage Segment	Alongside
External & Internal Environment	Daylight, clear sky, moderate visibility, Northerly light breeze, calm sea with no swell; air temperature: 31 °C and sea temperatures: 21 °C.
Persons on Board	26

1.2 Description of the Vessel

CMA CGM Manta Ray (**Figure 1**) was a 54,152 gt container vessel, owned by CMA CGM S.A. The French Line, and managed by CMA CGM International Shipping Co. Pte. Ltd., Singapore (the Company). The vessel was built by Hanjin Heavy Industries & Construction Co. Ltd., Republic of Korea, in 2007. American Bureau of Shipping (ABS) acted as the classification society as well as the recognized organization, in terms of the International Safety Management Code, for the vessel.

CMA CGM Manta Ray had a length overall of 294.05 m, a moulded breadth of 32.20 m, and a moulded depth of 21.60 m. The vessel had a summer draft of 13.50 m, which corresponded to a summer deadweight of 68,008.50 metric tonnes (mt), and a container carrying capacity of 5,086 TEU.

Propulsive power was provided by a 9-cylinder, two-stroke, single-acting, slow speed, MAN B&W 9K90MC-C marine diesel engine, which produced 41,130 kW of power at 104 rpm. This drove a fixed-pitch propeller, enabling *CMA CGM Manta Ray* to reach a service speed of 24.3 knots.

At the time of the occurrence, *CMA CGM Manta Ray* was loaded with 30,339 mt (2,554 TEU) of containerized cargo, drawing forward and aft draughts of 8.60 m and 10.70 m, respectively.

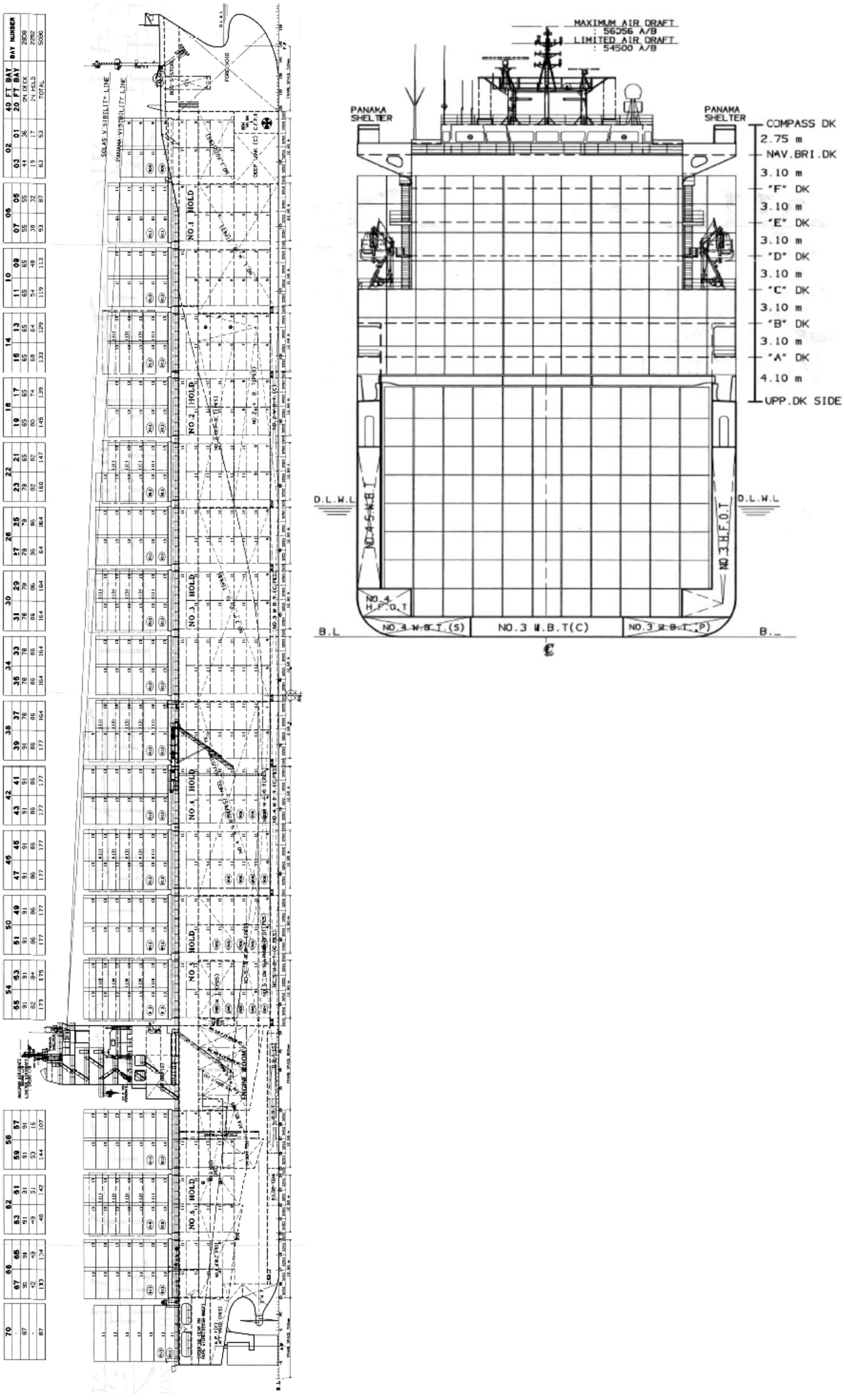

Figure 1: Extract of *CMA CGM Manta Ray*'s GA Plan.

1.3 Crew

The Minimum Safe Manning Certificate of *CMA CGM Manta Ray* prescribed a crew of 15[1]. At the time of the occurrence, there were 26 crew members on board, comprising of Russian and Filipino nationals.

The fatally injured oiler was a 44-year-old Filipino national. He had 13 years of seafaring experience, all of which were served in the rank of an oiler with STCW III/5 qualifications. His most recent certificate of proficiency was issued by the Maritime Industry Authority (MARINA), the Philippines, in July 2014. He had served with the Company for over six years, prior to this occurrence, and he had joined *CMA CGM Manta Ray* on 28 June 2022, at Hong Kong.

Wiper 1 was one of the two wipers assigned to the same task as the fatally injured oiler. He was a 25-year-old Filipino national. He had about three years of seafaring experience, one of which was served in the rank of a wiper. He held STCW III/4 qualifications for a rating forming part of an engine-room watch, and his certificate of proficiency was issued by MARINA, in March 2021. This was his first employment term with the Company. He had joined *CMA CGM Manta Ray* on 22 October 2022, along with the second engineer.

The other wiper (Wiper 2) was a 24-year-old Filipino national. He had about four years of seafaring experience. This was his first employment term with the Company and his first in the rank of a wiper. He held STCW III/4 qualifications for a rating forming part of an engine-room watch. His certificate of proficiency was issued by MARINA, on 18 March 2022. He, too, had joined *CMA CGM Manta Ray* on 22 October 2022.

1.4 Environment

The vessel's records indicated that at the time of this occurrence, the sky was clear, and the visibility was about three nautical miles (nm). A light breeze was blowing

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1 Provided that the unmanned machinery space (UMS) and the bridge control systems were operational, and at least two deck officers held Global Maritime Distress and Safety System (GMDSS) General Operator's Certificates.

from the North and the sea state was recorded as 'calm', with no swell. The air and sea temperatures were recorded as 31 °C and 29 °C, respectively.

1.5 Narrative[2]

On 07 November 2022, *CMA CGM Manta Ray* was engaged in cargo operations, while berthed at the port of Laem Chabang, Thailand. At 0745, the engine-room crew members gathered in the engine control room (ECR) for a daily work plan meeting and related toolbox talks. The oiler, and Wipers 1 and 2 were assigned to transfer heavy scrap, metal items that remained on board after the vessel's recent dry dock works, from the engine-room workshop to the port side of the external 'A' deck of the accommodation.

At 0800, the oiler and Wipers 1 and 2, commenced the task. The three crew members collected all the items into a drum in the workshop, following which, they hoisted the drum using the port side block of the overhead monorail crane, located at the aft of the accommodation. The crane was operated by the oiler. At 0955, the drum was transferred at the planned location (**Figure 2**). Whilst Wiper 1 started to cover the drum with tarpaulin, Wiper 2 went down to the main deck to get the necessary tools to secure the cover. In the meantime, the oiler was hoisting the crane's port side block to secure it in its parking position.

[2] Unless otherwise specified, all times in this safety investigation report are local (LT = UTC + 8).

Figure 2: The drum with the scrap, metal items

At around 1009, while Wiper 1 was covering the drum, he heard a loud sound coming from where the oiler was standing. Turning his head in that direction, he saw the oiler sitting on the deck, bleeding from the head. He immediately called out to Wiper 2 for help. Wiper 2 hurried up to the external 'A' deck and on realizing the severity of the situation, he rushed down to the ECR to notify the chief and second engineers. **Figure 3** shows the accident site and the positions of the crew members at that time.

The third officer, who was in the vessel's office on the 'A' deck, also heard the loud sound and came to the external 'A' deck to investigate further. Seeing the injured oiler, he went back into the office and notified the master and the chief officer over the telephone.

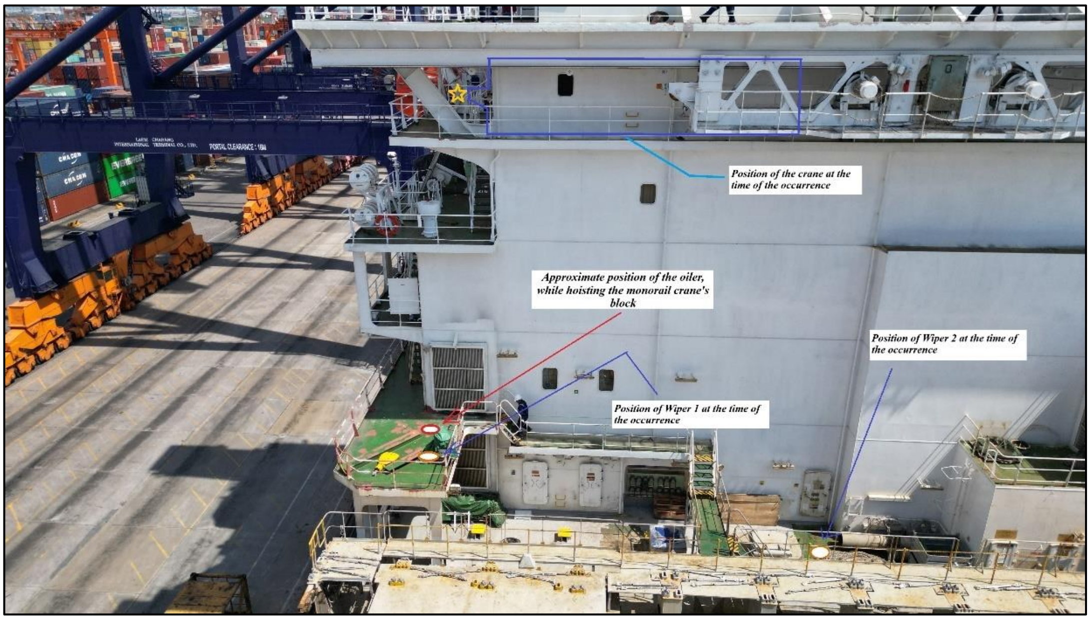


Figure 3: The positions of the crew members at the time of the occurrence

A couple of minutes later, the master, chief officer, chief engineer and second engineer arrived at the accident site. They observed that the oiler was still conscious and that in addition to a head injury, he had also suffered a leg injury. They also noticed the monorail crane's port side block (**Figure 4**) and the wireless remote controller lying in the vicinity.

Figure 4: The monorail crane's port side block, as found after the occurrence; red arrow: the wireless remote controller (not in the same position as found immediately after the occurrence)

The master requested the present crew members to provide support and first-aid to the injured oiler, without moving him. The master then contacted the vessel's local agents via a mobile phone and requested for an ambulance to transfer the injured oiler to a shore hospital. He then informed the Company of the occurrence.

The ambulance arrived at 1120, administered further medical aid to the injured oiler and then prepared a stretcher to transfer him to the pier. At 1152, the ambulance left the terminal, with the injured oiler.

1.6 Crew Members' Observations at the Accident Site

While waiting for the ambulance, the master and chief engineer inspected the overhead monorail crane and found the following:

- the crane was directly above the accident site (as seen in **Figure 3**);
- the crane's port side hoisting wire had parted about one metre from its securing point (**Figures 5** and **6**);
- the crane's port side winch foundation was damaged (**Figure 7**), and
- the drive chain of the port side winch's hoist limit switch was disengaged from its small sprocket (**Figure 8**).

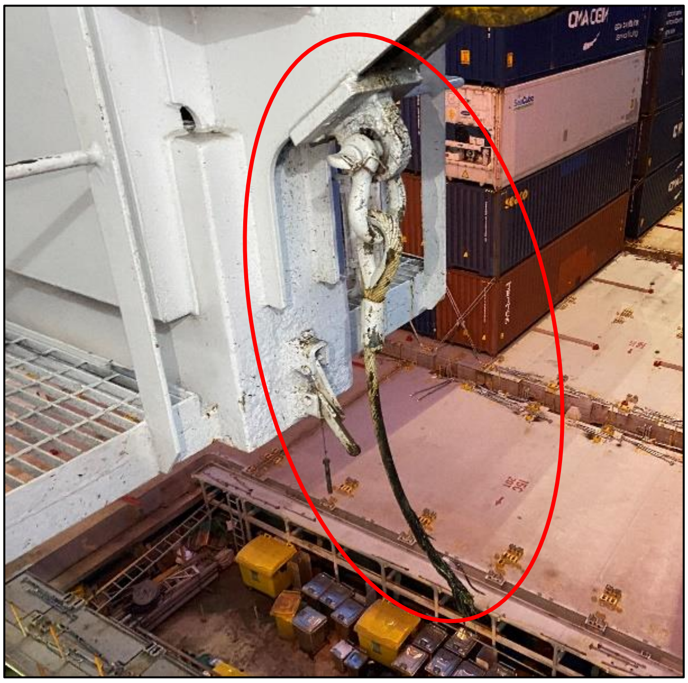


Figure 5: The fixed end of the monorail crane's parted wire (port side)

Figure 6: The running end of the parted wire

Figure 7: The damaged port side winch foundation

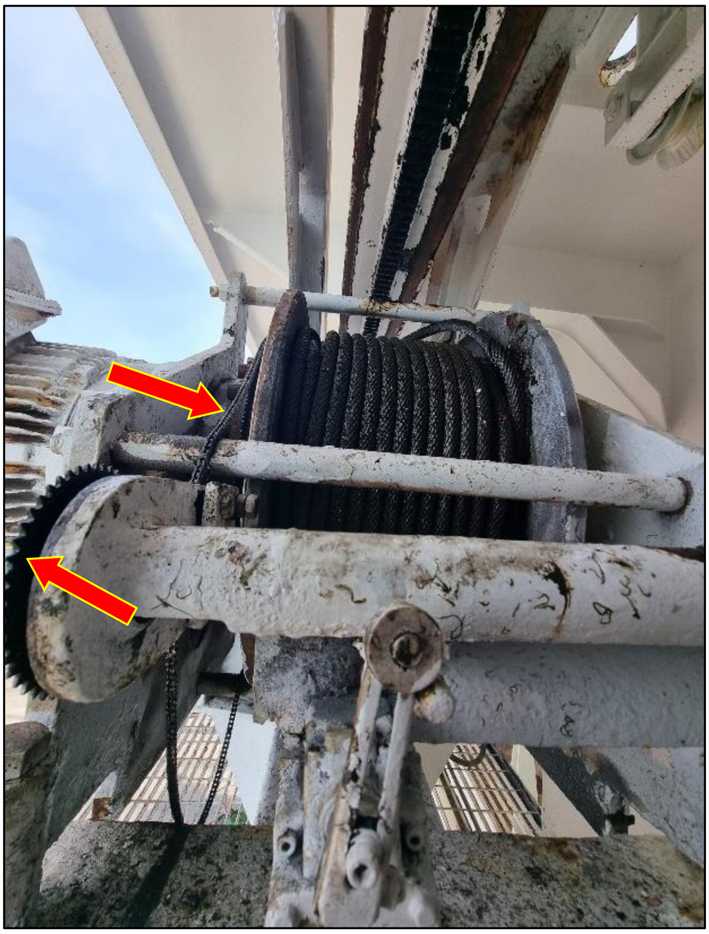


Figure 8: The disengaged port side hoist limit switch drive chain and its small sprocket

1.7 Medical Examination at the Hospital

A medical examination at the hospital, confirmed that the injured oiler had suffered several fractures of the skull, ribs, and right leg. He was immediately admitted into the intensive care unit but succumbed to his injuries at 1344, on the same day.

1.8 The Monorail Crane

The vessel was fitted with two overhead monorail cranes: one in the engine-room and one on deck, aft of the accommodation, for receiving provisions and receiving / landing of spare parts, *etc*. Each of the monorail cranes had a safe working load (SWL) of 10 tons.

The monorail crane on deck (*i.e.*, the one involved in the accident) had been in service between 15 and 20 years. It was an electric, sliding, two-hook type crane (**Figure 9**), with a total travelling length of 42.2 m and hoisting height of 34.0 m. It had a traversing speed and hoisting speed of 10 $mmin^{-1}$.

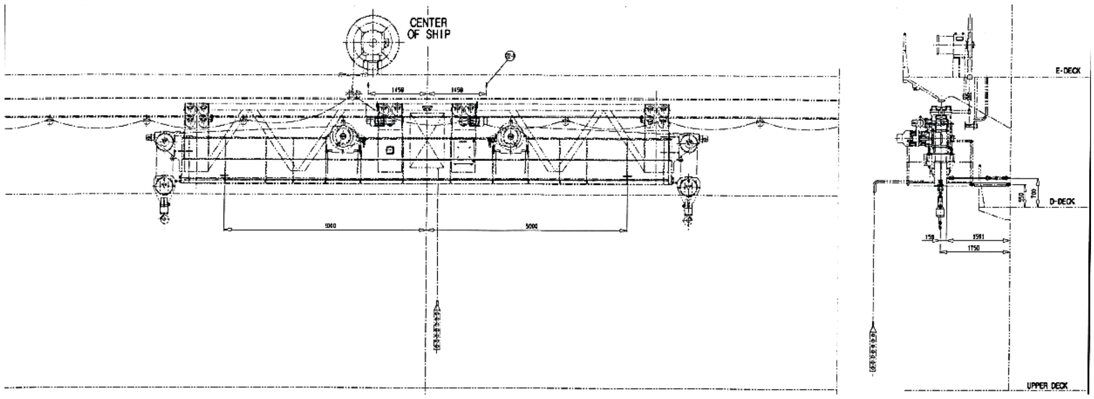


Figure 9: Extract of the monorail crane's general arrangement plan

The crane was designed to be operated in harbour, with a maximum list of 3° and a maximum trim of 2°. It was provided with a pendant remote controller, which travelled with the crane. The crane was equipped with safety limit switches for hoisting and travelling. For hoisting, the limit switches were set for the blocks' upper and lower limits and the overload limit, while for travelling, they were set for the port and starboard end limits.

The overload limit switches were designed to cut off power to the winch motor once the load current exceeded the set high load (H-Load) and low load (L-Load) current limits, within the set overload reaction time (O-Time) of either 0.5 second or 1.0 second.

Both monorail cranes were overhauled and tested by a shore service company, during the vessel's dry dock in September 2022. Information received by the MSIU stated that following these tests, the monorail cranes were also tested and certified by the vessel's classification society. Amongst other works, the overhauling of the monorail crane on deck included the renewal of the reel cables, wire rope, travelling reducing gear, the rack on the crane's beam, sheave, hook thrust bearing, hook locking device, shackle, visual light, and drive chain of the port side winch's limit switch. After the wire rope was replaced, the winch limit switches were adjusted by the shore service company.

The newly installed wire rope was manufactured in July 2021. It was a 20 mm, 18 * 7 WSC (wire strand core), rotation resistant, galvanized steel wire rope, with a tensile strength of 1960 Mega Pascals (MPa). Its minimum breaking force was certified at >/= 257 kilo Newtons (kN) and its actual breaking force, which was a summation of actual test results of the individual wires, was certified to be 298 kN.

The service company had also installed new, wireless remote controllers for each of the monorail cranes. Around the time of the occurrence, the oiler had been using the wireless remote controller, as seen in **Figure 4**.

Following the overhaul, the shore service company carried out the following tests:

- function tests of the limit switches for hoisting and lowering;
- function tests of the warning light;
- function tests of the travelling gear / rack;
- function tests of the cable reeling;
- the turning of the hook thrust bearing;
- the rotation of the sheaves; and
- function tests of the remote controllers.

Following the works, load tests were carried out on both monorail cranes, whereby the brakes were confirmed to hold the test load without slipping. Information received by the MSIU confirmed that these were also tested and certified by the vessel's classification society.

1.9 Post-Accident Testing of the Wire Rope

After the accident, the MSIU received a request from the Company, stating that the Company's legal department, the vessel's insurers and its Protection and Indemnity (P&I) Club required sections of the parted wire and the limit switch assembly. After discussions with the Company, it was agreed that relevant tests would be conducted by an accredited and neutral testing facility in Singapore. Following this agreement, a site assessment and failure analysis (load tests and laboratory analysis) of the monorail crane, was arranged for by the vessel's P&I Club.

The site assessment was conducted on 08 December 2022, by an entity engaged by the P&I Club. In addition to the damages observed by the crew members after the accident, this entity reported the following on the port side arm of the monorail crane:

- the block's sheave was deformed and seized within the block;
- the ferrule at the fixed end of the parted wire rope showed signs of abrasion[3] (**Figure 10**);
- the crane's sheave was deformed;
- the damaged port side winch foundation was leaning towards the crane's hoisting block *i.e.*, towards the direction of the load;
- abrasion grooves were observed on the round bar of the port side winch drum housing, which appeared consistent with damages caused by the disengaged drive chain of port side hoist limit switch, and a gap was observed between the winch drum housing and the sprocket housing;
- the small sprocket appeared to be lacking lubrication and grease stains were observed on the foundation below it, suggesting that the drive chain may have been disengaged for quite some time prior to the failure; and
- two additional bolts were found to have been installed at the connection of the winch drum housing to the sprocket housing (**Figure 11**), while one bolt was missing from the hoist limit switch.

[3] The safety investigation noted that similar signs of abrasion were also observed on the ferrule on the fixed end of the starboard side wire.

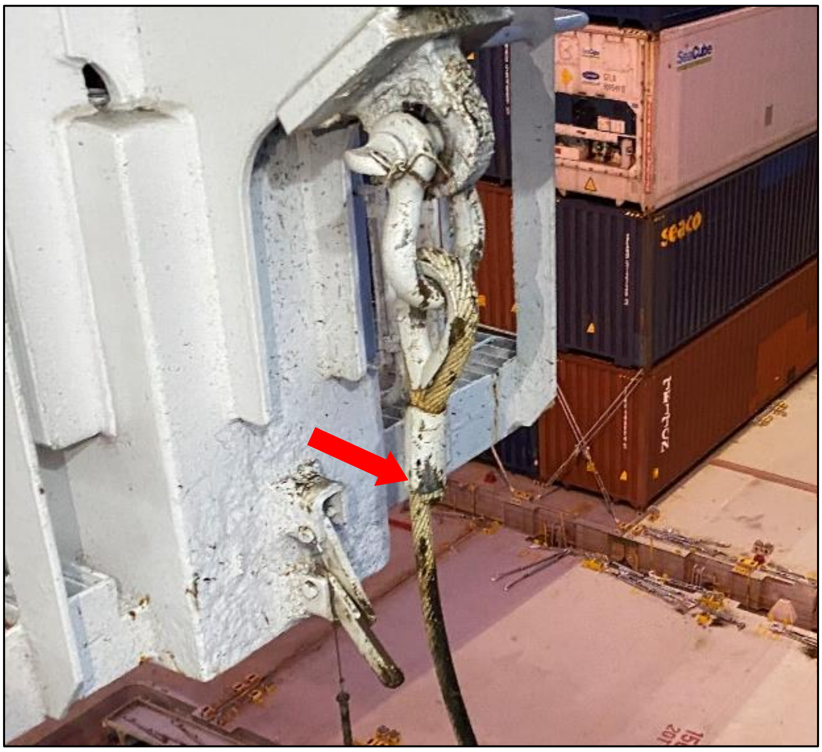


Figure 10: The abrasion marks (red arrow) observed on the ferrule at the fixed end of the parted wire rope

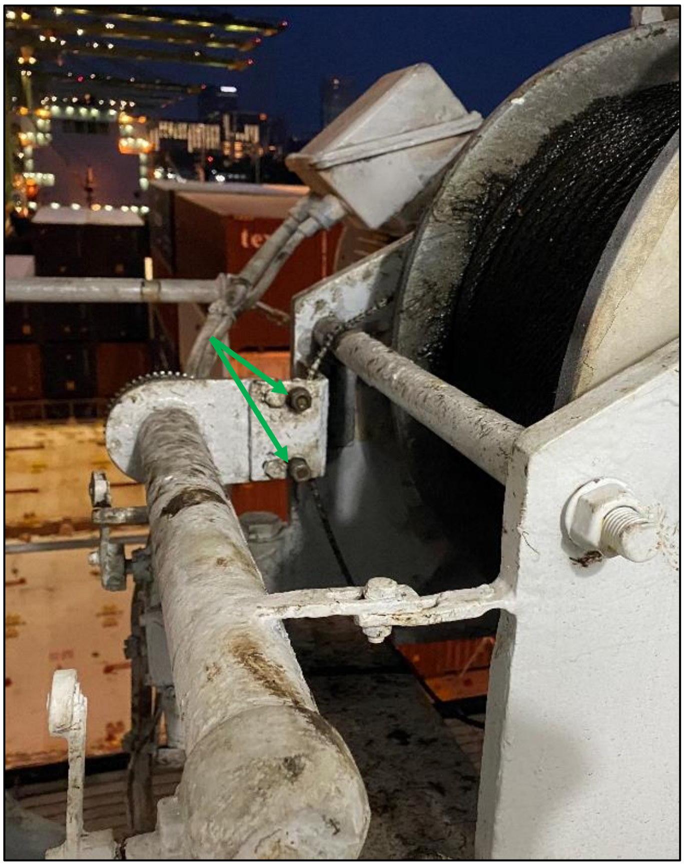


Figure 11: The additional bolts (green arrows) that were found installed

Based on the findings on site, the entity noted that the port side hoist limit switch had most likely not activated when the block was hoisted, thus allowing the block to be hoisted even further. This subsequently resulted in an overload of the hoisting system, leading to the eventual failure and parting of the wire rope, and the damages to the winch foundation. The likely failure of the hoist limit switch was attributed to the disengaged drive chain.

The site assessment also included three-dimensional (3D) scanning of the port and starboard side winch drum housing assemblies of the monorail crane, using a Faro "Freestyle 2" 3D scanner. This was conducted on 21 December 2022.

On 14 February 2023, a waterbag load test was conducted on the starboard arm of the monorail crane, using a 15-ton load cell and a 15-ton waterbag. During the test, it was noted that the port side overload limit switch had the H-Load set at 41.5 A, while the starboard side overload limit switch had the H-Load set at 42.0 A. The other settings were the same for both overload limit switches *i.e.*, the L-Load was set at 0.5 A, the delay time (D-Time)[4] at 3 s, and the O-Time at 0.5 s. Both, the port and starboard side, overload limit switches were tested for functionality during the load test and both tripped when the test load was increased to 11 tons, and about four seconds after the current exceeded the set H-Load, thus indicating that they were functioning as designed[5]. Intermittent actuation of the hoist button of the remote control, did not allow the overload limit switch to detect the current consistently, with the readings being detected at either 0.0 A or the surge current[6].

During the site assessment, this entity also identified the critical samples for a laboratory analysis to determine the cause of the failure, as listed below:

- the parted wire rope, including the fixed end and 3 m on the running end, and the crane's sheave;

[4] Delay taken by the motor to reach the normal operating current.

[5] Based on the settings, it was noted that the overload limit switches were not designed to protect against over-hoisting of the blocks. This is discussed further in Section 2.6 of this safety investigation report.

[6] A camera was placed facing the overload limit switch to log the current consumption readings of the crane's motor.

- the port side hoist limit switch assembly, including the drive chain, sprockets and touch bar housing, winch drum gear, winch drum housing bar and plate, and the limit switches;
- the port side block, including the hook and sheave; and
- the starboard side hoist limit switch's drive chain and sprockets.

Metallurgical analysis included the following:

- for the wire rope:
    1. a visual examination with photographic documentation;
    2. fractographic examination;
    3. energy dispersive X-ray (EDX) analysis;
    4. metallographic examination; and
    5. a hardness test.
- a visual examination with photographic documentation, and measurements of the drive chains and sprockets of the port and starboard side hoist limit switch assemblies; and
- a visual examination with photographic documentation of the hook and sheave of the port side block.

The failure analysis report was completed on 15 June 2023 and was made available to the safety investigation on 31 July 2023.

The processed 3D scan results did not reveal any major discrepancies between the critical dimensions of the port and starboard side winch drum housing assemblies.

1.10 Drug and Alcohol Tests

Alcohol tests were carried out on all crew members, about an hour after the oiler was medically evacuated from the vessel. The results of all these tests returned negative. No drug tests were conducted.

1.11 Records of Hours of Work / Rest

The oiler's records of hours of work / rest indicated that he had 12.5 hours of rest, prior to commencing work at 0600 on the day of the occurrence.

2 ANALYSIS

2.1 Purpose

The purpose of a marine safety investigation is to determine the circumstances and safety factors of the accident as a basis for making recommendations, to prevent further marine casualties or incidents from occurring in the future.

2.2 Cause of Death

The shore hospital reports attributed the death of the oiler to multiple fatal injuries and fractures, suffered after the monorail crane's port side block fell on him. The MSIU was unable to access the autopsy report.

2.3 Laboratory Analysis of the Wire Rope

During the visual examination of the parted wire rope, no significant damages were observed on the outer strands of either section. However, the fractured surfaces of both sections matched each other, with the fracture running straight across the thickness of the rope, which is typically seen in overload failures (**Figure 12**).

Examination of the individual wires revealed nicking of the outer wires of the inner strand and the WSC, with the nicking being more severe on the former. When examined under a stereomicroscope[7], the wires showed a majority of cup and cone fractures (**Figure 13**) and oblique fractures (**Figure 14**), indicating that the wire rope had sustained an overload failure.

[7] The wires were observed under a Keyence VHX 7000 series, digital microscope.

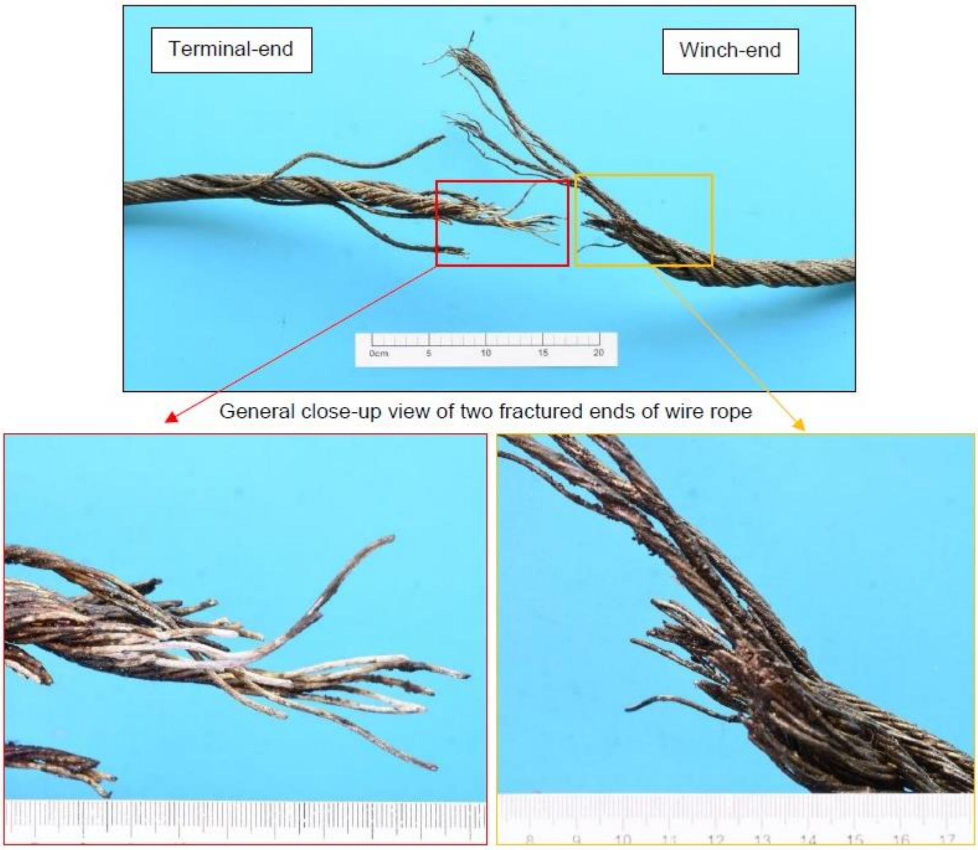


Figure 12: Close-up view of the fractured surfaces of the fixed (terminal) and running (winch) ends of the parted wire rope
***Source*: Failure Analysis Report**

Figure 13: Cup and cone fracture seen on a wire from the WSC of the parted wire rope
***Source*: Failure Analysis Report**

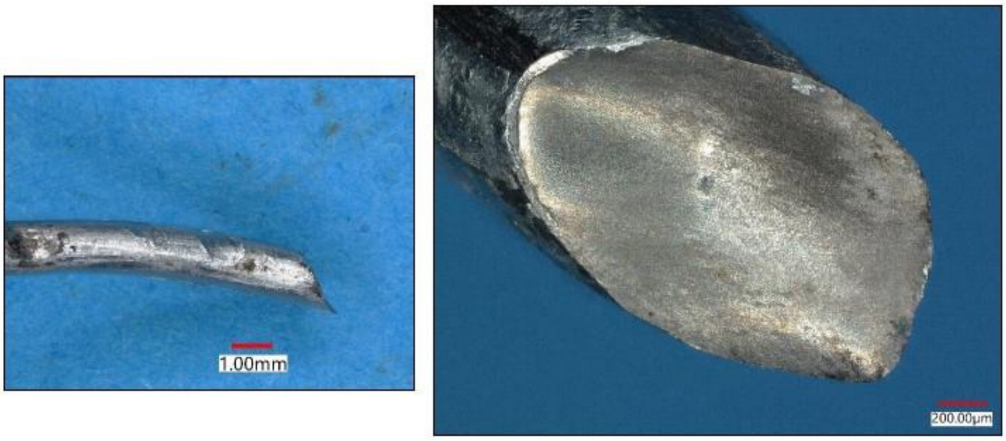


Figure 14: Oblique fracture seen on a wire from the inner strand of the parted wire rope
***Source*: Failure Analysis Report**

Following the visual examination, fractographic examination was conducted on the fracture surfaces of representative wires with different morphologies, using a JEOL IT-300LV scanning electron microscope (SEM).

On the oblique fracture surfaces of the wires of the outer and inner strands, as well as the WSC, elongated dimples, consistent with ductile overload failure, were observed (**Figure 15**). The surfaces of the cup and cone fractures generally showed distinct equiaxed dimpled features (**Figure 16**).

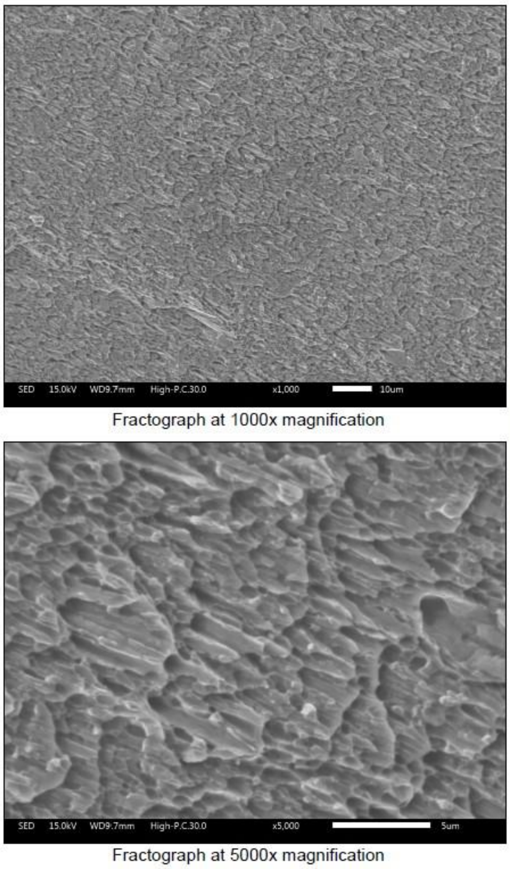
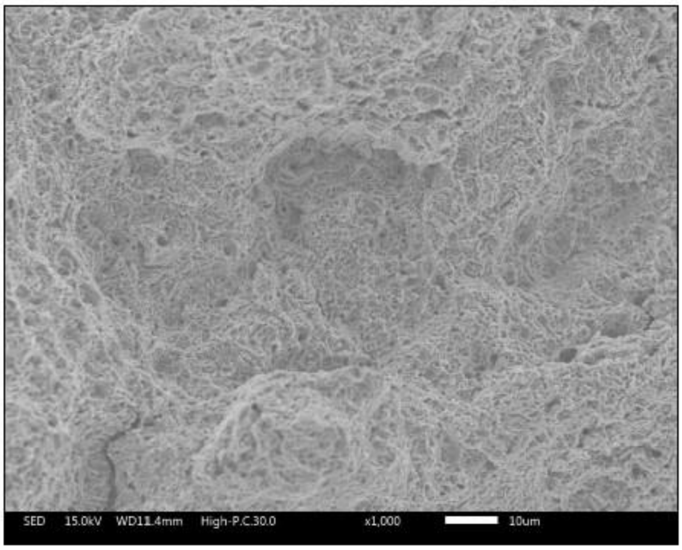
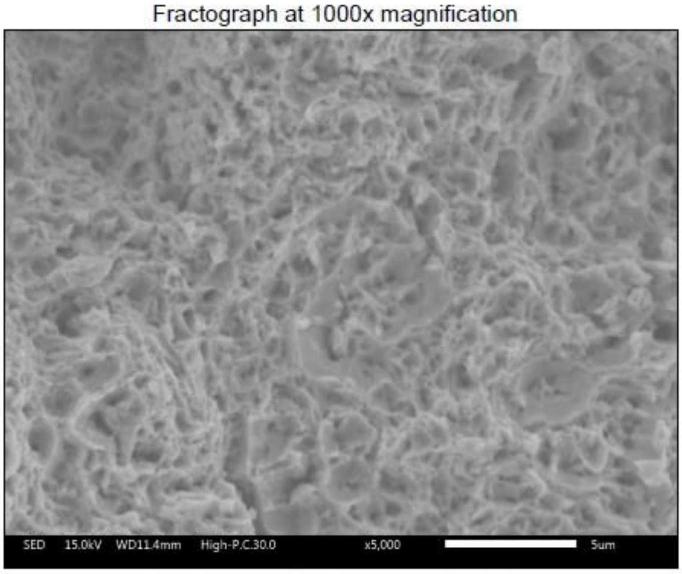


Figure 15: Fractography of an oblique fracture surface of an inner strand wire
***Source*: Failure Analysis Report**



Fractograph at 1000x magnification



Fractograph at 5000x magnification

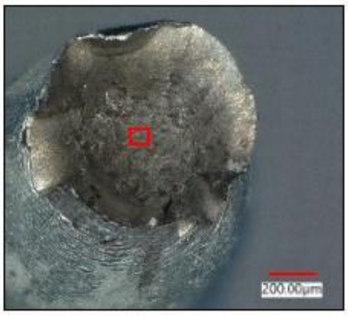


Figure 16: Fractography of a cup and cone fracture surface of an outer strand wire
***Source*: Failure Analysis Report**

Sectional metallographic examinations were then conducted on a cross-sectioned representative sample of the intact wire rope from the fixed end, and on longitudinally sectioned representative individual wires with different fracture morphologies.

On the representative intact wire rope, varying degrees of deformation were observed on the outer and inner strands and the WSC, with the outer wires of the inner strand showing more deformation than those of the outer strand and the WSC.

On the wires with oblique fractures, localized grain deformation was observed adjacent to the fractured surface, corresponding to the regions of inter-wire nicking.

Martensite formation was observed adjacent to the region of inter-wire nicking on the representative wire of the inner strand. A layer of martensite was also observed on the outer diameter of the representative wire of the WSC.

The wires with cup and cone fractures manifested significant necking and grain deformation was observed on the fractured end. A martensite layer was observed near the extremities of the wire of the WSC. The martensite formation was attributed to the large amount of heat generated during the overload failure.

Micro-hardness tests were conducted on the metallographic sections of the individual wires, using an LTF Isoscan HV 1 AC Plus micro-hardness tester with a penetration load of 1 kilogram-force (kgf) at 400x magnification. The average hardness of the wire base metal, away from the fracture, ranged from 474 HV[8] to 536 HV. Approximate conversions for average hardness, using ASTM A370-19e1[9], gave the approximate tensile strength of the wires to range from 1594 MPa to 1850 MPa *i.e.*, lower than the tensile strength stated on the wire rope's certificate.

Based on the aforementioned examinations, the laboratory analysis of the wire rope found that the individual wires with oblique fractures, were generally affected by deformation and / or inter-wire nicking, while the individual wires with cup and cone fractures, had likely failed when the cross-section of the wire rope was unable to withstand the load imparted by the winch motor at the time of the occurrence.

2.4 Analysis of the port side hoist limit switch's sprockets and drive chain

A closer examination of the abrasion grooves found on the round bar of the winch drum housing, revealed red paint in the grooves, under a white paint coating. This suggested that the grooves may have been present from before and only the white paint coat was abraded off by the disengaged drive chain around the time of the occurrence. The metallurgical laboratory also cited a report (dated 13 August 2022) which suggested that there was a previous instance where the port side drive chain had been found disengaged.

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[8] Vickers Pyramid Number.

[9] *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*, by the American Society for Testing and Materials.

The small sprocket (from where the drive chain was found disengaged) was observed to have been generally covered in an adherent layer of paint and dry grease, indicating the drive chain had been disengaged from the sprocket for a long period of time. Microscopic examination revealed degradation of gear teeth, towards their tips (**Figure 17**), with the thinnest measuring 0.50 mm and the thickest being 1.55 mm.

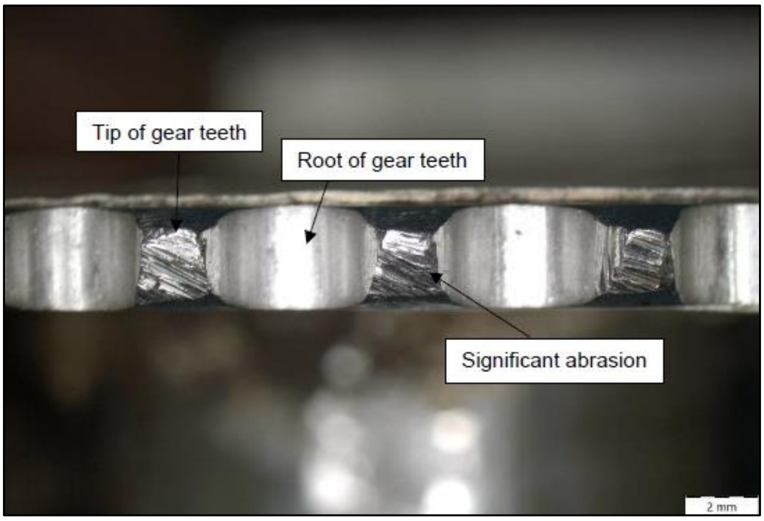

Figure 17: Top view (microscopic) of the gear teeth of the small sprocket
***Source*: Failure Analysis Report**

The visual examination of the big sprocket[10] revealed a localized deformation (a deviation of 3.45 mm), bent away from the winch drum. Localized abrasion was observed on the side profile of the gear teeth, and further close-up examination revealed a deformed tooth (a deviation of 0.80 mm), bent away from the winch drum. The laboratory analysis report stated that this deviation could have likely caused the drive chain to jump off the big sprocket during rotation[11].

The drive chain was observed to be covered in a thick layer of grease and paint. Microscopic examination, after cleaning in an ultrasonic bath of kerosene, revealed wastage and adherent paint on the outer plates of the chain, as well as adherent paint on the internal surface of the rollers (**Figure 18**).

[10] Mounted on the winch drum assembly.

[11] It has to be clarified that **Figure 8** in this safety investigation report shows the drive chain disengaged from the small sprocket.

Figure 18: Microscopic view of the drive chain, with the adherent white paint visible
***Source*: Failure Analysis Report**

Furthermore, a gap was observed between the drive chain and the sprocket teeth, in the regions of the adherent paint, on the internal surface of the chain's rollers, when these regions came into contact with the sprocket (**Figure 19**).

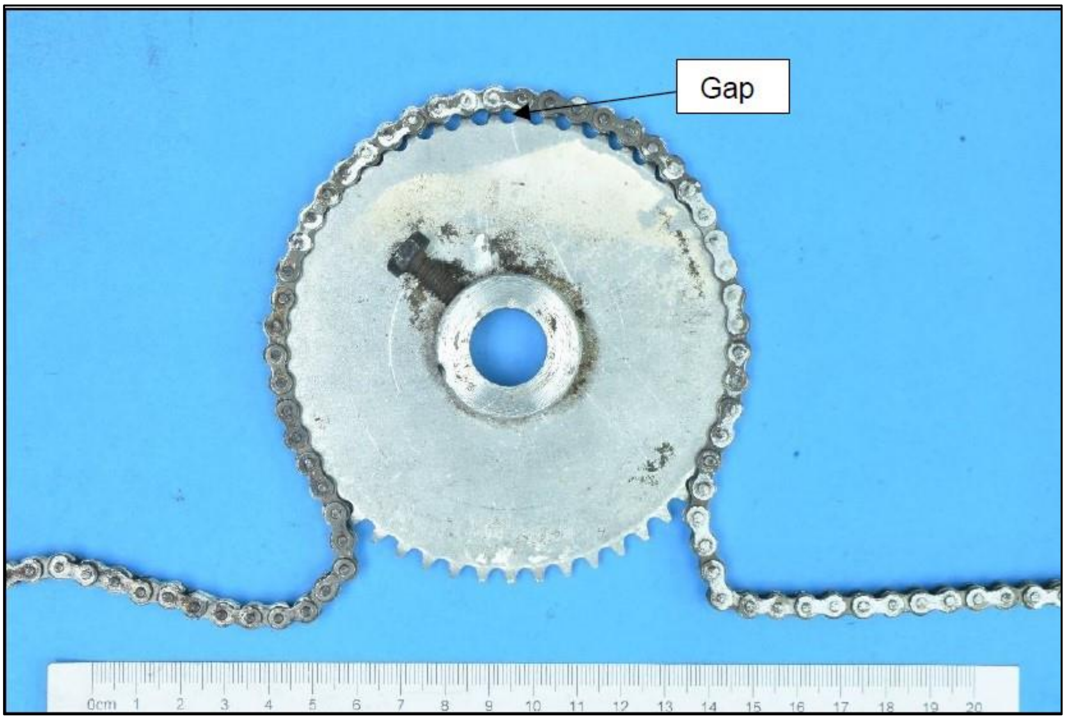

Figure 19: Gap between the drive chain and the small sprocket
***Source*: Failure Analysis Report**

It is highly likely that such a gap would have contributed to the drive chain jumping off the sprockets. Once the drive chain was dislodged, the safety feature of the hoist limit switch would be lost, allowing the block to be raised above its highest point and come into contact with the crane's sheave. Following this, the crane would have been solely dependent on the overload limit switch as a safety barrier prior to failure[12].

2.5 Analysis of the port side block, including the hook and sheave, and the crane's sheave

When closer examinations of the deformations found on the sheaves of the port side block and the crane were carried out, it appeared that these deformations were the result of contact between the two sheaves (**Figures 20, 21** and **22**). The deformations observed on the block and the crane's sheave were also indicative of contact between the block and the crane's sheave (**Figure 23**).

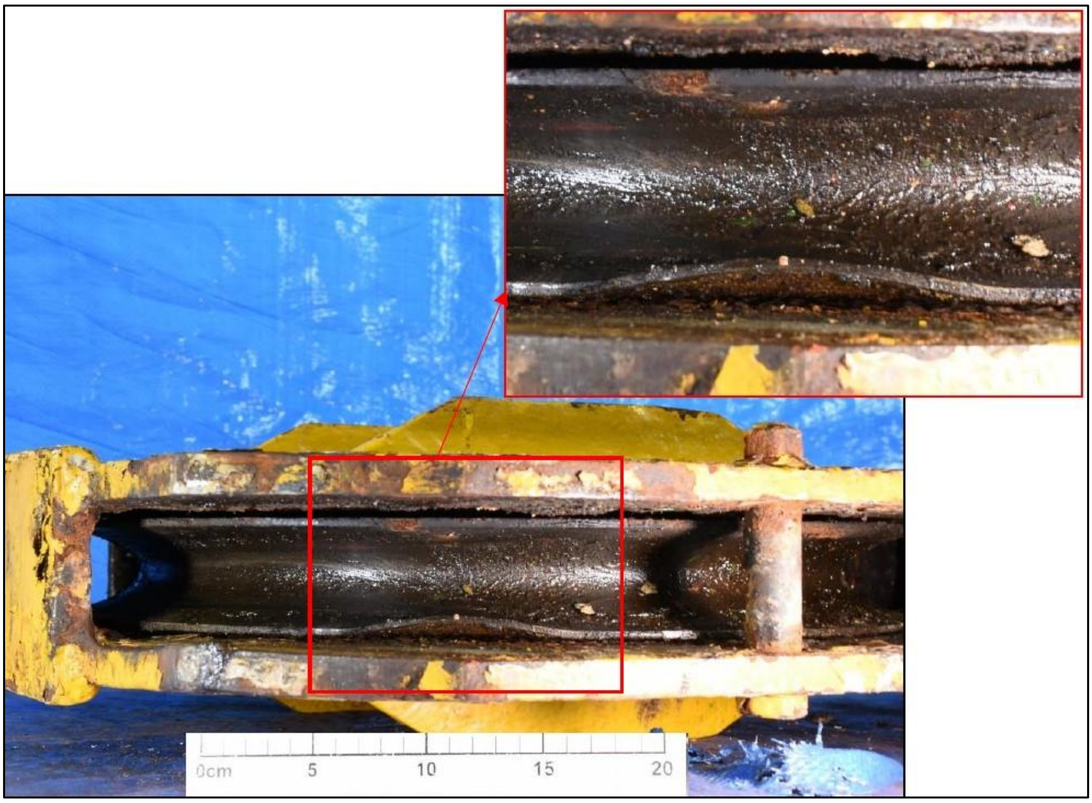

Figure 20: The deformation on the port side block's sheave
***Source*: Failure Analysis Report**

[12] *Vide* Footnote no. 5.

Figure 21: The deformation on the crane's sheave
***Source*: Failure Analysis Report**

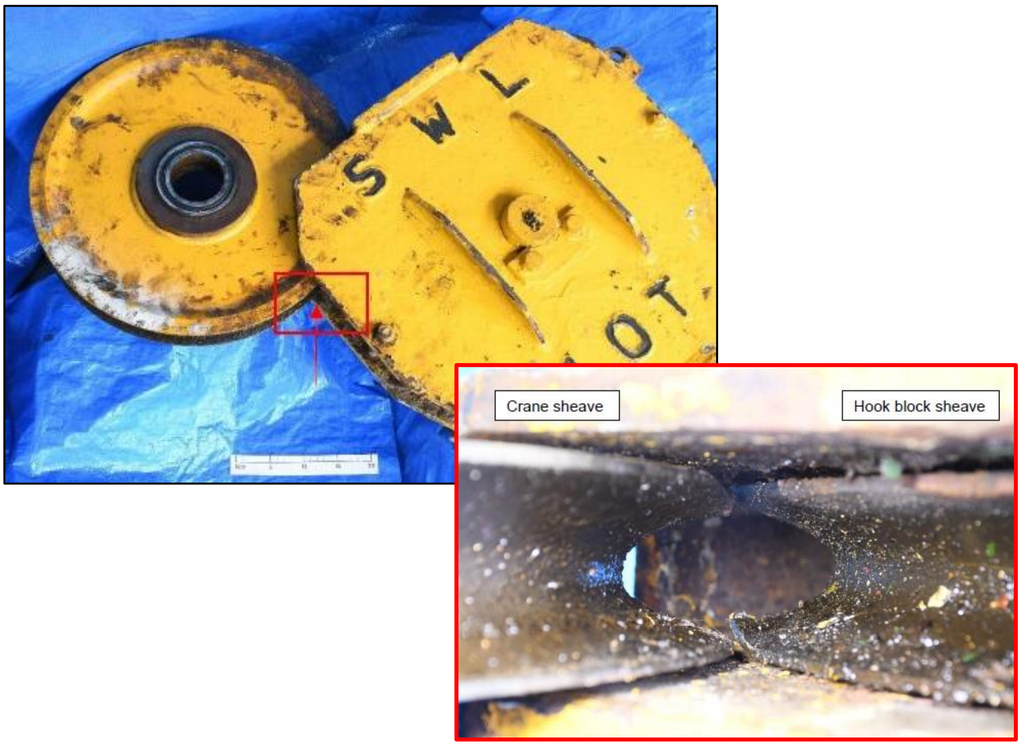

Figure 22: Contact between the two sheaves
***Source*: Failure Analysis Report**

Figure 23: The point of contact between the block and the crane's sheave
***Source*: Failure Analysis Report**

2.6 Analysis of the Functioning of the Overload Limit Switches

As mentioned earlier in this safety investigation report, the overload limit switches for both the port and starboard side arms of the monorail crane were tested and found to be functioning as designed. However, the set delay times for the motors suggested that the overload limit switches were intended to protect solely against overloading, and not against over-hoisting. The longer D-Time ensured that the overload limit switches would not activate and trip the motors when the current surged at the time of starting. On the other hand, the longer D-Time prevented the overload limit switches from reacting quickly in the case of over-hoisting. As a result, approximately 670 mm of wire rope would have been winched in four seconds[13]. This would have imparted significant and continuous tension on the wire rope, leading to its failure before the activation of the overload limit switch.

Further to the above, during intermittent operation of the hoist button on the remote control, the current detected by the overload limit switches would not remain stable for the four seconds required for the overload limit switch to activate. This would allow the wire rope to be tensioned intermittently and overloaded until its failure, without the overload limit switch being activated.

2.7 Crane's Planned Maintenance System

Records made available to the safety investigation and going back to July 2022, *i.e.*, almost two months prior to the September overhaul, did not contain detailed and specific records of the maintenance carried out, except for the month of July which indicated inspection of wires and the steel condition. There was no reference to the drive chain and the sprockets of the hoist limit switches and therefore, the safety investigation was not in a position to determine whether these were visually inspected (and no abnormalities found) or missed altogether.

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[13] As mentioned earlier, both overload limit switches tripped about four seconds after the current exceeded the set H-Loads.

2.8 Position of the Oiler, while Hoisting the Crane's Block

As seen in **Figure 3**, the oiler was standing directly below the monorail crane's port side arm when the accident occurred. Considering the height from which the block fell, the safety investigation is of the opinion that any location on the port side of the external 'A' deck would have been a hazardous location to stay in. The safest location may have been the external 'D' deck, at around the same level as the monorail crane. In fact, this was the location that the bosun stated that he would always be at, when he operated the monorail crane[14].

2.9 Supervision of the Task

The task of transferring items using the monorail crane would generally be considered as a routine task on board a vessel and as such, it would not require any form of supervision. This was also the case on board *CMA CGM Manta Ray*.

In hindsight, especially considering the possibility that the drive chain of the port side hoist limit switch may have disengaged from the sprockets in the past, one may argue that a crew member should have been stationed to check that the block was not hoisted too high. The safety investigation analysed such a decision. Taking into consideration the fact that of the four crew members involved, only the bosun and the oiler had been on board prior to the overhaul of the monorail cranes in September, the safety investigation hypothesised that the following four possibilities apply:

1. the oiler and the bosun were on board when the monorail cranes were overhauled but had not witnessed a previous disengagement of the chain from the sprocket;
2. there were no other issues with the monorail cranes since the overhaul in September and therefore, the crew members had no cues that the drive chain had disengaged once again[15];

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[14] The bosun also stated that he had always used the pendant remote controller and never the wireless remote controller, prior to this occurrence.

[15] It must be recalled that the metallurgical analysis suggested that the chain had been disengaged for a period of time and not on the day of the accident. That detail was missed even because of the location of the drive chain.

3. there was no reason for the crew members to expect that the limit switch would not work; and
4. the risk of a wire rope failure was not assessed because it may have been perceived that the operation did not warrant one.

2.10 Fatigue and the Consumption of Drugs / Alcohol

Whilst the fatally injured oiler’s hours of work / rest, preceding the occurrence, met the relevant requirements of the STCW Code and MLC, 2006 (as amended), the safety investigation was unable to verify the quality of his rest. Furthermore, in the absence of a toxicology report, the safety investigation was unable to confirm whether the oiler may have been under influence of any drugs / alcohol, around the time of the occurrence, or not.

Nonetheless, the oiler’s behaviour and /or actions were not symptomatic of fatigue or intoxication and therefore, the safety investigation did not consider fatigue and drug / alcohol consumption as contributory factors to this occurrence.

THE FOLLOWING CONCLUSIONS AND RECOMMENDATIONS SHALL IN NO CASE CREATE A PRESUMPTION OF BLAME OR LIABILITY. NEITHER ARE THEY LISTED IN ANY ORDER OF PRIORITY.

3 CONCLUSIONS

Findings and safety factors are not listed in any order of priority.

3.1 Immediate Causes of the Accident

.1 The oiler suffered fatal injuries after the monorail crane's port side block fell on him, while he was hoisting it. He was standing directly under the crane's port side arm around that time.

.2 The wire rope of the monorail crane's port side arm had parted about a metre from its fixed end. A laboratory analysis of the parted wire rope showed that the failure was caused by the overloading of the wire rope.

3.2 Conditions and Other Safety Factors

.1 Deformations found on the port side block, its sheave and the crane's sheave suggested that the crane's sheave had come into contact with the block as well as the block's sheave, while the block was being hoisted, thereby overloading the wire to cause its failure.

.2 The port side hoist limit switch's drive chain had disengaged from its small sprocket at some point in time, prior to the occurrence, rendering the hoist limit switch inoperative. The crew members only became aware of this matter after the occurrence.

.3 The laboratory analysis of the port side hoist limit switch's drive chain and sprockets revealed wear of the gear teeth of the small sprocket and traces of adherent paint on the internal surface of the drive chain rollers. This prevented the drive chain from making full contact with the sprocket teeth.

.4 The paint may have led the drive chain to disengage from the small sprocket, prior to the occurrence.

.5 The overload limit switches' settings would not have protected the wire rope against over-hoisting.

4 RECOMMENDATIONS

CMA CGM International Shipping Co. Pte. Ltd., Singapore is recommended to:

16/2023_R1 replace the existing overload limit switches on the deck monorail cranes to a load limiter and thereby eliminate the incorporated delay time;

16/2023_R2 replace the deformed port side large sprocket with a new one;

16/2023_R3 replace the small sprockets on port due to manifested abrasion and wear patterns and inspect the starboard side sprocket and replace, if necessary;

16/2023_R4 conduct an exhaustive inspection of the system and analyse whether the adaptations are necessary to better manage the fair wear and tear of the sprockets over time;

16/2023_R5 ensure that the drive chain systems of the deck monorail cranes are part of the planned maintenance system with the necessary precaution taken to prevent the inadequate lubrication at the prescribed time intervals;

16/2023_R6 consider the possibility of positioning the crew members operating the deck monorail cranes on 'D' deck to observe better the hoisting and lowering operations and take timely actions, if necessary.