Bundesstelle für Seeunfalluntersuchung
Federal Bureau of Maritime Casualty Investigation

Investigation Report 582/22

Serious Marine Casualty

Bridge allisions on the Kiel Canal with a mobile harbour crane carried on the heavy-lift vessel MERI on 30 November 2022

18 June 2024

This investigation was conducted in conformity with the Law to improve safety of shipping by investigating marine casualties and other incidents (Maritime Safety Investigation Law – SUG). According to said Law, the sole objective of this investigation is to prevent future accidents. This investigation does not serve to ascertain fault, liability or claims (Section 9(2) SUG).

This report should not be used in court proceedings or proceedings of the Maritime Board. Reference is made to Section 34(4) SUG.

The German text shall prevail in the interpretation of this investigation report.

Issued by:
Bundesstelle für Seeunfalluntersuchung – BSU
(Federal Bureau of Maritime Casualty Investigation)
Bernhard-Nocht-Str. 78
D-20359 Hamburg

Director: Ulf Kaspera
Phone: +49 40 3190 8300
Fax: +49 40 3190 8340
posteingang@bsu-bund.de
www.bsu-bund.de

Amendments

Page	Amendment	Date

Contents

Figures

Abbreviations

BSU	Federal Bureau of Maritime Casualty Investigation
CET	Central European Time
COLREGs	International Regulations for Preventing Collisions at Sea
E	East
Evo	Evolution
GDWS	Federal Waterways and Shipping Agency
kts	Knots
kW	Kilowatt
LBV.SH	Schleswig-Holstein regional authority for roads and transport
LHM	Liebherr Harbour Mobile
Lpp	Length between the perpendiculars
m	Metre
N	North
N.t.M	Notices to mariners
NOK	Kiel Canal
NvD	Nautical supervisor
PN	Gauge datum
RCC	Regional control centre
Ref.	File reference
S/N	Serial number
SDPS	Ship data processing system
SDR	Ship data reconciliation
SeeSchStrO	German Traffic Regulations for Navigable Maritime Waterways
t	Tonne
THB	Täglicher Hafenbericht
UCA	United Canal Agency GmbH
UTC	Universal Time Coordinated
VDR	Voyage data recorder
VTS	Vessel traffic service
WSA	Waterways and shipping office
WSPR	Waterway police station

1 SUMMARY

At the end of November 2022, the Finnish-flagged heavy-lift vessel MERI was carrying a mobile harbour crane from Rostock to Esbjerg, a port on the Danish North Sea coast. Kiel Canal (NOK) was chosen as the route. Relevant documents indicate that the ship and cargo exhibited a permissible height to pass the bridges on the NOK safely.

However, while passing beneath the first bridges, the high bridges at Holtenau, on 30 November 2022, the mobile harbour crane's tower head struck the hollow box girders of both carriageways of the bridges. The force of the impact broke the lashings that were securing the 643 t crane to the deck. This allowed the crane to tilt far enough toward the stern to pass under both bridges. In the process, it lost eight counterweights, three of which fell into the water. In both cases, the crane then tipped forward again after passing beneath due to its centre of gravity, crashing back onto the deck with its running gear and supporting pads. The crane was destroyed in the process. The MERI's deck was also damaged. It was deformed and the crane jib penetrated part of it. The bridges sustained considerable damage. The bridges and the NOK were temporarily closed to all traffic. In particular, automobile traffic was seriously disrupted until the primary damage to the bridge was repaired on 21 December 2023. The cost of the bridge repairs stood at some EUR 6 million.

Two investigators from the BSU immediately went to the scene of the accident to secure evidence and inspect the damage to the bridges, the MERI and her cargo, as well as to establish the consequences for safe passage of the canal as far as was necessary and possible.

After analysing the initial findings of the investigation, the BSU decided to conduct a main investigation. Human judgement suggested that the primary cause could only be that the height of the loaded crane was different than that specified in the cargo documents and indicated on the crane. However, this had to be proven first so as to then be able to answer the questions below, in particular:

- How could this have happened?
- Why was the crane's actual height not noticed in time at any point?
- How can a similar incident be prevented in the future?

A few days after the accident, the BSU attempted to determine the height of the damaged crane from the deck of the MERI. Shipboard equipment[1] was used and visibility was good. The measurement of the figures required for an angle calculation failed for various reasons, further raising the BSU's awareness of the issue of height measurements and their complexity when considering all the underlying conditions for determining suitable measuring arrangements.

[1] A laser distance meter, a tape measure and a sextant were used, knowing full well that sextants are generally no longer carried on board.

Bridge allisions on the NOK are extremely rare accident events. The BSU's research indicates that there have been four accidents in the past 35 years. Of the ten bridges[2] in total, four different bridges – one railway bridge and three road bridges – have been struck. In two cases, the heights of the ships were changed by the commissioning of the on-board cranes during the canal voyage in such a way that the permissible heights were exceeded. Only in the case of the KANOK NAREE on 11 December 1993[3] was one of the shipboard crane, a derrick, higher than permitted without commissioning and the ship, coming from Brunsbüttel, ran into the Hochdonn railway bridge. In the case of both the KANOK NAREE and the MERI, the heights given in the relevant plans were either unclear or incorrect. In both cases, the heights had not been measured beforehand on the ship's side, as is customary and generally permissible. In both cases, the incorrect heights was not detected by the height monitoring in the locks.

Every bridge allision resulted in the temporary closure of the NOK. The bridge structures were always damaged, at times severely, and human lives were always endangered. In the opinion of the BSU, it is thanks only to fortunate circumstances that no one was injured during previous bridge allisions.

Against this background, the BSU commissioned a metrological report. This report involved an examination of which measuring arrangements for determining the height of the ship and cargo could be implemented on board the ship and/or in the locks on the NOK. In particular, the advantages and disadvantages of measuring arrangements – including the measuring arrangement currently used in the locks – were assessed with regard to practicality and traceability. Taking into account the practicability, more complex measuring arrangements with which the Administration could safely establish ship heights in a lock area were only considered in principle.

During the analysis of all available evidence, the investigation also focused on the effort and time required up to the closure of the bridge, meaning that the emergency management of all parties involved after the allision was considered in greater detail.

[2] Information on the ten bridges: *Brücken* [bridges] (nok-sh.de) (2023-08-07).

[3] Ruling of the Maritime Board (Ref.: SeeA1-DI 8/94 K), archived at the Federal Archives under Ref. B 175/737: Motor Vessel 'Kanok Naree'.- *Beschädigung der Eisenbahnhochbrücke Hochdonn über den Nord-Ostsee-Kanal bei Kilometer 18,8 am 11. Dez. 1993* [damage to the high railway bridge over the Kiel Canal at Hochdonn, kilometre 18.8, on 11 December 1993] - Archivportal-D (2023-05-23). At the request of the BSU, the Federal Archives released the ruling for the purpose of marine casualty investigation 582/22 MERI (official purposes). This ruling will be available to the public from 2026.

2 FACTUAL INFORMATION

2.1 Photograph of the vessel

Figure 1: The MERI laden with two mobile harbour cranes.[4]

2.2 Ship particulars

Name of ship:	MERI
Type of ship:	Heavy-lift vessel (Open Deck Carrier)
Flag:	Finland
Port of registry:	Turku
IMO number:	9622502
Call sign:	OJPH
Owner (according to Equasis):	Meriaura Oy (Meriaura Ltd.)
Shipping company:	Meriaura Ltd.
Year built:	2012
Shipyard:	STX Finland Turku
Classification society:	Bureau Veritas
Length overall:	105.4 m
Breadth overall:	18.8 m
Draught (max.):	4.9 m
Gross tonnage:	3,360
Deadweight:	4,964 t
Engine rating:	3 × 1,200 kW
Main engine:	3 x Wärtsilä 6L20
Service speed (max.):	12.6 kts

[4] Source: Meriaura Ltd. Only one crane was loaded aft on the day of the accident.

Hull material:	Steel
Minimum safe manning:	8

2.3 Voyage particulars

Port of departure:	Rostock, Germany
Port of destination:	Esbjerg, Denmark
Type of voyage:	Merchant shipping/international
Cargo information:	Mobile harbour crane (LHM 600 – Evo6)[5] as deck cargo
Crew:	9
Draught at time of accident:	D_f = 4.7 m, D_a = 5.05 m
Pilot on board:	Yes
Canal helmsman:	Yes
Number of passengers:	None

[5] LHM: Liebherr Harbour Mobile; Evo: Evolution.

2.4 Marine casualty

Type of marine casualty:	Serious marine casualty Allision with two bridges due to an excessively high load.
Date, time:	30 November 2022 at 0436[6]
Location:	Kiel Canal (NOK), canal kilometre 96.7 (high bridges at Holtenau)
Latitude/Longitude:	φ = 54°22.12'N, λ = 010°7.33'E
Ship operation and voyage segment:	Fairway mode
Place on board:	Cargo deck, aft
Consequences:	Two road bridges sustained structural damaged. According to the press release[7], the repairs to the two bridges were almost completed at a cost of EUR 6 million on 21 December 2023. The consequences for each bridge in detail:

The Olympiabrücke bridge (in normal service for northbound motor vehicles) was closed up until 14 June 2023 and then from 26 June to 4 September 2023. A weight limit of 12 t was imposed between 15 June and 25 June 2023. The Olympiabrücke bridge was closed to pedestrians and cyclists from 8 March to 7 September 2023.

One lane of the Prinz-Heinrich-Brücke bridge (in normal service for southbound motor vehicles) was opened to traffic in both directions as follows:

- from 0600 to 2100 on 7 December 2022 for motor vehicles up to 3.5 t;
- from 12 December 2022 with no time limit for all regular service buses;
- from 0600 to 2100 on 15 December 2022 for motor vehicles up to 12 t;
- from 22 December 2022 for all buses and motor vehicles up to 12 t.

The Prinz-Heinrich-Brücke bridge was opened to pedestrians and cyclists on 1 December 2022. The Prince-Heinrich-Brücke bridge was closed for repair work from 4 September to 21 December 2023.

[6] Unless otherwise stated, all times are Central European Time (CET) = UTC + 1 hour (local time at the scene of the accident).
[7] *Inter alia*, THB (*Täglicher Hafenbericht*) [daily port report] of 22 December 2023.

A destroyed LHM 600 – Evo6 mobile harbour crane.

Pollution due to hydraulic oil escaping from the crane.

The NOK was closed to shipping for several hours as a result of the crane's counterweights falling off in the bridge area.

Parts of the MERI's cargo deck and railing were damaged, in particular. It was not possible to continue the voyage because the crane was damaged, unsecured and too high.

Extract from the Kiel Canal navigational chart (BSH DE42)[8]

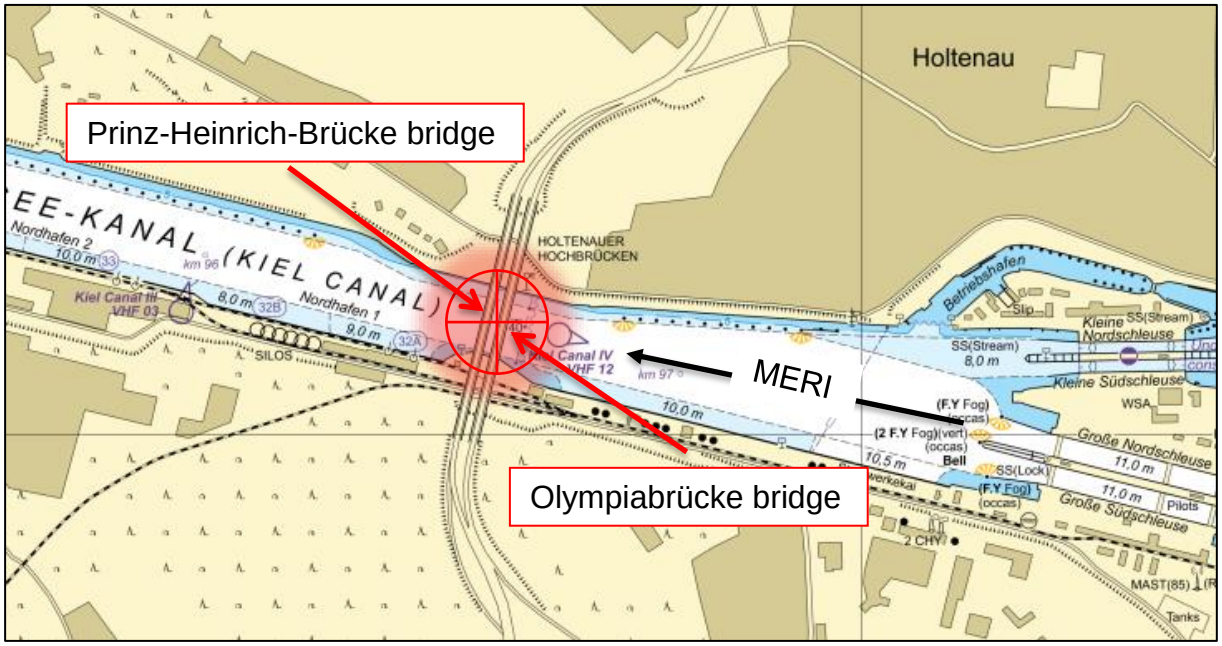

Figure 2: Scene of the accident

2.5 Shore authority involvement and emergency response

Agencies involved:	Vessel Traffic Service (VTS) NOK II, Waterway Police Station (WSPR) Kiel, Regional Control Centre (RCC) Middle, surrounding police stations, road maintenance depot.
Resources used:	Numerous patrol cars and police officers deployed to completely close the two bridges.
Actions taken:	NOK closed to shipping, the two high bridges closed to all traffic, MERI moored at berth 33 in the Nordhafen 2 port (NOK, Kiel-Wik).

[8] Issue 3 of 26 August 2021. Corrected up to N.t.M 15/2023.

3 COURSE OF THE ACCIDENT AND INVESTIGATION

3.1 Course of the accident

The account of the course of the accident is based in particular on recordings from the MERI's VDR[9], the height measurement report and the log entries of the lock service personnel, the statements of the first nautical assistant at the lock, as well as the statements of the pilot and the master of the MERI.

The MERI, a heavy-lift vessel flying the flag of Finland, had loaded an LHM 600 mobile harbour crane to transport it from the crane's manufacturer in Rostock to the customer in Esbjerg on the Danish North Sea coast. As is usual with such ships, the superstructure with the ship's bridge is positioned at the bow. The open cargo deck extended from the superstructure to the stern. The crane was lashed aft on this deck. Accordingly, the highest point of the ship, the crane tower, was located in the aft section. The crane jib was positioned and secured on the cargo deck in the direction of the fore section. For the passage through the Kiel Canal, the ship had received admission for passage from WSA[10] Kiel Canal to pass through the canal once with a maximum height of 40.20 m at a gauge datum[11] of up to +5.20 m following a corresponding request. The admission for passage was based on a stowage plan which indicated the exact details of the crane's maximum height of 40.124 m above the waterline at a draught of 4.78 m (see Annex 9.1 to the report).

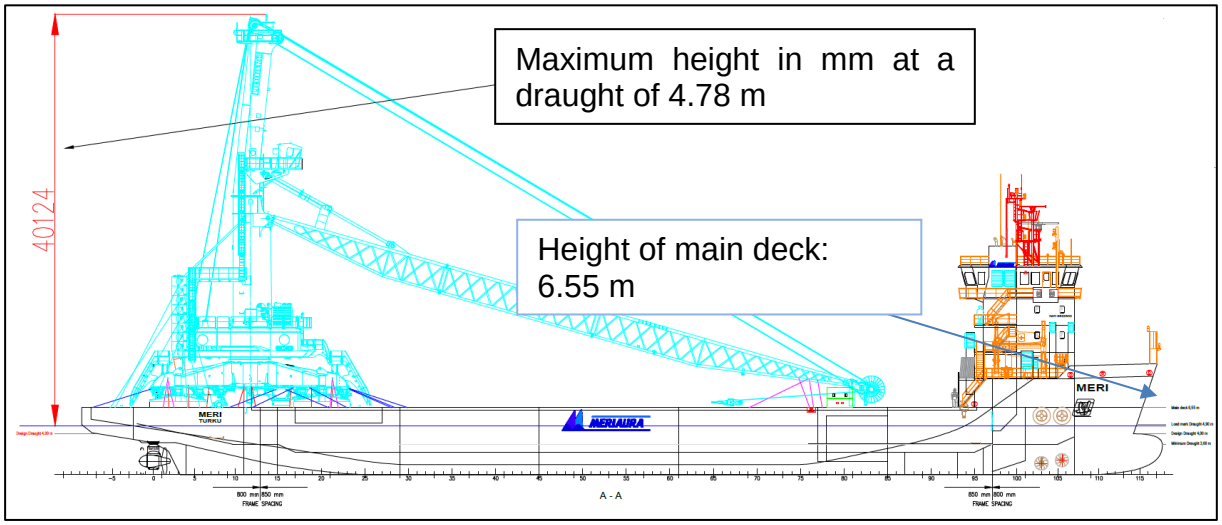

Figure 3: Stowage plan (extract) [12]

Basis for WSA Kiel Canal's decision to authorise the MERI to pass through the NOK once with a maximum height of 40.2 m.

[9] VDR: Voyage data recorder. A Consilium F1 VDR was installed on the MERI.
[10] WSA: Waterways and shipping office.
[11] Gauge datum is five metres below the official vertical datum used for maps. Accordingly, gauge datum is -5 m in relation to vertical datum.
[12] Source: WSA Kiel Canal.

The MERI sailed into the Große Nordschleuse lock at Kiel-Holtenau at 0307 on 30 November 2022 and made fast with her port side on the central pier. One pilot and two canal helmsmen boarded and arrived on the bridge at about 0315.

The nautical assistants of the lock service used a laser measuring instrument in an attempt to remeasure the ship's height, as specified by the ship and authorised by WSA Kiel Canal. The master and the pilot could clearly see the light beams directed at the crane tower through the MERI's bridge windows. At 0317, Kiel Canal 4 (call sign of the lock at Kiel-Holtenau) asked the MERI by radiotelephone for the height of the cargo deck above the waterline (freeboard). The master advised via the pilot that the MERI had a maximum height of 40 m and that permission had been granted. The freeboard for the aft area was specified as 1.60 m.

From the pilot's perspective, the height measurements were made in the normal manner. He did not expect any problems. To his knowledge, the NOK had a declining water level of gauge datum +4.93 m at 0300 and was therefore already below the authorisation for the one-off passage at a maximum height of 40.20 m. The clearance distance between the crane tower and the underside of the bridge should therefore increase further.

The lock personnel made several unsuccessful attempts to determine the overall height with laser measurements. At 0331, Kiel Canal 4 informed the MERI that the canal passage would not be possible and that they would have to stay there. When the MERI asked how long, Kiel Canal 4 stated until the height is clarified and once more asked the MERI what the master would say the maximum height was. Kiel Canal 4 replied to the answer, 40, by stating that 40 metres does not even come close.

The pilot gave the master an account of the radio traffic with Kiel Canal 4, which was conducted in German. The master referred the pilot to the existing authorisation for the passage with a height of up to 40.20 m, stating that this was reportedly not the first time the MERI had transited the NOK with such a special authorisation.

At 0334, Kiel Canal 4 asked the MERI if the ship could increase her draught by 10 cm by ballasting aft. The MERI had an authorisation for 40.20 m and they had a calculated result of 40.30 m. The crane's height is reportedly 38.70 m and the height from the upper edge of the cargo deck to the waterline would be 1.61 m. The MERI could reportedly not proceed in this condition. After the pilot had translated the facts to the master, the latter confirmed that the draught could be increased by 10 cm by ballasting. The pilot informed Kiel Canal 4 accordingly. Kiel Canal 4 acknowledged this statement and informed the MERI that she currently had a draught of 4.80 m and that they would continue to try to measure the height via a different measuring position in the meantime. The MERI could reportedly not proceed in this condition.

The MERI called Kiel Canal 4 at 0345, reporting that the draught at the stern had now increased by 10 cm. Kiel Canal 4 acknowledged receipt of this message and informed the MERI that they would continue to take height measurements and that they could read a draught of about 5.05 m at the stern. Kiel Canal 4 asked if the draught could be determined on the basis of technical equipment. The master confirmed via the pilot a draught of 5.05 m. Kiel Canal 4 informed the MERI about further measurement attempts and stated that the mathematical results looked quite good.

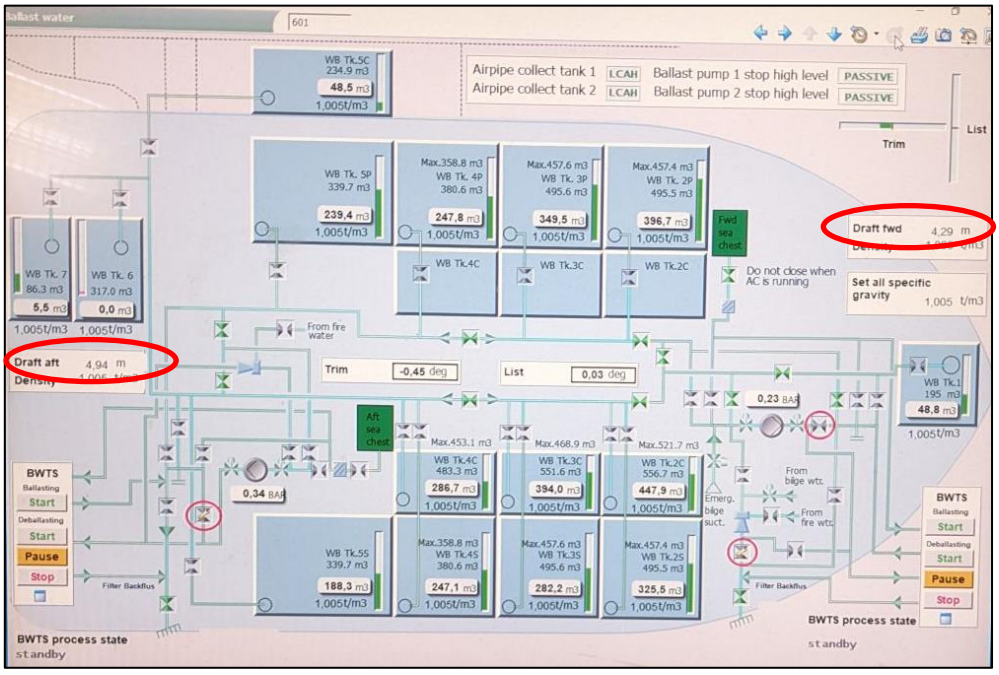

Figure 4: Draught (fore/aft) of the MERI[13]

In the meantime, the multi-purpose vessel MADIKEN was waiting for permission to enter the Große Nordschleuse lock in order to exit the canal seaward. At 0358, Kiel Canal 4 informed the MERI that it was reportedly not possible to measure the height of the crane using the laser but that the height from the top of the deck to the waterline could be measured and that everything, including draught, was plausible. They had arrived at 40.20 m and this would comply with the authorisation. However, a call to VTS NOK II is reportedly still necessary. The MADIKEN would then first be authorised to enter the lock so as to moor opposite the MERI. After that, the likelihood of the MERI being allowed to proceed was actually very high.

At 0423, the MADIKEN reported to Kiel Canal 4 that she had made fast in the lock and asked whether the MERI would now be allowed to exit for the canal first or whether the MADIKEN would leave the lock for the sea. In the view of Kiel Canal 4, the MERI was able to depart, so it called the latter and asked if she could proceed. The MERI confirmed that she was ready to leave after receiving clearance and asked if she could proceed. Kiel Canal 4 confirmed this and the MERI cast off at a water level of gauge datum +4.61 m.

[13] Source: BSU. Photograph taken at 1245 on 30 November 2022.

At 0429, the MERI passed the lock's inner gate, sailed for the middle of the canal and picked up speed. At about 0435, the MERI reached the first of the two high bridges at Holtenau, Olympiabrücke bridge, at a speed of almost 7 kts in the middle of the canal. The master was standing in the aft section of the bridge. According to the master, the pilot had sat down on a chair on the starboard side. Both were watching the canal helmsman at work, who was steering the MERI well from their point of view. The pilot was concentrating on the bridge passages ahead and suddenly felt a violent blow combined with a forceful jolt, causing him to lose his balance even though he was seated. A second violent blow followed immediately afterwards. He immediately realised that they must have touched both bridges, the last one being the Prinz-Heinrich-Brücke bridge. He could see no other explanation. The bridge allisions occurred within 31 seconds of each other in the period from 043608 to 043639.

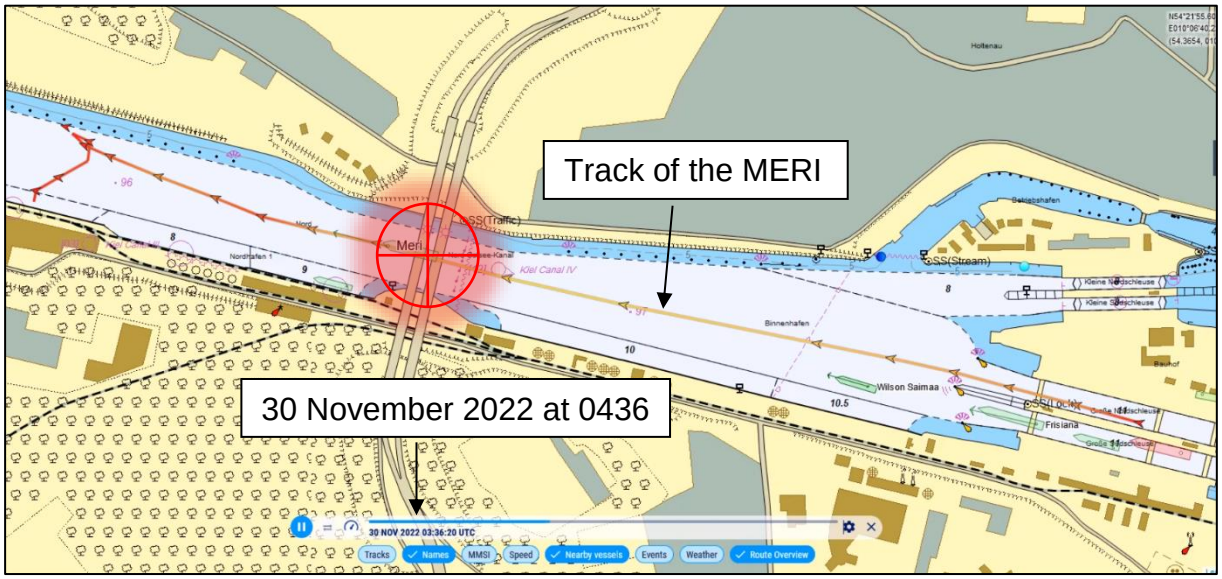

Figure 5: Track of the MERI based on AIS data (MarineTraffic)

The master immediately took charge of the Schottel propulsion system and the pilot called VTS NOK II (call sign: Kiel Canal 3), which is responsible for traffic flow control of the eastern section of the NOK, by radiotelephone at 043656. At 043722, after corresponding feedback from Kiel Canal 3, the pilot reported contact with the Holtenau bridge. After being asked by Kiel Canal 3 if they thought they had touched the bridge in Holtenau, the pilot confirmed and made the traffic behind aware of his report, stating that he hoped the traffic behind is also aware, leaving from the lock. Kiel Canal 3 immediately prohibited the MERI from continuing, ordered her to go to the dolphins for the time being and warned the traffic on the NOK. The MERI made fast in the area of dolphin 15 on the northern side of the canal.

Damage controls were carried out on board the MERI. In particular, the crew found after an initial assessment that the collision had not resulted in any injuries or fatalities on board and that two or three of the crane's counterweights, each weighing 25 t, had gone overboard. The MERI and Kiel Canal 3 exchanged information about the damage scenario.

At 0438, immediately after the report was received, VTS NOK II informed Waterway Police Station (WSPR) Kiel by telephone about the allision and requested that the bridges be closed. At 0440, VTS NOK II closed the NOK on the section between Schwartenbek and the lock at Kiel. After VTS NOK II had set all the main emergency measures in motion, it ordered the MERI to proceed to berth 33 opposite in Nordhafen port, where she made fast at 0540.

Regional Control Centre (RCC) Middle notified WSPR Kiel of the same situation immediately after the call with VTS NOK II had ended. A local resident had been woken by a loud bang and called the RCC. Due to the reports received, WSPR Kiel and the RCC agreed to close the high bridges at Holtenau to road traffic until further notice. RCC Middle then arranged for traffic warnings and the closure of all carriageways, including all footpaths and cycle paths. The RCC also contacted Schleswig-Holstein's regional authority for roads and transport (LBV.SH) so that the competent authority could assess the consequences of the accident with structural engineers and initiate further measures if necessary.

Following the deployment of numerous patrol cars from the surrounding police stations, the closures were completed at 0455 in the northbound direction and 0514 in the southbound direction, 38 minutes after the allision. The road maintenance depot responsible then took charge of the roadblocks, etc.

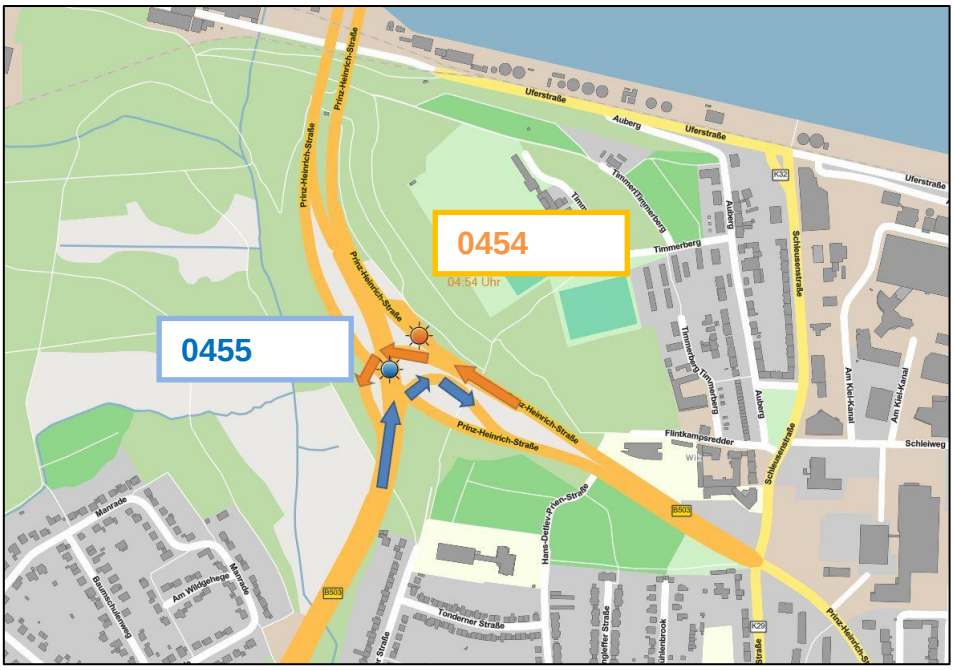

Figure 6: Roadblock at the Holtenau high bridges in the northbound direction[14]

[14] Source: Drawing WSPR Kiel.

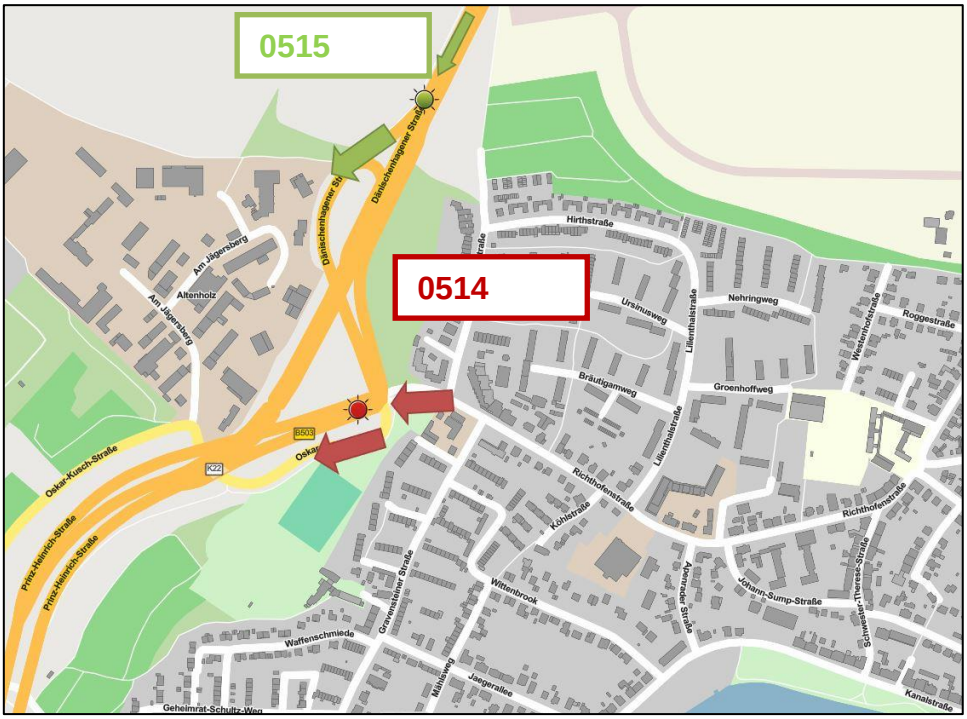

Figure 7: Roadblock at the Holtenau high bridges in the southbound direction[15]

3.2 Investigation

At 0508, 32 minutes after the allision, WSPR Kiel informed the BSU about the accident. The BSU asked the WSPR to initiate certain preliminary investigations in accordance with the SUG. The BSU immediately travelled to the scene of the accident to secure evidence and to inspect the damage to the bridges, the MERI and her cargo, as well as to establish the consequences for safe passage of the canal as far as was necessary and possible.

After analysing the initial findings of the investigation, the BSU decided to conduct a main investigation. Human judgement suggested that the primary cause could only be that the height of the loaded crane was different than that specified in the cargo documents and indicated on the crane. However, this had to be proven first so as to then be able to answer the ensuing questions:

- How could this have happened?
- Why was the crane's actual height not noticed in time at any point?
- How can a similar incident be prevented in the future?

Following receipt and analysis of the requested evidence, the investigation also focused on the effort and time required to close the bridge, meaning that the emergency management of all parties involved after the allision was considered in greater detail.

[15] Source: Drawing WSPR Kiel.

3.2.1 Damage and consequences of the accident

During the passage beneath the high bridges at Holtenau, the crane's tower initially struck the hollow box girder of the Olympiabrücke bridge. The force of the impact broke the lashings that secured the 643 t crane to the deck and were configured for swells up to a significant wave height of 4 m. This allowed the crane to tilt far enough toward the stern to pass under the bridges. The crane then fell forward again after passing under the bridge due to its centre of gravity, crashing back onto the deck with its running gear and supporting pads. During this period, three of the eight counterweights, each weighing 25 t, fell into the canal from the stern of the ship, taking part of the railing with them in the process. The crane tower had righted itself in the meantime and then struck the hollow box girder of the second bridge, Prinz-Heinrich-Brücke bridge, shortly afterwards. The crane tilted toward the stern again and fell forward back onto the loading deck after passing under the bridge.

The crane was destroyed as a result of the allisions. The crane jib, laying on the cargo deck toward the bow, had broken in two, damaged the railing on the starboard side with its attachments, and dented and penetrated the deck. The running gear was smashed, some of the supporting pads had torn off and the machinery housing was buckled. An analysis of drone images revealed damage on the tower head from the points of contact with the bridges' hollow sections. Hydraulic oil had leaked from damaged pipes on the crane onto the deck and partly into the water of the canal. Oil binding agents were spread across the MERI's deck and oil barriers were laid out at berth 33. The following photographs were taken on the day of the accident.

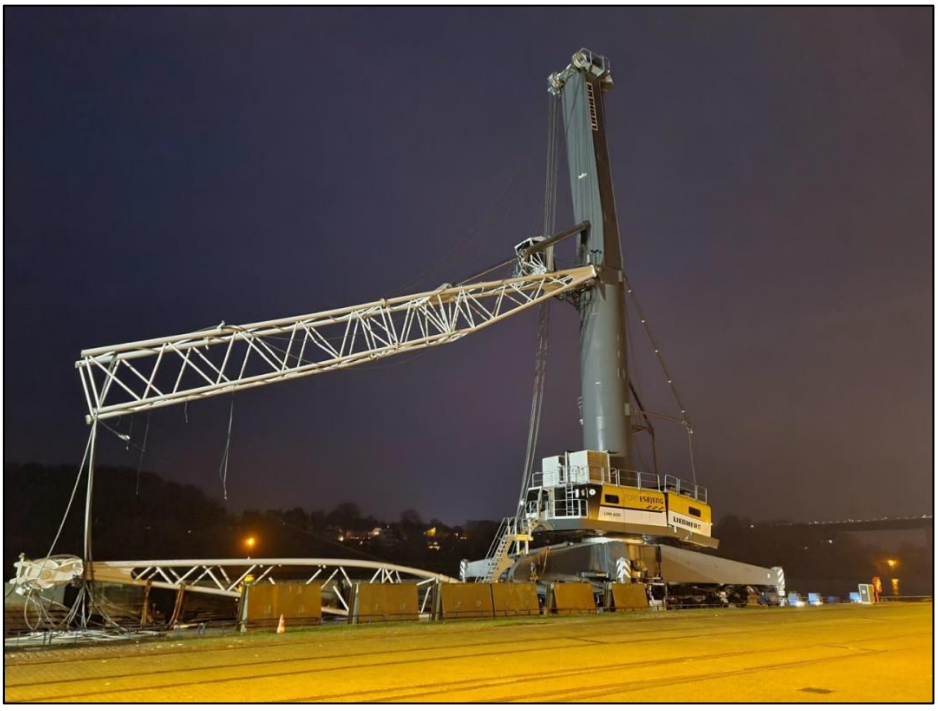

Figure 8: Panoramic photograph of the crane with broken jib[16]

[16] Source: WSPR Kiel. Photograph taken at 0715 on the day of the accident.

Figure 9: Forward section of the jib[17]

The jib was laid down on the deck for transportation. The safety cables broke as a result of the allision. The photograph shows the oil binding agent used by the crew.

Figure 10: Remnants of some attachments from the jib[18]

[17] Source: WSPR Kiel.
[18] Source: WSPR Kiel.

Figure 11: Penetrated deck[19]
The helmet is used for size comparison.

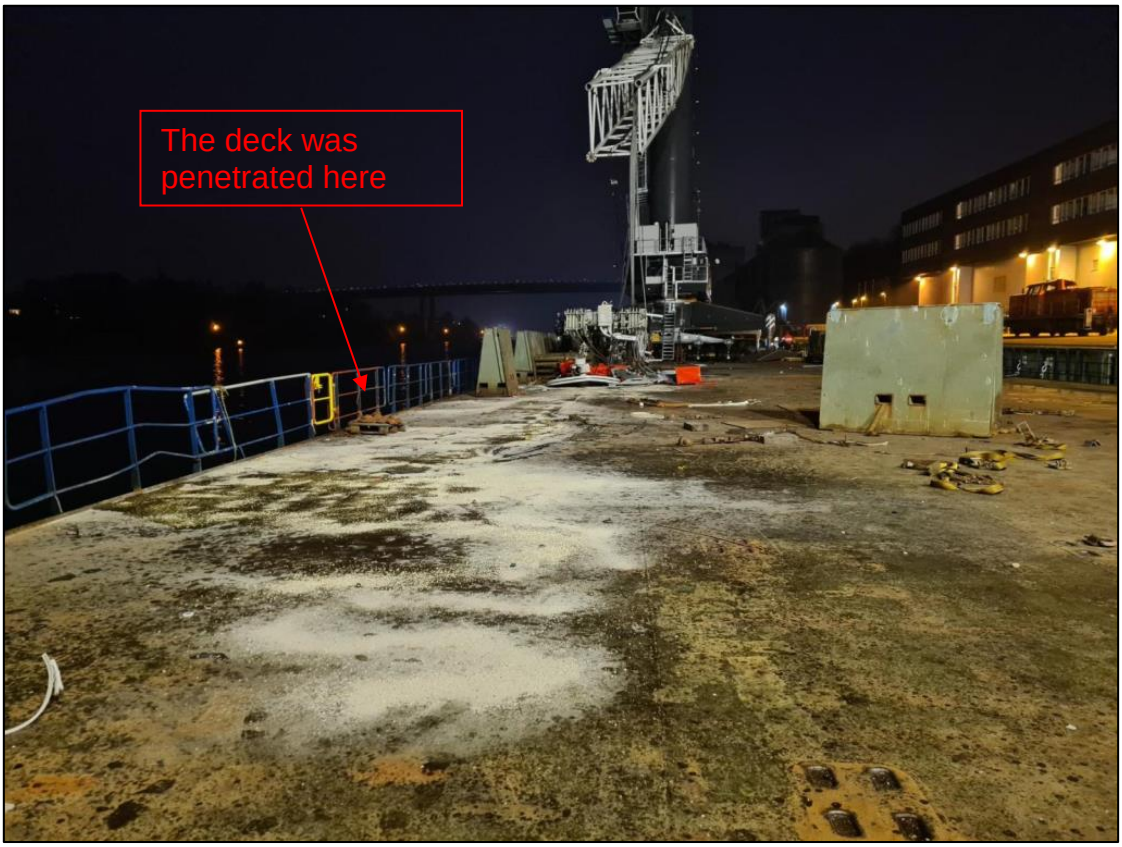

Figure 12: Cargo deck of the MERI[20]
View to aft. *Inter alia*, the oil binding agent on the upper deck and the buckled railing on the starboard side (front left in the photograph) can be seen.

[19] Source: BSU.
[20] Source: WSPR Kiel.

Figure 13: Fallen counterweights[21]
Part of the railing is missing from the stern, which fell into the canal with three counterweights.

Figure 14: Buckled machinery housing, destroyed running gear[22]
The left rear supporting pad had torn away from the support base.

[21] Source: WSPR Kiel.
[22] Source: BSU.

Figure 15: View of the left-hand side of the crane[23]
The steel support base was broken. The forward left supporting pad no longer stood on the wooden substructure. The machinery housing was buckled.

[23] Source: WSPR Kiel.

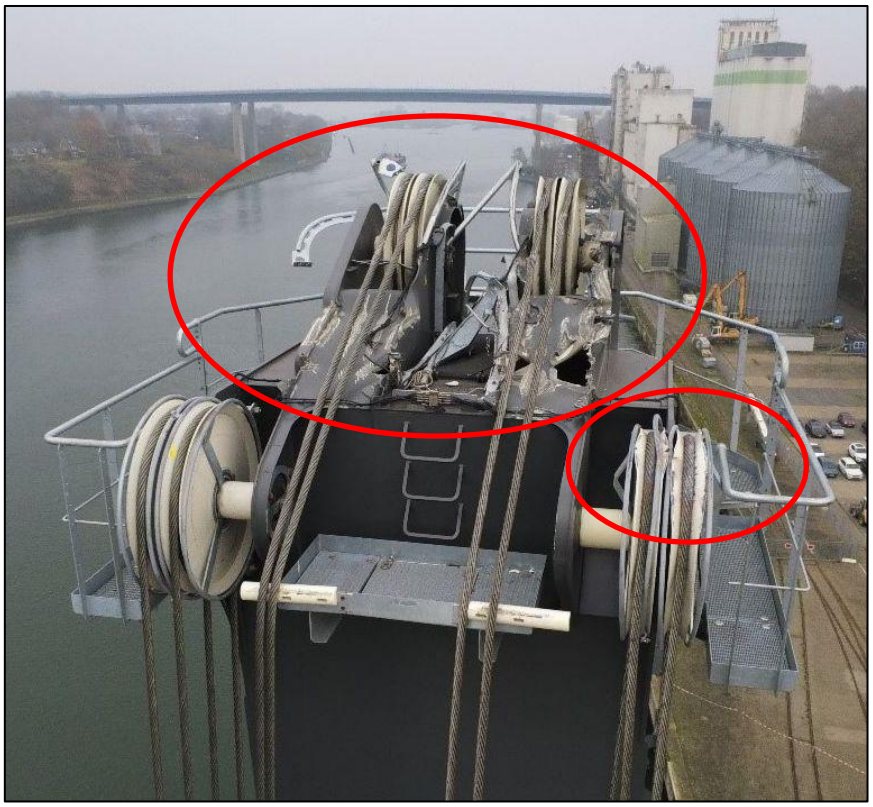

Figure 16: Damage to the crane tower (front)[24]

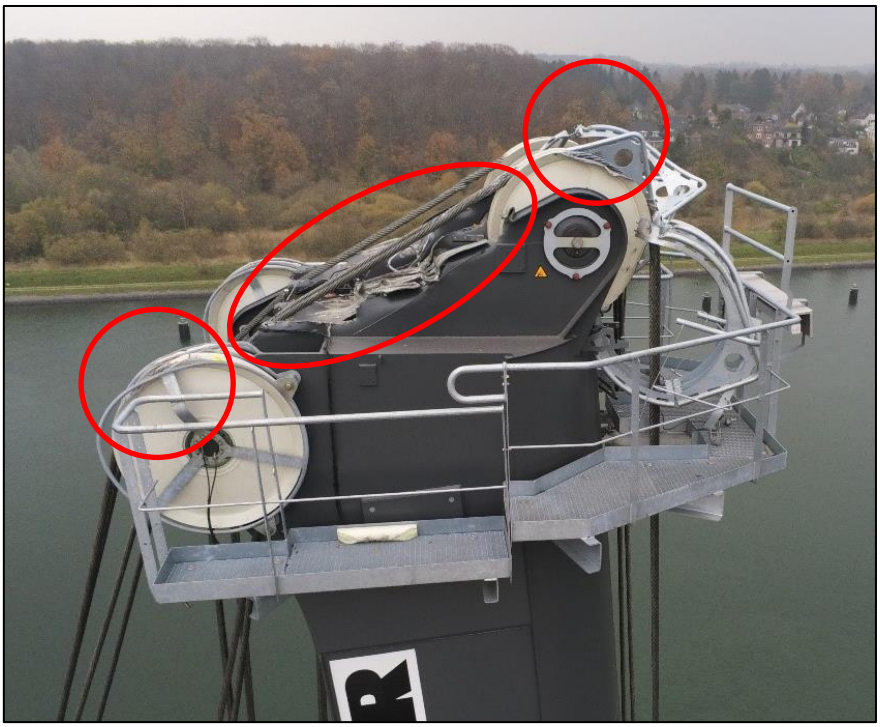

Figure 17: Damage to the crane tower (left-hand side)[25]

[24] Source: DMT Engineering Surveying GmbH & Co. KG. Drone photograph.
[25] Source: DMT Engineering Surveying GmbH & Co. KG. Drone photograph.

The crane had to be secured immediately for its stability and the subsequently necessary dismantling operation.

Figure 18: Secured crane. Photograph taken on 9 December 2022[26]

[26] Source: BSU.

Viewed from an external position, there was apparently only minor damage to the two bridges. A technical assessment revealed structural damage inside the hollow box girders.

Figure 19: Olympiabrücke bridge (eastern Holtenau high bridge) [27]

Figure 20: Deformed hollow box girder (Olympiabrücke bridge)[28]

[27] Source: WSPR Kiel.

[28] Source: WSPR Kiel. The BSU has been provided with additional photographs in the WSPR's photographic report. These made it possible to reconstruct the deformations on the hollow box girder.

Figure 21: Prinz-Heinrich-Brücke bridge (western Holtenau high bridge)[29]

Figure 22: Damaged hollow box girder (Prinz-Heinrich-Brücke bridge)[30]

Only part of the damage could be captured on photographs.

The NOK and both high bridges had to be closed temporarily.

[29] Source: WSPR Kiel.
[30] Source: WSPR Kiel.

After localising the counterweights and performing a risk assessment, VTS NOK II reopened the closed canal section at 2045 on the day of the accident, subject to conditions. Only one vessel was allowed to pass the scene of the accident at minimum speed and with maximum consideration/caution. Lock operation was organised so that maritime traffic did not build up in the area of the restricted northern harbour.

Based on the damage scenario, the LBV.SH decided on the clearance of the bridges. See Chapter 2.4 for details.

The closures had a considerable impact on the otherwise usual traffic flows. The passenger ferry ADLER 1, which regularly crosses between Kiel-Wik and Holtenau, was unable to cope with the rush of passengers during peak traffic hours. Since there were long waiting times, the much larger passenger ferry SCHWENTINE was deployed, which from 2 to 6 December 2022 initially also crossed between Kiel-Holtenau (Tiessenkai quay) and the Reventlou jetty. From 6 to 13 December 2022, the SCHWENTINE replaced the ADLER 1 on her route during peak traffic hours between 0530 and 1000 and 1400 and 1945.

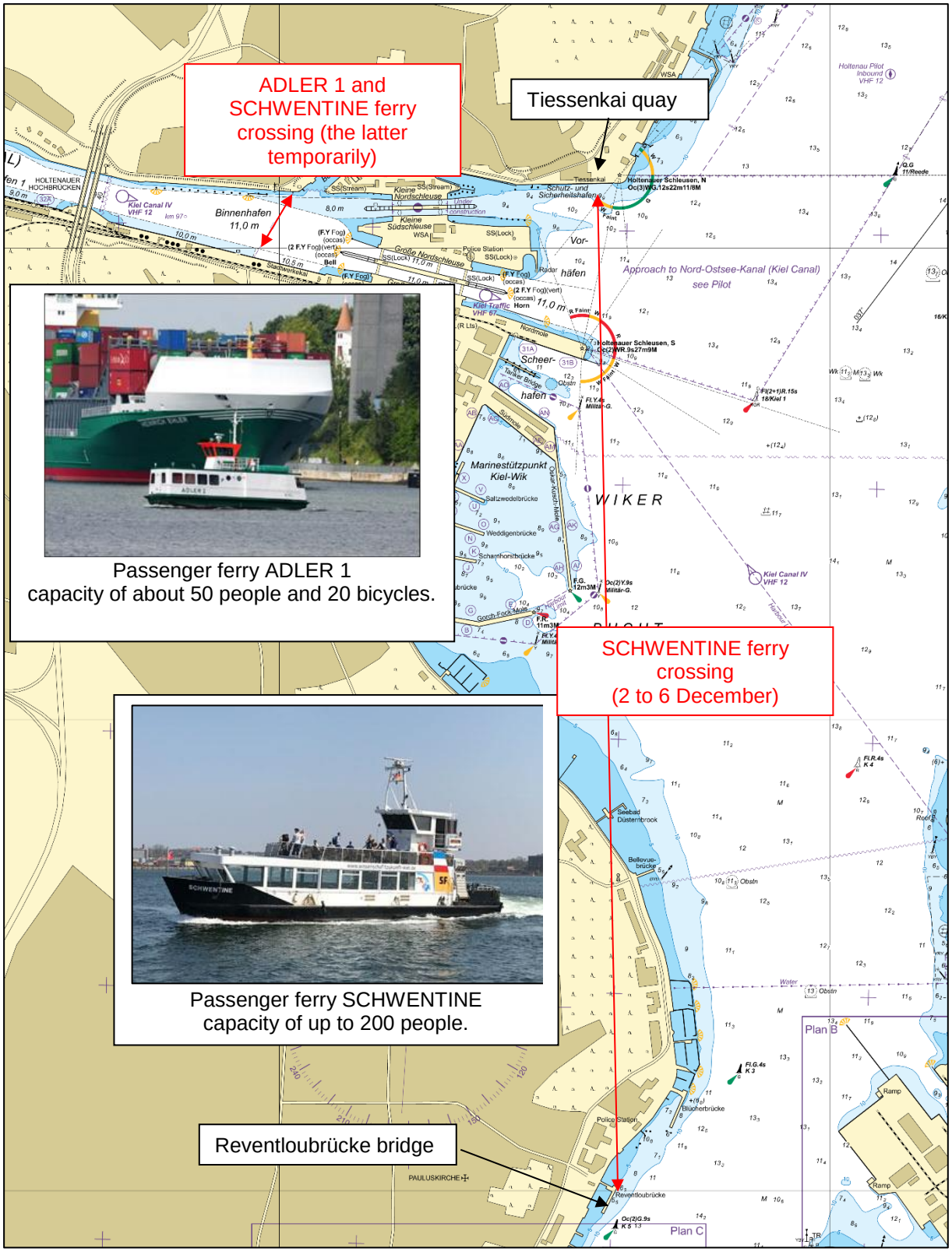

Figure 23: Ferry crossings following the bridge closures[31]

[31] Extract from the Kiel Fjord Navigational Chart, BSH DE34, Issue 13 of 16 June 2022. Corrected up to N.t.M 15/2023. Source of ADLER 1 photograph: WSA Kiel Canal. Source of SCHWENTINE photograph: Schlepp- und Fährgesellschaft Kiel mbH (SFK).

3.2.2 Cargo: One crane for the Port of Esbjerg

Inter alia, the BSU inspected the destroyed crane during the investigation on board the MERI and noted the shipping label prepared by the crane's manufacturer.

Figure 24: Shipping label[32]

Figure 25: Shipping label (close-up)

[32] Source: BSU.

According to the shipping label, the crane's height should be 38.25 m. The water level of the NOK was gauge datum +4.61 m when the accident happened. The Administration had authorised the passage up to a water level of gauge datum +5.20 m, meaning that this alone should have provided a buffer of 0.59 m. After assessing all the relevant facts obtained at the scene, there was no credible indication as to why the crane's tower should have been higher than the authorised maximum height of 40.2 m. According to initial internet research, LHM 600 cranes were offered in different heights. The investigators therefore considered how high the crane actually was and whether a crane other than the one specified on the shipping label may have been transported. In consultation with the BSU, the Federal Waterways and Shipping Agency (GDWS) instructed an external company to measure the clearance heights of both bridges and the height of the damaged crane a few hours after the collision.

According to the cargo documents and the crane inscription, the crane was intended for the Port of Esbjerg. A few days after the accident, the BSU received the ordered crane's (LHM 600 Litronic®) technical data from its recipient following a corresponding request. These data indicated that the ordered crane's tower height should be 43.2 m, i.e. 4.95 m higher than indicated on the shipping label.

The crane's manufacturer also answered all of the BSU's questions without delay. The Port of Esbjerg had ordered an LHM 600 – Evo6 – 58m LR.

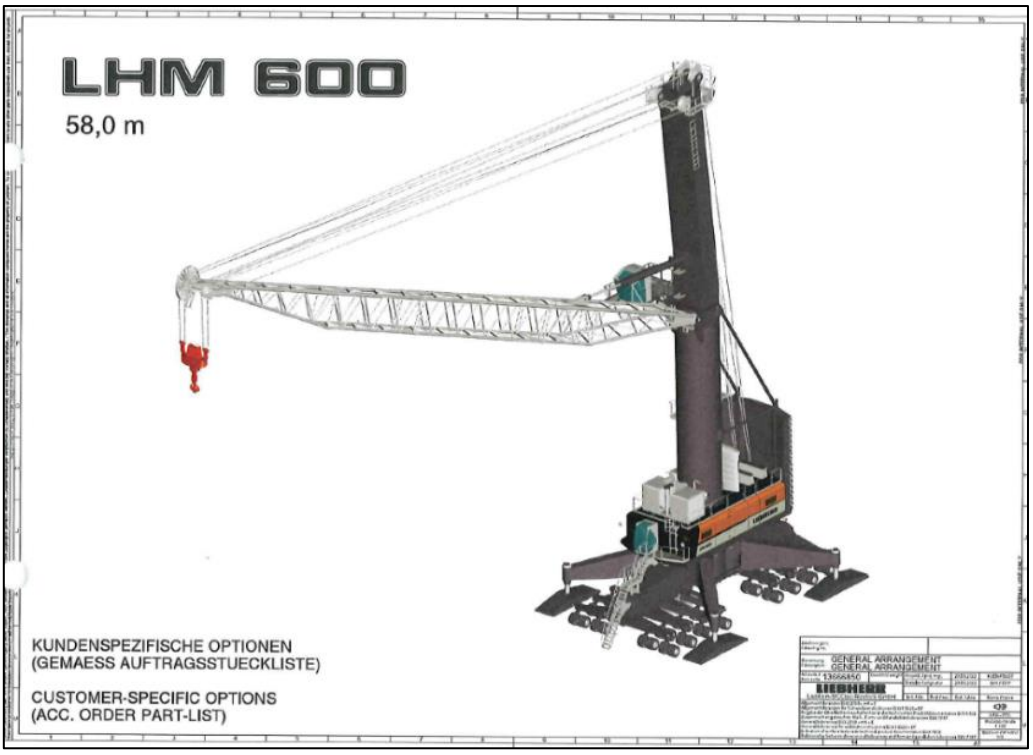

Figure 26: LHM 600 – Evo6 – 58m LR[33]

[33] Source: Liebherr-MCCtec Rostock GmbH.

The manufacturer determined the height of the tower based on the design drawing and did not remeasure it. Depending on how the crane is supported during transport, i.e. standing on wheels or supporting pads, the top edge of the uppermost cable pulleys should be at a minimum and maximum height of 42.7 m and 43.2 m, respectively. A tower height of 43,186 mm is specified in the relevant design drawing.

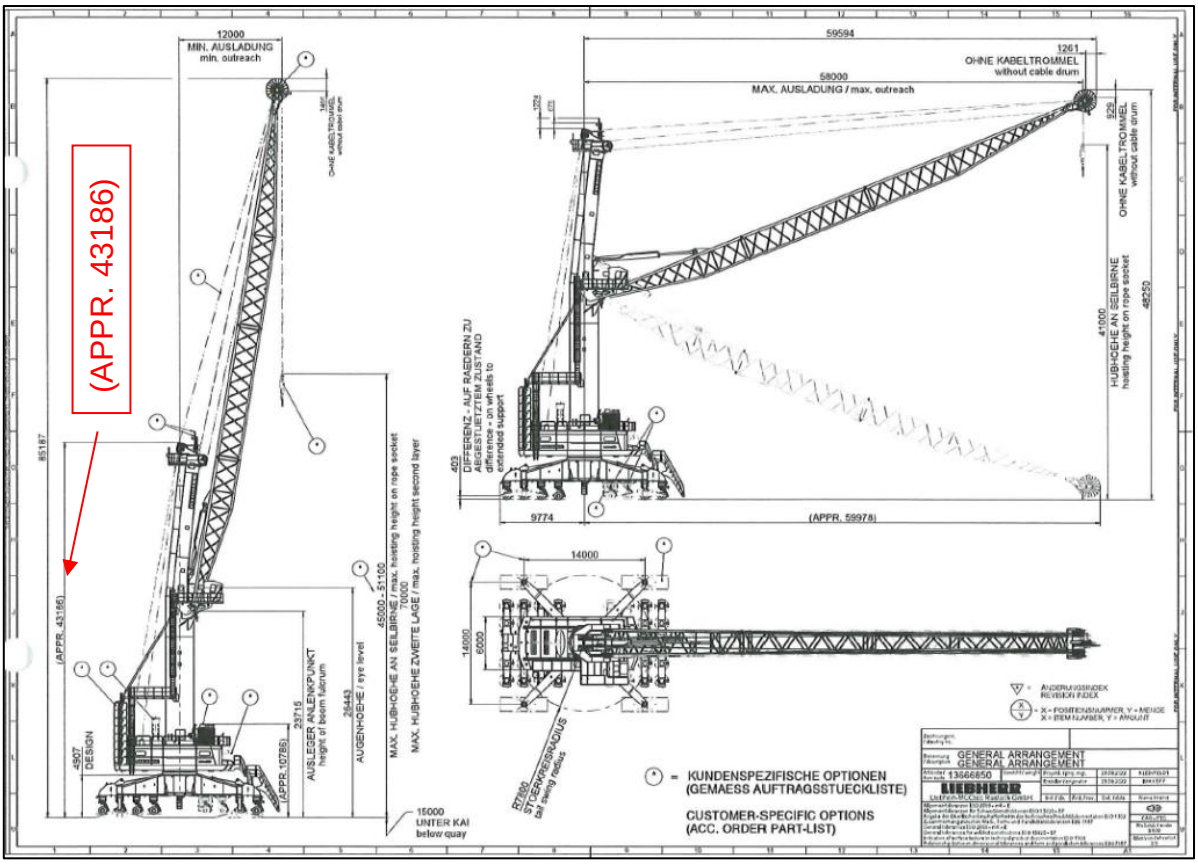

Figure 27: LHM 600 – Evo6 – 58m LR design drawing[34]

Taking into account the actual support and placement of the jib, the relevant height of the crane involved in the accident would have been 43.35 m according to the crane manufacturer's information, and not the 38.25 m stated on the shipping label. Accordingly, the ordered crane was 5.1 m higher.

The serial number (S/N) of the crane being delivered should be 141952. This number corresponded to the S/N on the loaded crane's nameplate.

[34] Source: Liebherr-MCCtec Rostock GmbH.

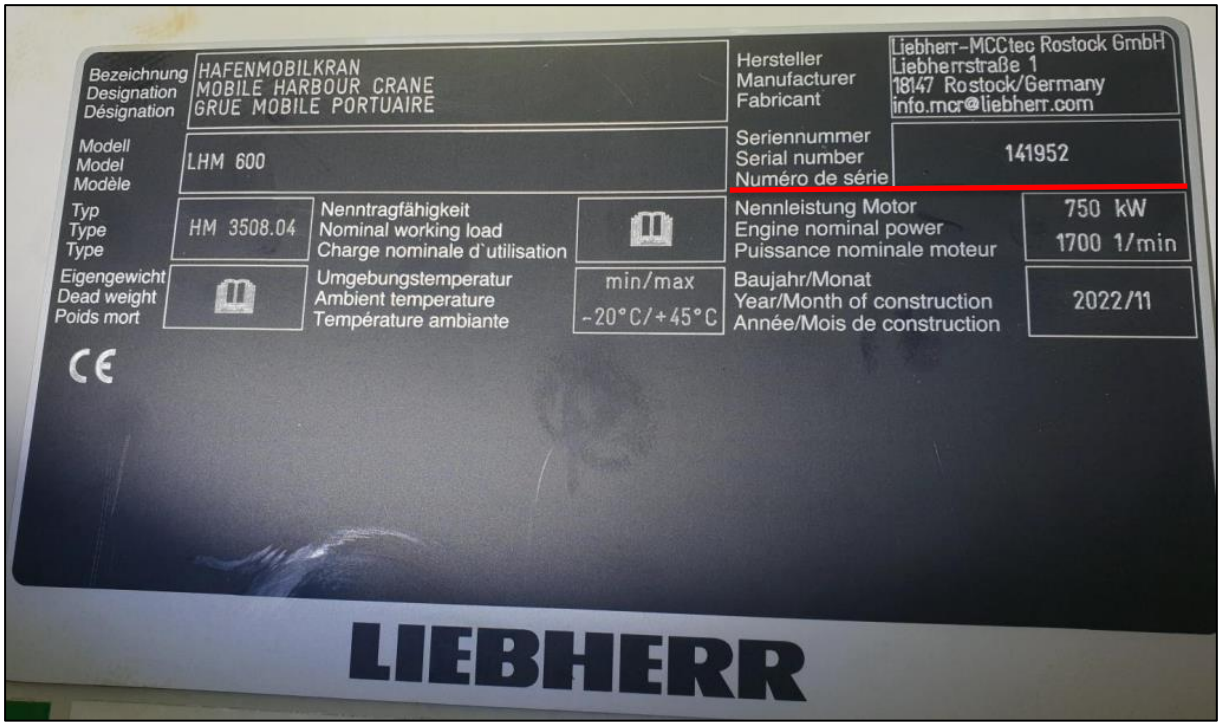

Figure 28: Nameplate of loaded crane[35]

According to the crane's manufacturer, the crane carried on the MERI was one of the first cranes from the sixth evolutionary stage (Evo6), introduced in 2022, to be delivered. In addition to changes in the design and build, the tower had been raised by almost five metres. The design drawing of this new LHM 600 Evo6 was released on 23 September 2022. The manufacturer believed that in this particular case there was evidently a problem in connection with the transport drawing sent to the owner, which did not show the current evolutionary stage. On being questioned, the manufacturer stated that numerous people from several departments were reportedly involved in preparing for shipping and loading and that internal company processes were being reviewed and improved as required following this accident.

In view of the fact that cargo information can be incorrect at any time for a variety of reasons and that such errors must always be recognised as early as possible in order to avoid similar incidents, the BSU subsequently concentrated on the relevant issues. The investigation focused in particular on the responsibility of the owner, the charterer, the master and the canal's Administration. The BSU remained in contact with the crane's manufacturer in order to take its investigation results into account.

3.2.3 Voyage and transport planning

The crane destined for the Port of Esbjerg was to be transported and delivered by Meriaura Ltd, which owns and operates the MERI. According to the charter agreement, Meriaura Ltd. was responsible for securing the cargo. The crane's manufacturer was the charterer of the MERI and, in particular, responsible for preparing the transport drawings and loading the crane. In the remainder of this report, the term 'charterer' refers to the crane manufacturer's department responsible for transport. Where

[35] Source: WSPR Kiel.

appropriate, the crew should support lashing operations, subject to local port regulations. Prior to this accident, both companies had carried out more than a hundred similar transport operations in the previous 15 years without any particular incidents, many of which – the crane's manufacturer estimates a mid-double-digit number – via the NOK.

On 21 June 2022, the charterer sent an email under project number 141.952, announcing the need to transport an LHM 600 from Rostock to Esbjerg on or after 9 December. Three files were attached to the email:

- one Project 141952, Type LHM 600 – 58 M packing list (draft version);
- one transport drawing (7600 897 12 00 000 000) dated 30 May 2022, and
- a shipping label (partly completed).

According to the information on the packing list, a LHM 600 – 58 M crane with a height of 3825 cm was to be transported. A tower height of 38230 mm was noted on the transport drawing.

Meriaura Ltd. sent its offer a few hours later. Meriaura Ltd. stated in the offer that they could transport via the NOK with a special dispensation if necessary. The crane's height was reportedly decisive. As a precautionary measure, Meriaura Ltd. submitted an offer for both the NOK passage and for the route around Skagen. The price for the route around Skagen was some 19% higher than the cost of the NOK passage.

The parties involved agreed on the date of transportation in the correspondence up until August, in particular. In an email dated 19 August 2022, the charterer pointed out for the first time in the context of the transport date that the crane to be transported would be a new version, an Evo6. There would be delays in the delivery of some of the components required and the transport date, which had been brought forward in the meantime, would have to be treated with a degree of flexibility.

On 22 August, Meriaura Ltd. enquired about the final crane height in order to double-check this for the preparation of the contractual offer.. The charterer sent an email which specified a crane height of 38.25 m. The contract, dated 19 August 2022, was signed. According to the email correspondence and freight rate, the NOK passage was agreed upon. No specific route can be inferred from the wording of the contract.

Meriaura Ltd. prepared the 'FROM ROSTOCK TO ESBJERG LHM 600 (141.952)' transport manual.

3.2.4 The transport manual

The transport manual serves as an operational guide and contains all the activities, procedures and calculations required for transport with the MERI in accordance with the introductory text. The structure is correspondingly extensive:

TABLE OF CONTENTS

Figure 29: Table of contents in the transport manual (part 1)

MERIAURA | TRANSPORT MANUAL LHM600(141.952)

Figure 30: Table of contents in the transport manual (part 2)

The following was noted during the investigation:

- Cover page: The cover page contains a table (title block) indicating in particular the version number, issue date, notes and the review status by the originator, Meriaura Ltd. Checks and revisions of the manual were not documented in this title block. According to the notes in the table, the first draft should be reviewed by the client, presumably the charterer.

Rev	Issue date	Notes	Meriaura Prepared	Meriaura Checked
1	17.10.2022	Issued for client's review.	[redacted]	

Figure 31: Documentation of drafts and reviews (initials blacked out)[36]

- Annex 2: According to the cover page, Annex 2 should contain a design drawing[37] (General Arrangement) of an LHM 550. Enclosed is the transport drawing of an LHM 600 sent by the charterer in June. No designation of the crane model

[36] Source: Extract from the cover page of the transport manual.
[37] The crane's manufacturer refers to the general arrangement plan in German as '*Konstruktionszeichnung*' [design drawing].

(LHM 600 Evo6) can be taken from the actual transport drawing. The transport drawing is relevant for the transport manual. This is the only source of crucial information, such as the tower height and the length of the crane jib to be lashed to the deck. Annex 2 also contains a draft version of the packing list.

- Annex 5 (stowage plan): According to the title block, the stowage plan was prepared on 17 October 2022. Neither the review nor the approval were documented in the title block. An amended version of this stowage plan was sent to the canal's Administration on 28 November 2022 for the granting of the special dispensation without documenting the change in the title block. In the amended version, the draught was increased by 0.78 cm in order to comply with the maximum permitted height for the NOK passage. Mathematically, the amended draught should have resulted in a height of 40.132 m based on the existing stowage plans, and not the height of 40.124 m specified in the amended plan.

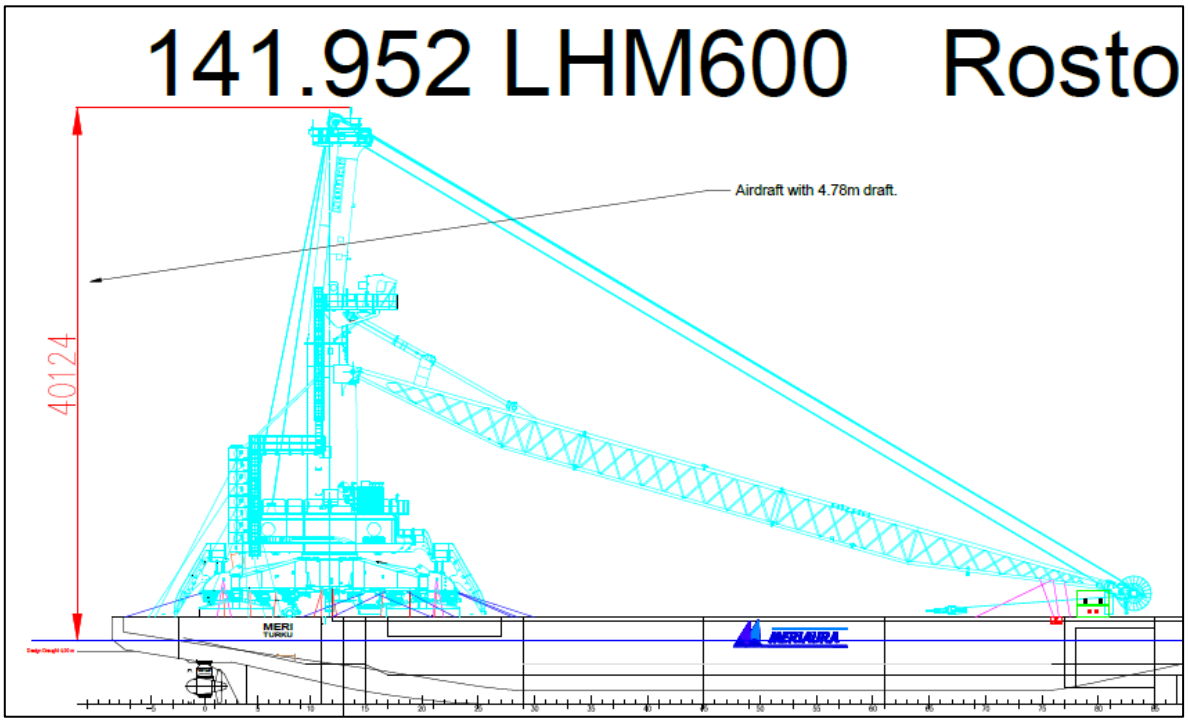

Figure 32: Height information from the stowage plan for the special dispensation

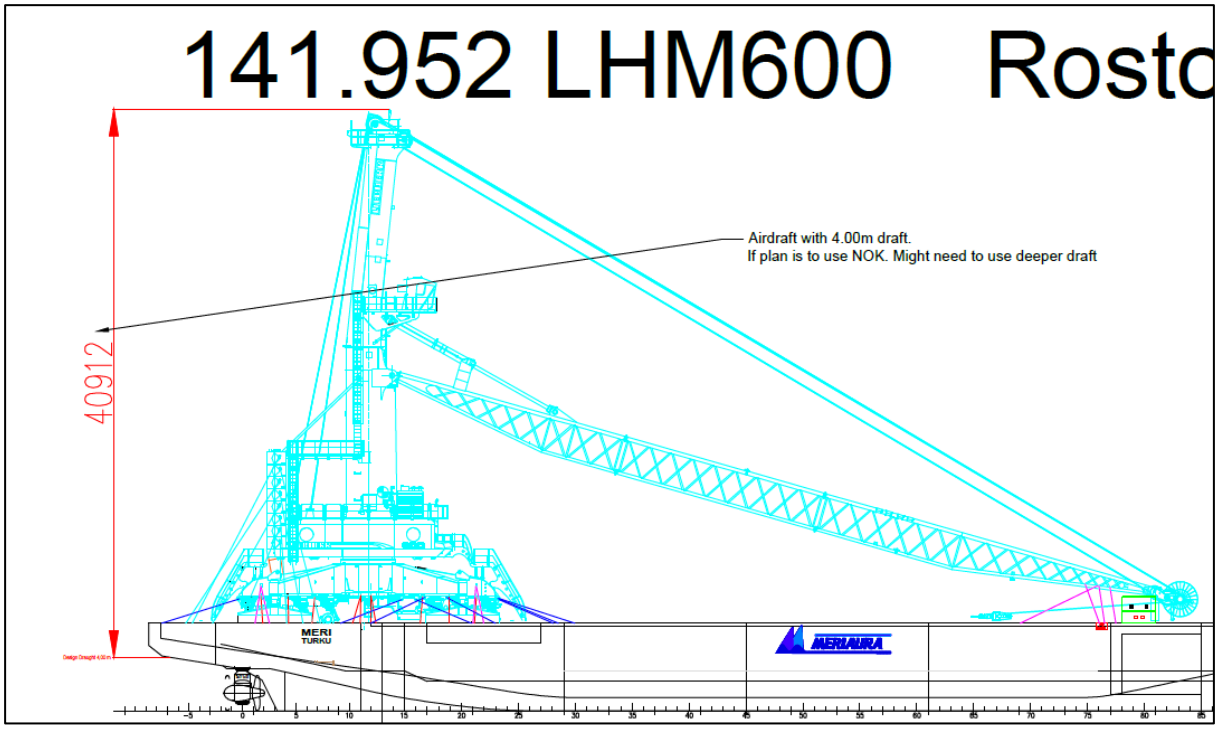

Figure 33: Height information taken from the stowage plan in the transport manual

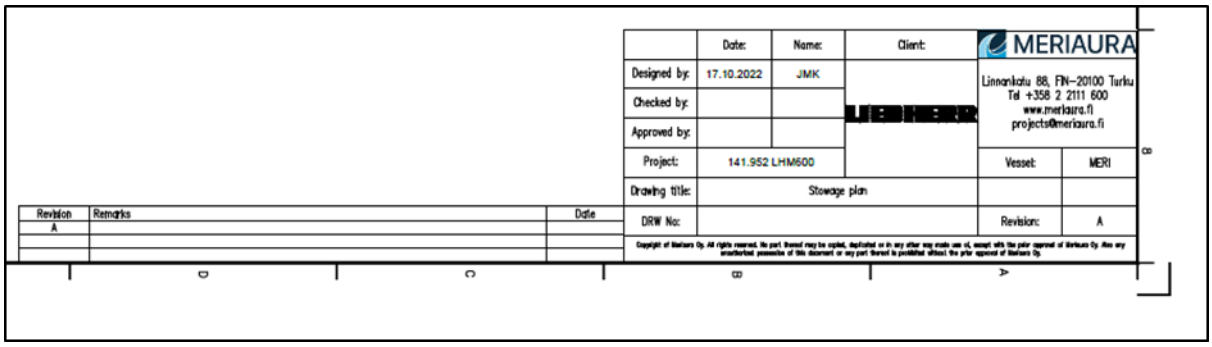

Figure 34: Identical title block in the stowage plan

(taken from the transport manual/application for the special dispensation)

- Chapter 8 (navigation)/Annex 9: This chapter refers to a list of waypoints in Annex 9. According to the heading, Annex 9 should include a voyage plan with ports of refuge. However, this Annex merely contains a road map in which a route through the NOK is drawn.

Figure 35: Voyage plan according to the transport manual[38]

In accordance with Chapter 8 route deviations are permitted if, in the opinion of the master, the weather and other environmental conditions necessitate a change. The introductory notes in the transport manual are somewhat broader. According to these notes, the master must define the best route possible, taking into account the weather, sea state and cargo restrictions, in particular. In view of the fact that the master had at least no traceable influence on the preparation of the manual, these statements are not consistent with the internationally binding rules according to SOLAS Chapter V Regulation 34. According to these rules, the master is solely responsible for voyage planning and Regulation 34-1 states that his discretionary power may not be restricted by the owner, charterer or company operating the ship. The master's professional judgement is authoritative. Germany has regulated this accordingly in the Ordinance on the Safety of Shipping (Verordnung über die Sicherung der Seefahrt) for all ships sailing on maritime waterways, among other things, in Section 9 (freedom of decision of the master in the interests of safe navigation). It states: "The master may not be prevented by the shipowner, the charterer or any other person from making a decision which, in the professional judgment of the master, is necessary for the safe navigation of the ship, especially in heavy weather and rough seas."[39]

[38] Source: Annex 9 to the transport manual.
[39] Ordinance on the Safety of Shipping of 27 July 1993 (Federal Law Gazette I p. 1417), last amended by Article 544 of the Ordinance of 31 August 2015 (Federal Law Gazette I p. 1474).

Neither Chapter 8 (Navigation) nor any other part of the transport manual contains any reference to the NOK's height restrictions and the special dispensation that may be required. The special dispensation from WSA Kiel Canal obtained on request was not included with the manual, either.

3.2.5 Loading

The crane was moved from the pier onto the MERI via the aft deck.

Figure 36: Loading the LHM 600 Evo6 onto the MERI[40]

Lashing was to begin in accordance with Section 6.1.6. of the transport manual when the crane was positioned according to the stowage plan in Annex 5.

[40] Source: Drone images, Liebherr-MCCtec Rostock GmbH. Photographs of this crane with jibs set down were not available.

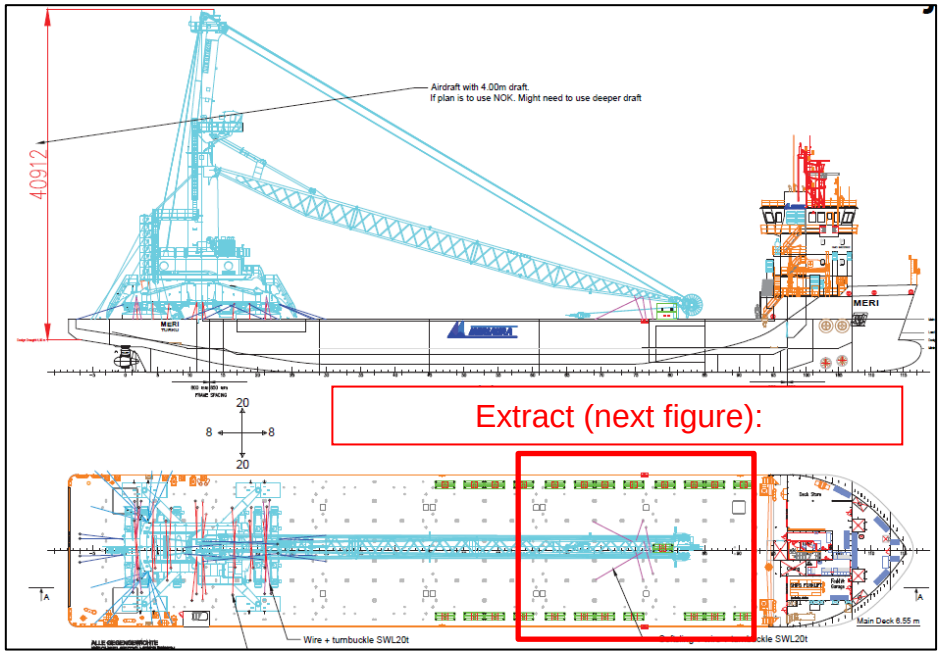

Figure 37: Stowage plan (extract) for Project 141952 LHM 600[41]

Inter alia, the position of the jib can be taken from this stowage plan.

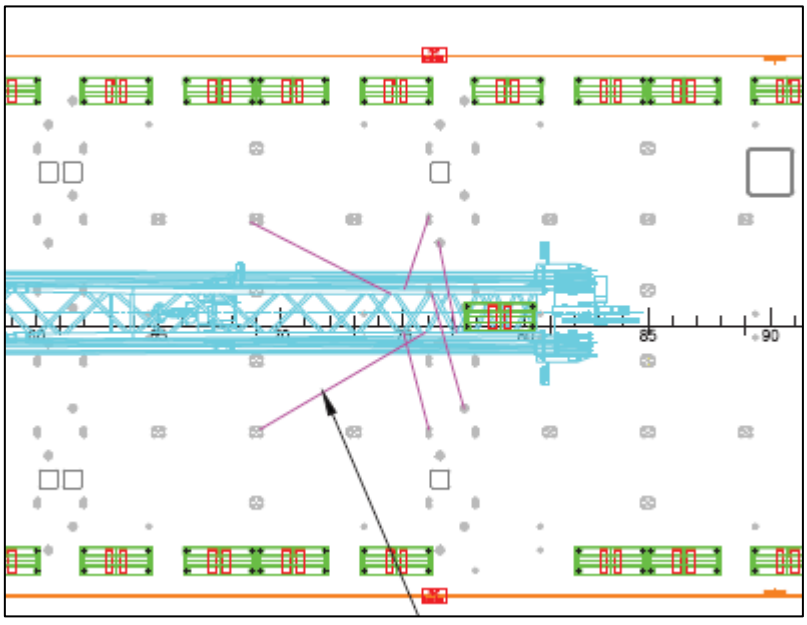

Figure 38: Stowage plan (detail) showing the position of the jib

According to the plan, the jib was to be set down with the ship's frame no. 85.

The transport drawing included in Annex 2 to the transport manual contains additional dimensions, including the length of the crane jib set down for transport. According to the attached drawing, the length of the set down crane jib should be 73.329 m. The transport drawing for the LHM 600 Evo6 actually transported, which the crane's

[41] Source: Transport manual, Annex 5.

manufacturer provided for the investigation, indicates a length of 71.712 m due to the modified design. According to the plan, the jib of the crane loaded on board was 1.617 m shorter.

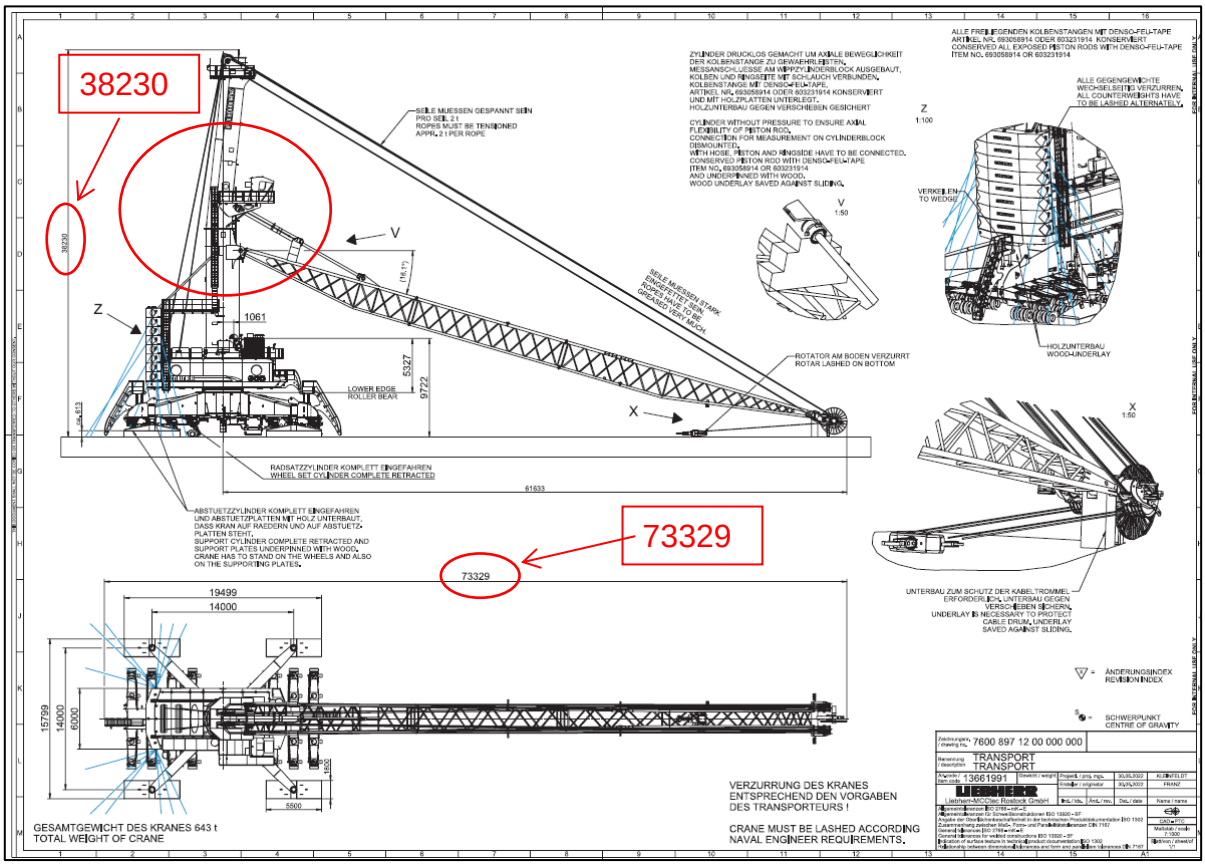

Figure 39: Transport drawing of the LHM 600 from the transport manual

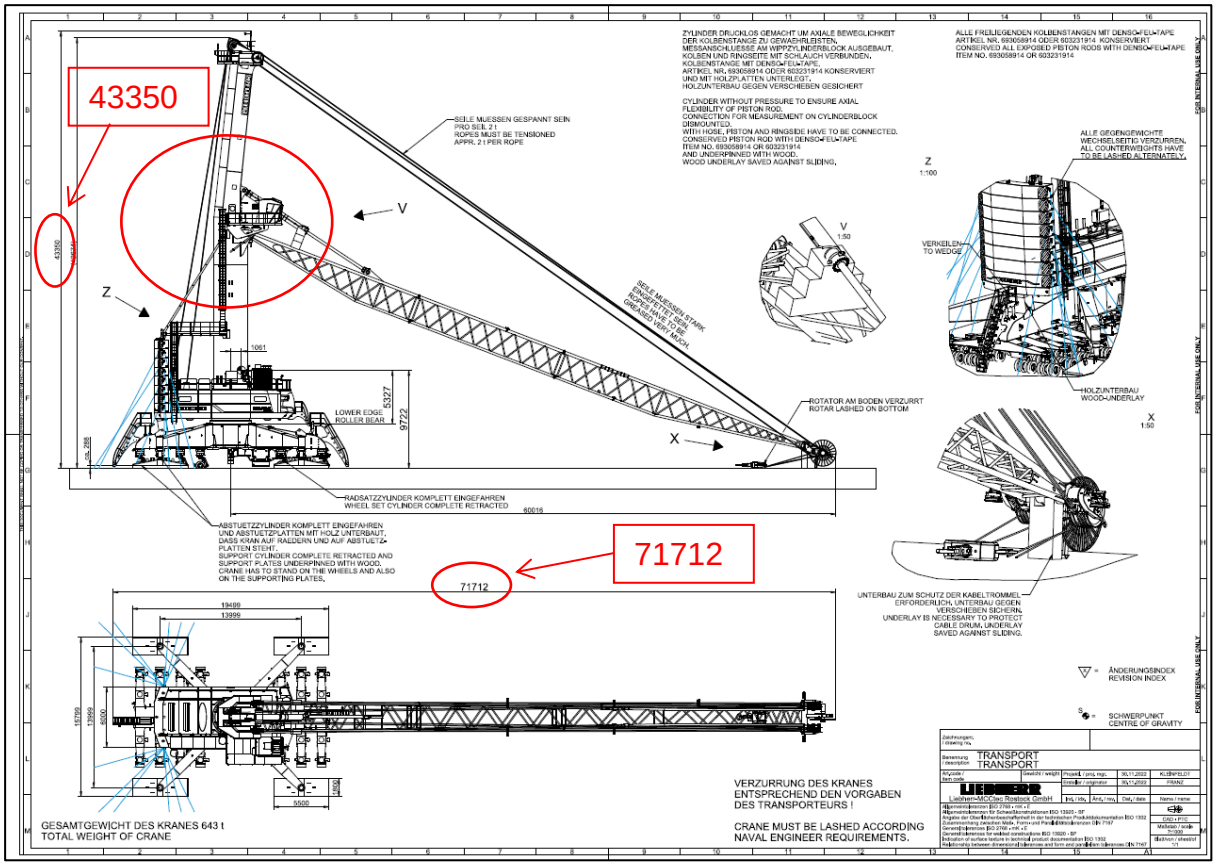

Figure 40: Transport drawing for the LHM 600 Evo6 located on board[42]

3.2.6 Admission for passage (special dispensation)

Ten bridges with a clearance height of 42 m must be passed when sailing through the NOK. Accordingly, the canal may only be navigated by vessels not exceeding a height of 40 m above water level.[43] According to Section 42(6) SeeSchStrO, the competent waterways and shipping office may deny the right of passage for vessels that do not comply with paragraph 1 or permit passage subject to certain conditions.

At 1205 on 28 November 2022, United Canal Agency GmbH (UCA Kiel) applied by email to WSA Kiel Canal on behalf of the MERI for admission for passage through the canal at a height of more than 40 m. The draft version of the stowage plan dated 17 October 2022 indicating a tower height of 40.124 m and draught of 4.78 m was attached to the informal application (see comments on the stowage plan in Chapter 3.2.34).

[42] Source: Liebherr-MCCtec Rostock GmbH.

[43] See Section 42(1)(1) (Admission for passage) in conjunction with the Notice issued in the Federal Gazette pursuant to Section 60(1) (Authorisation to issue shipping police notices and ordinances) SeeSchStrO. References: German Traffic Regulations for Navigable Maritime Waterways, as amended and promulgated on 22 October 1998 (Federal Law Gazette I p. 3209; 1999 I p. 193), as amended by Article 2 of the Regulation of 11 May 2023 (Federal Law Gazette 2023 I No 127). Notice of the Federal Waterways and Shipping Agency, Outstation North, of 28 January 2014 concerning the German Traffic Regulations for Navigable Maritime Waterways (Federal Gazette AT 31.01.2014 B7). A legible version of the SeeSchStrO in conjunction with all Notices in the Federal Gazette is published under ELWIS - Section 42 (2023-06-19).

WSA Kiel Canal reviewed the stowage plan to determine whether the height specified in the plan was correct. Admission for passage was granted one day later at 1550 on 29 November 2022 for a single passage with a maximum height of 40.2 m. It was limited until 5 December 2022 and subject to the following conditions:

1.) The maximum height must not exceed **40.20 m**. During the canal passage, no changes that could cause the maximum height to be exceeded may be made.

2.) If possible, the canal bridges must be passed in the middle.

3.) The admission for passage is valid up to a canal water level of gauge datum **+5.20 m**.

4.) The authorisation is subject to subsequent additions, amendments and supplements to conditions if so required for maintaining the safety and easy flow of traffic.

According to information given by WSA Kiel Canal, about ten admissions for passage are issued each year for a maximum of +0.20 m above the officially published height of 40 m. This extended height limit is not published; however, it is known to parties regularly involved in such application procedures, such as the UCA. From the Administration's point of view, only applications that can be approved are submitted.

Section 42(1) SeeSchStrO lays down the basic requirements for admitting any vessel or composite unit, whether pushed or towed, floating gear or floating plant and installations wishing to navigate the NOK. The following requirements must be met:

- the dimensions (length, breadth, height, draught) made known by the Administration in accordance with Section 60(1) SeeSchStrO may not be exceeded;

- stability and manoeuvrability must be ensured;

- the rudder-angle indicator must be adequately illuminated;

- objects shall not protrude beyond the side of the vessel, and

- the safety and easy flow of traffic shall not be affected in any other way.

3.2.7 Monitoring of ship and equipment heights (NOK locks)

VTS NOK monitors the heights reported by ships in the NOK locks so as to avoid all bridge allisions if possible. Since monitoring failed in the case of the MERI, the theoretical and practical aspects of the monitoring strategy were investigated.

3.2.7.1 Internal administrative provisions for height monitoring

In accordance with an internal administrative provision[44], the Große Schleuse lock control centre was operated by two nautical assistants in the lock service, a so-called first and one other assistant.

The duties of all personnel belonging to VTS NOK, which includes the lock personnel, are documented in administrative provisions[45].

Section 7(3) VV-WSV 2408 describes the basic duties of nautical assistants. Accordingly, nautical assistants procure data, process it, make it available to the nautical supervisor (NvD), who has primary responsibility, and assist her/him in carrying out her/his duties. The nautical assistant only undertakes measures in relation to shipping on the instructions of the NvD.

According to Section 7(2) VV-WSV 2408, the NvD is responsible for the administrative and technical supervision of the federal employees during her/his watch. She/he analyses all available data and information and takes the necessary action with regard to shipping. As part of her/his duties, the NvD performs the river and navigation police duties assigned to the competent waterways and shipping office in the latter's capacity as the river and navigation police authority. The NvD is responsible for the measures that have been ordered and executed by her/him.[46] The NvD performs her/his duties from VTS NOK's control station, which is located at the lock in Brunsbüttel, where they are assisted by a navigator in control services and a nautical assistant in control services. According to the Shipping Administration, the controllers are basically responsible for one direction of travel, eastbound or westbound.

Inter alia, VV-GDWS 24-7 to Section 7(3) VV-WSV 2408 defines the specific tasks of the assistants in the lock service: The first nautical assistant in the lock service directs and monitors operation of the Große Schleuse lock during her/his watch. She/he coordinates the approach of shipping to the large and small locks.[47] In accordance with the applicable Annex 0 to the VV-GDWS 24-7, her/his duties include monitoring the ship dimensions permissible for canal traffic and supervising the nautical assistants in lock service and the personnel in lock deck service, which involves the delegation of necessary work in the lock area[48].

[44] See Annex 0 (additional operating instructions for Vessel Traffic Service NOK in Brunsbüttel) to VV-GDWS 24/7 (administrative provision of the Federal Waterways and Shipping Agency).
[45] Administrative provision of the Federal Waterways and Shipping Administration (VV-WSV 2408) in conjunction with the supplemental administrative provision of the Federal Waterways and Shipping Agency (VV-GDWS 24-7) – operation of Vessel Traffic Service NOK 2019 and the applicable Annex 0: Additional operating instructions for Vessel Traffic Service NOK in Brunsbüttel.
[46] NvDs manage the VTS NOK watch in shifts with the support of nautical assistants. The main duties of VTS NOK include
- prevention of threats to the safety and ease of shipping;
- prevention of dangers emanating from shipping, including those to the marine environment;
- keeping waterways in a condition fit for shipping;
- traffic flow control in the sense of the uniform optimum management and control of maritime traffic.

[47] See VV-GDWS 24-7 to Section 7(3) VV-WSV 2408.
[48] See Annex 0 to VV-GDWS 24-7.

The nautical assistant in the lock service supports the first nautical assistant in the lock service[49]. In addition to other duties, Annex 0 states that she/he monitors the ship dimensions permissible for the canal and controls the ship heights permissible for the NOK in accordance with Annex 6 to VV-GDWS 24-7.

Annex 6 sets out the specific rules for monitoring vessel and equipment heights in the locks on the NOK as follows[50]:

a. In the case of vessels whose height above water level is 37 m or more, the master shall sign a declaration (Annex 6/1) stating the actual height of the vessel and assuring that the permissible height of 40 m above the water level will not be exceeded during the canal passage.

b. Vessels for which there are doubts about compliance with the permissible height above the water level of 40 m shall be inspected in the locks with particular diligence. In principle, doubts generally exist in the following cases:

   - in the case of vessels (e.g. floating cranes and floating equipment) whose rigging height can be changed above the permissible height of 40 m above the water level at any time;

   - for vessels with a declared height above water level of 37 m or more. [This does not apply to vessels that regularly (quarterly) navigate the NOK and whose maximum height cannot exceed 40 m above water level. In such cases, the first nautical assistant in the lock service must ask the master on VHF before the NOK passage and document whether the height has changed due to structural measures as compared to the last voyage through the NOK in the measurements report.];

   - for vessels with high superstructures/masts/antennas whose height is not clearly indicated and/or if it is perceived that the height is 37 m or more above water level.

[49] See VV-GDWS 24-7 to Section 7(3) VV-WSV 2408.

[50] The BSU has inserted the structure contained in the following information so as to make the text easier to understand from the perspective of the BSU.

In the aforementioned cases, the first nautical assistant in the lock service must determine the height above water level of the vessel in question using the appropriate altimeter.[51] The measurements shall be made in accordance with the attached instructions (Annex 6/3) and documented in a specified report.

If measurements using the measuring instrument

- are not usable;
- cannot be made, or
- the average measurement exceeds the value of 39 m above water level,

then the vessel traffic service must determine the maximum height of the vessel through presentation of the appropriate documents from the vessel (e.g. general arrangement plan or a height certificate from a recognised classification society). The height determination must be presented by the ship's command and checked for plausibility by the vessel traffic service. If doubts persist, then the height of the vessel must be determined by a measurement carried out on board.

[…]

If the master cannot demonstrate in a credible and convincing manner that the permissible height of 40 m is not exceeded, then the vessel's height must be reduced through appropriate measures, such as lowering the derrick/crane jib or ballasting, before the passage through the canal, until there is no longer any doubt as to compliance with the permissible height, otherwise the NOK passage must be prohibited.

The results of the height inspection with the measuring instrument shall be entered in the measurements report (Annex 6/2). The height assessment by the ship's command based on the ship's documentation and/or local remeasurements must also be entered in the measurements report and signed by the ship's management.

The measurement accuracy of the measuring instrument must be verified using the defined reference object (Annex 6/4). This check must be recorded in the measurements report.

The finally determined value of the height inspection must be entered in the SDPS[52] or SDR[53]. In the event of questionable results or heights ≥ 39 m, the corresponding measurements report must be sent to the NvD for evaluation.[54]

---

[51] See Annex 6 to the additional operating instructions for Vessel Traffic Service NOK. Monitoring of ship and equipment heights in the locks on the NOK.

[52] SDPS: Ship data processing system (according to the associated Annex 0, where this term is abbreviated to NOKweb).

[53] SDR: Ship data reconciliation (according to Annex 0).

[54] See Annex 6 to the additional operating instructions for Vessel Traffic Service NOK. Monitoring of ship and equipment heights in the locks on the NOK.

3.2.7.2 Height measurement in practice (the MERI case and others)

In particular, the BSU's below knowledge of the height measurements of the MERI and other vessels is based on

- WSPR Kiel's investigation note of 30 November 2022 on the questioning of the lockmasters on watch regarding laser altimetry in conjunction with the photographic report of WSPR Kiel of 1 December 2022 (images of the altimeter, reference point, measurement reports of the MERI and other ships);

- the measurements report and logbook entries for the lock;

- the entries in the Kiel Canal operating log;

- the visual inspection of the measuring arrangement in the lock at Kiel on 16 January 2023 and the BSU's interviews with the nautical assistants in the lock service involved in the height measurement of the MERI;

- the personal interview conducted on 10 March 2023 by the BSU with the NvD working in VTS NOK (Brunsbüttel) on the day of the accident;

- the measurement instructions according to Annex 6-3 (Version 2.1), and

- the Metrological report. Analysis of measuring arrangements, see Annex 9.3 to the report.

At the Kiel-Holtenau lock, the nautical lock assistants immediately attempted to measure the height of the MERI, as they had been provided with the MERI's admission for a single passage with a maximum height of 40.2 m via the SDR and basically every vessel with a specified height of 37 m above water level must be inspected.

A Riegl RTS21-HA laser measurement system mounted on a pole was available for the measurement.

Figure 41: Altimeter in pre-installed holder[55]

This holder is located in Kiel next to the lock service's control centre. View of the northern lock chamber. External storage battery on the ground. The measuring instrument and storage battery are kept separately in the control centre when not in use.

The instrument consists of the L-Mount 21-HA system component for the angle measurement and FG21-HA laser tape for the distance measurement. Basically, the RTS21-HA is inserted into an existing bracket fitted to the balustrade of the lock control centre's balcony area and fastened with wing screws. The instrument is levelled using knurled screws and a permanently mounted spirit level. The power supply is provided by a storage battery. The RTS21-HA is ready for use after the instrument has been calibrated using a reference point near the control centre.

[55] Source: WSPR Kiel.

Figure 42: Altimeter mounted and ready for operation[56]

Figure 43: Altimeter levelled using a spirit level[57]

[56] Source: WSPR Kiel.
[57] Source: WSPR Kiel.

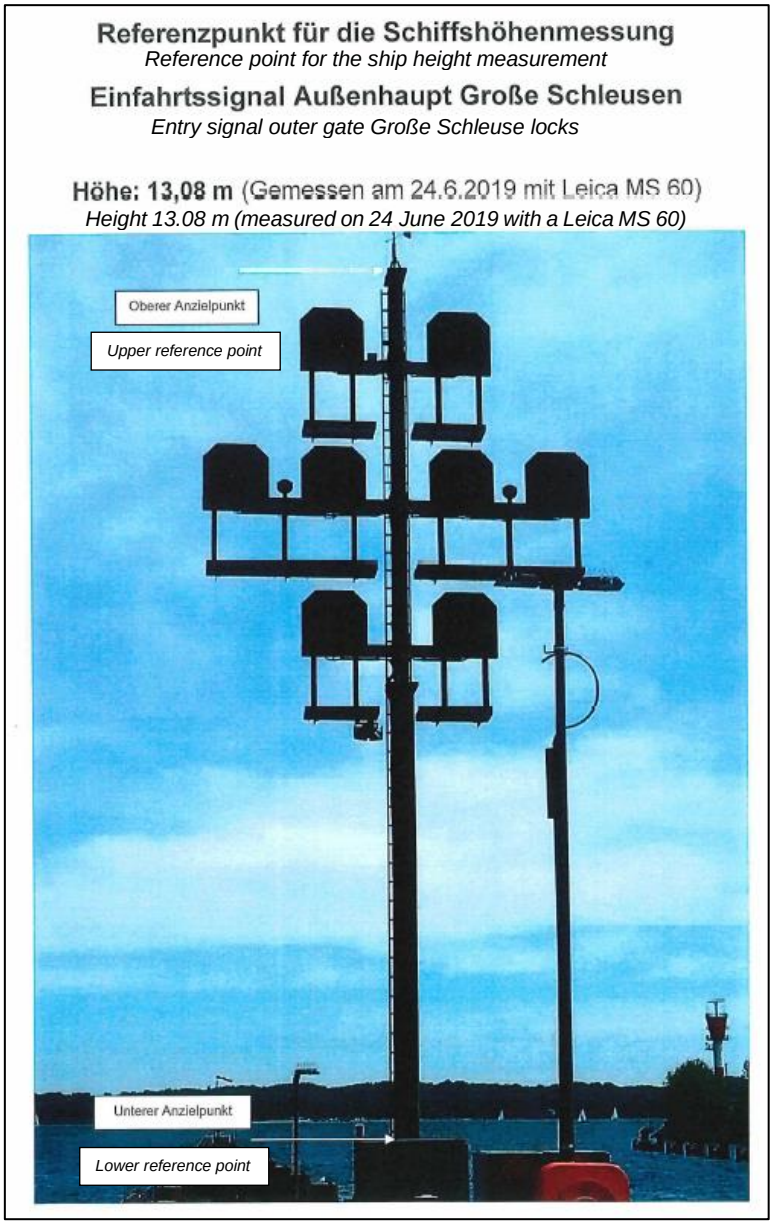

Figure 44: Reference point – one of several in the lock area[58]

The first measuring point is targeted through an lens system and the measurement triggered by pressing the TRIG/PROG button. The distance measurement is based on a pulsed semiconductor laser and requires the reflection of the laser beam at the measuring point. If the measurement is successful, the measured distance and the inclination angle of the first measurement appear on the display for one second or for as long as the TRIG/PROG button is pressed. As soon as a '2' appears on the display, the second measuring point can be targeted and the measurement triggered. The measured height is then automatically displayed to the nearest centimetre and the laser tape ready for another measurement. According to the regulations, five measurements, which must not deviate from each other by more than 15 cm, are required.

[58] Source: WSA Kiel Canal.

Both the waterway police and the BSU investigators tested the device on different days in good visibility. In both cases, the heights of the vessels in the locks at these times could be measured.

In the case of the MERI, the laser tape did not detect an upper fixed point according to the available information. This was neither possible with the help of light beams nor by attempting to carry out the measurement from other measuring points. Since the measurement could not be carried out, the first nautical lock assistant asked the MERI's master about the height and checked this information for plausibility.

The assistant could access the special dispensation and associated stowage plan via the SDR. Based on this, he estimated 38.40 m as the tower height and added 30 cm as a safety margin for the dunnage under the side supports. This resulted in a calculated tower height of 38.70 m (38.40 m crane height (plan) plus 0.30 m safety margin). A ship's side height (water surface to the upper edge of the deck) of 1.61 m was measured using the altimeter. Based on these data, a calculated height of 40.31 m was determined, which was higher than the authorised height of 40.20 m but could be compensated for by ballast. Communication of the verification and the required clearance by the NvD was made by phone.

According to the WSP's log and when reviewing the measurement reports made during various ship calls, it was noted that entries in logs requiring completion by hand were sometimes left open and height measurements could not always be carried out properly. When asked by the BSU, the nautical lock assistants encountered on scene estimated the number of successful height measurements at around 90%.

3.2.8 Metrological report

After assessing the initial findings of the investigation on board the MERI, the investigators considered the actual crane and clearance height. A few hours after the allision, the GDWS commissioned a metrological report from DMT Engineering Surveying GmbH & Co. KG (DMT[59]) with a view to reconstructing the prevailing conditions (clearance heights/crane height) at the time of the damage event. To this end, DMT recorded the local infrastructure with survey measuring arrangements such that the derived measurement data could be linked with other information, such as water levels, crane measurements, the ship's draught, etc.

DMT determined the following clearance heights based on the official vertical datum:

Olympiabrücke bridge: 42.50 m
Prinz-Heinrich-Brücke bridge: 42.55 m

[59] DMT: Deutsche Montan Technologie

The water level at the time of the accident was 4.62 m and thus 0.38 m below the vertical datum.

The clearance heights at the time of the accident were therefore as follows:

Olympiabrücke bridge: 42.88 m
Prinz-Heinrich-Brücke bridge: 42.93 m

A total height (from the waterline) of 44.12 m was determined for the highest point of the crane tower after the allision.

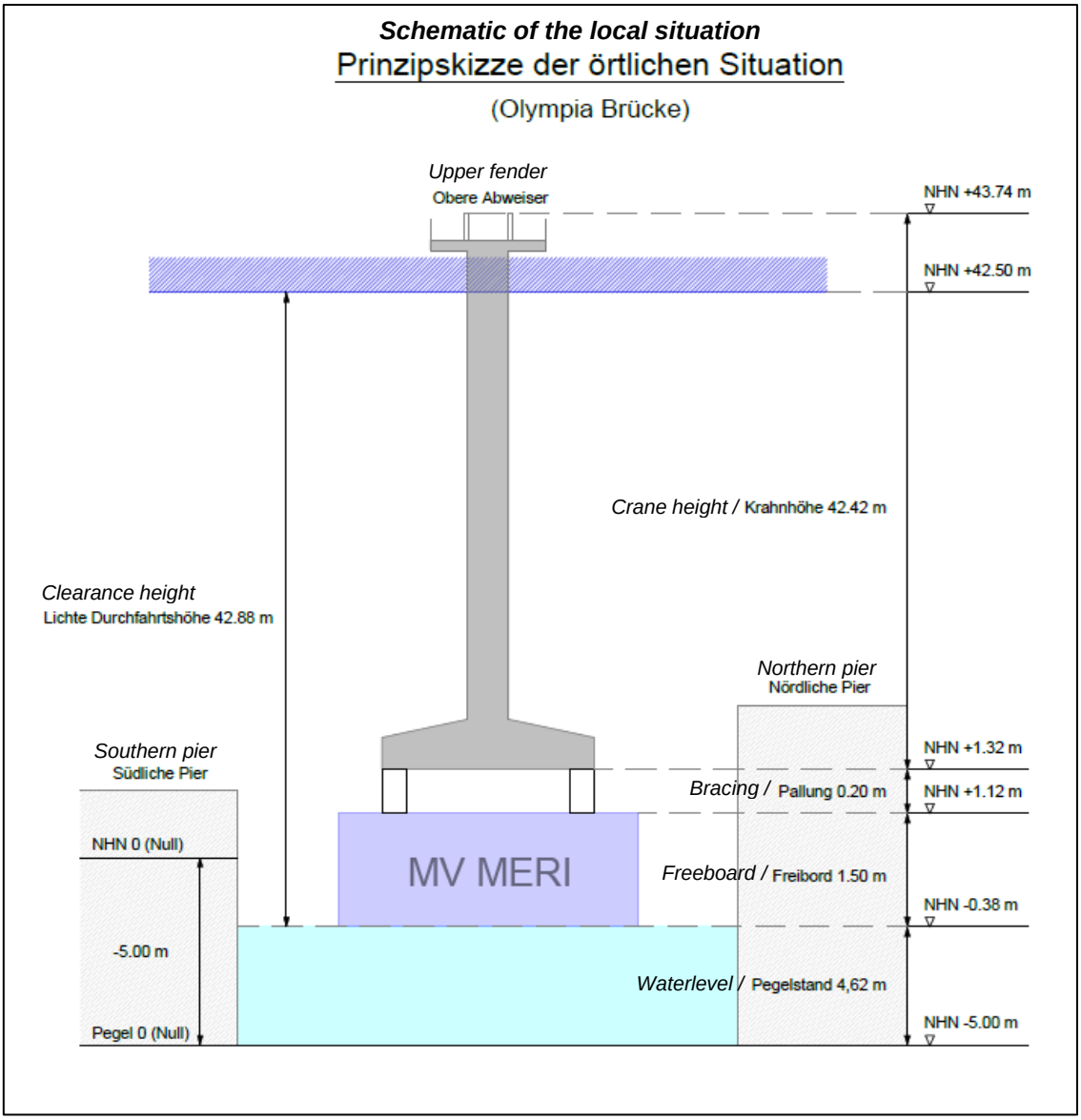

Figure 45: Drawing with measurements of the crane/bridge height (Olympiabrücke)[60]

[60] Source: Annex 2.1 to the metrological report of DMT (see Annex 3 to this report).

DMT arrives at the following conclusion in its report: Based on statically determined values, the metrological report shows the actual situation that prevailed at the time of the damage event. This 'static analysis' has demonstrated that the given crane height[61] on the MV MERI was too high for the respective passages.

Bridge	Clearance height	MV MERI	Difference
Olympia	42.88 m	44.12 m	+1.24 m
Prince-Heinrich	42.93 m		+1.19 m

The canal's Administration (WSA) issued a maximum air draught of 40.20 m for the passage permit. This meant that the MV MERI with cargo (LHM 600) exceeded this value by 3.92 m.

As part of the application for the canal passage, the technical drawing indicated a height of 38.25 m for the crane alone when lashed with hydraulic supports extended. The height specified corresponded with the package document attached to the crane. The actual measured height of the crane of 42.42 m thus deviated from the data attached to the crane and used by Meriaura Ltd. in its calculation by 4.17 m.

The basis of these results is documented in the attached expert report (Annex 9.2).

3.2.9 Bridge allisions on the NOK

The BSU's research indicates that three other bridge allisions have occurred on the NOK in the past 35 years.

On 7 October 1988, motor vessel FORT, sailing under the flag of Cyprus, crashed into the old Prinz-Heinrich-Brücke bridge. During a downpour, a cargo hatch was to be closed with the ship's own derrick just as she was passing the bridge. The derrick struck the lower edge of the bridge several times and the bridge had to be closed immediately.[62]

On 11 December 1993, the eastbound multi-purpose vessel KANOK NAREE damaged the lower steel structure of the high railway bridge at Hochdonn with a derrick that was set too high for this bridge. Rail traffic had to be suspended for almost three days. According to the ruling of the Maritime Board, this accident happened because the master, when determining the height of the vessel above water level, applied a measurement relating to the length of the heavy-lift derrick contained in the ship's rigging plan to the entire length of the boom, while the measurement was actually only for a shorter part of the derrick, i.e. the so-called buckling length (distance between the foot clevis pin and the upper load block).[63]

[61] In the opinion of the BSU, the term "given crane height" stands for "measured crane height".

[62] *Geschichte Holtenaus – Die Prinz-Heinrich-Brücke* [Holtenau's history – Prinz-Heinrich-Brücke bridge]. (apt-holtenau.de) (2023-05-23).

[63] Ruling of the Maritime Board (Ref.: SeeA1-DI 8/94 K), archived at the Federal Archives under Ref. B 175/737: Motor Vessel 'Kanok Naree'.- *Beschädigung der Eisenbahnhochbrücke Hochdonn über den Nord-Ostsee-Kanal bei Kilometer 18,8 am 11. Dez. 1993* [damage to the high railway bridge over the Kiel Canal at Hochdonn, kilometre 18.8, on 11 December 1993] - Archivportal-D (2023-05-23). At the request of the BSU, the Federal Archives released the ruling for the purpose of marine casualty

On 7 December 2006, the multi-purpose vessel WILMA struck the high bridge at Levensau because the ship's crew was moving one of the three cranes on board without paying attention to the maximum permissible height when passing the bridge.[64]

3.2.10 Expert report on measuring arrangements for height monitoring

On 9 December 2022, the BSU attempted to determine the height of the damaged crane from the deck of the MERI using shipboard equipment in good visibility conditions. To obtain the required values for an angle calculation,

- a laser distance meter;
- a sextant (knowing full well that sextants are generally no longer carried on board), and
- a tape measure

were used.

The measurement using the laser distance meter failed because it was not possible to find a suitable measuring point in the uppermost area of the crane tower with the naked eye and the device subsequently switched off repeatedly before the measurement began. Since this problem could not be rectified on scene, no further measuring attempts were made.

The height measurement with the sextant failed due to the lack of obvious fixed points at the lower and upper end of the crane. Furthermore, it was not possible to reliably measure the horizontal distance between the leading edge of the access ladder and the roller in the crane top in the ship's longitudinal direction, meaning that the results were not useful given the already known height of an undamaged crane. The 'supporting measurements' carried out with the tape measure (eye level/distance from the lower edge of the access ladder to the deck) were therefore irrelevant.

In view of the fact that none of the parties involved in the transport had measured the height of the crane's tower after loading and neither the height measurements in the lock nor the BSU's measurements using shipboard equipment yielded useful results, the BSU also contacted the surveying department at DMT Engineering Surveying GmbH & Co. KG (DMT), so as to be able to name and describe suitable measurement methods with technical expertise. Possible measurement methods were first categorised in initial discussions:

investigation 582/22 MERI (official purposes). This ruling will be available to the public from 2026. Maritime Boards investigate marine casualties with the aim of penalising involved holders of certificates of competency in navigation or ship operation.

64 Federal Bureau of Maritime Casualty Investigation – Investigation Reports – Investigation Report 607/06 (bsu-bund.de) (2023-05-23).

Category		Measuring equipment	Measuring arrangement	Scale	Operation	Execution
1	1.1	Tape measure	direct	1-dimensional	Distance measurement	manual
	1.2	Distomat				
2	2.1	Tacheometer	indirect	3-dimensional	Direction and distance measurement	
	2.2	Laser scanner				
3		Drone	direct		GPS-based	
4		Measuring camera	indirect		Photogrammetric	
5	5.1	Photoelectric barrier	optoelectronic			automatic
	5.2	Radar system	radiometric			

Based on these categories, the BSU commissioned DMT with preparing an expert report on measuring arrangements for monitoring ship and cargo heights in the locks on the NOK. In particular, the report was intended to define and evaluate measuring arrangements

- that are carried out by the canal's Administration now or should be carried out in the future, and

- that could be carried out at the request of the ship and traced by the canal's Administration.

Taking into account the principle of proportionality, more complex measuring arrangements that could be used to monitor ship heights independently of time and continuously in front of the locks should only be described basically, as the ship is generally responsible for determining the height of the ship including the cargo and a safe ship route can only be planned with knowledge of the height, *inter alia*. In particular in the carriage of project and heavy cargoes several characteristics of the cargo are detrimental for the safe carriage and such characteristic can hardly be determined by the carrier or the crew themselves. Just to mention the weight, the height, the center of gravity and suitable lashing points of heavy/oversize cargoes. In accordance with Chapter VI, Part A, Regulation 2 No. 2.1 of the SOLAS Convention, shippers shall provide appropriate information in advanc. Moreover, bridge allisions on the NOK are rare occurrences and have not resulted in physical injury thus far (see Chapter 4.1010).

3.2.11 Emergency management: Bridge safety

The bridge structures withstood the allisions and did not collapse. It took 38 minutes for both bridges to be closed. Until then, traffic could use the bridges. In view of the fact that both bridges were structurally damaged and had to be closed to all motor vehicles until 7 December 2022, the sequence of events leading up to the closure was investigated.

The following investigation is chiefly based on the recordings of the VDR, the VHF radiotelephone, information from VTS NOK, WSPR Kiel and Schleswig-Holstein's regional authority for roads and transport (LBV.SH).

According to the LBV.SH, damage to the carriageway, footpaths or cycle paths was not noticeable to bridge users after the allisions. According to the LBV.SH, there was theoretically a risk for users of the structures during the time between the allisions and the closure, as the structures could have gradually failed.

Based on the information available, the following timeline from the allisions to closure is produced:

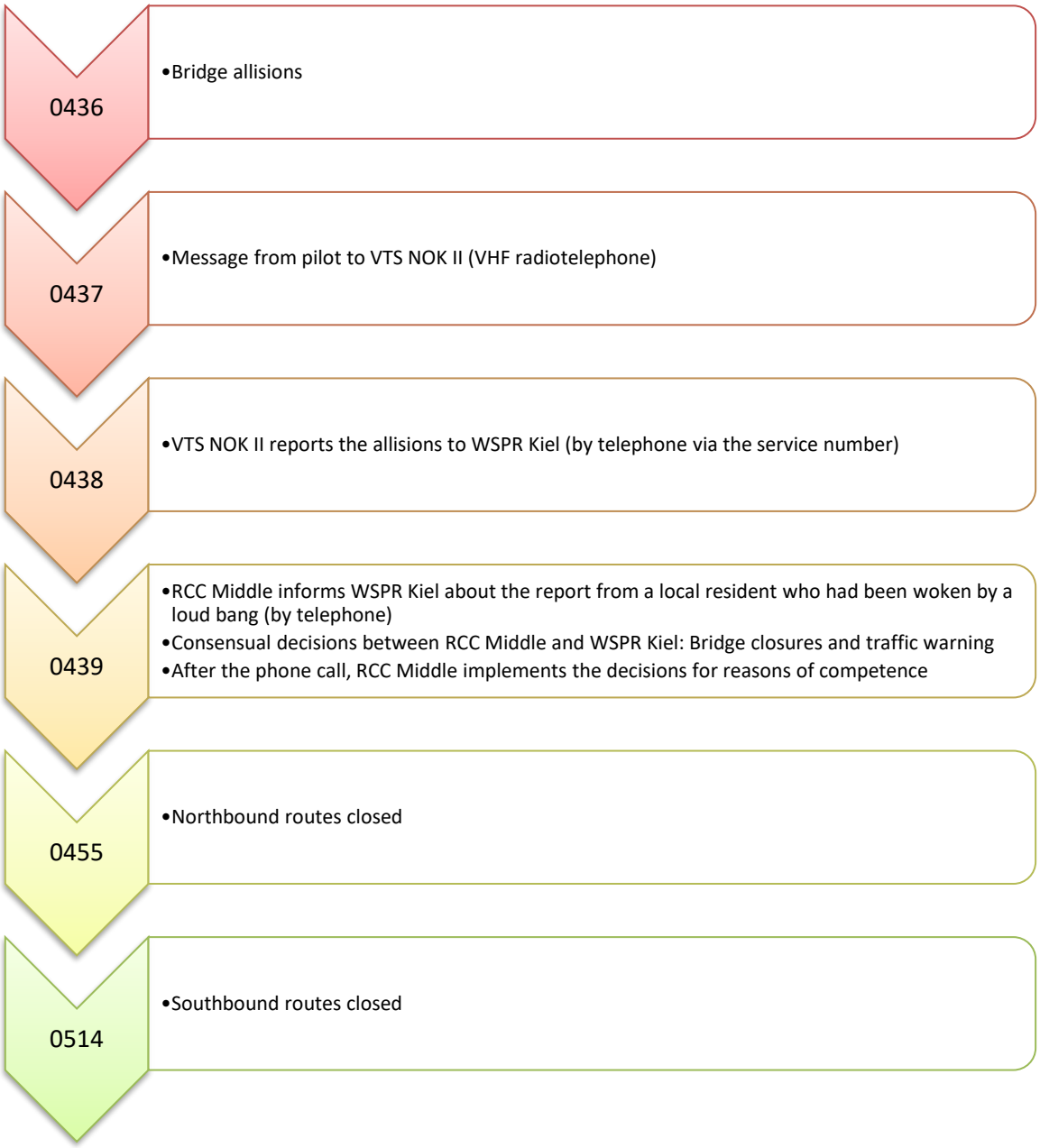

Figure 46: Timeline of the accident

From the accident occurring, it took only three minutes for the pilot's report to reach RCC Middle via WSPR Kiel, which was notified by VTS NOK, and for RCC Middle to issue traffic warnings and initiate the closures for reasons of competence. It then took 35 minutes from the decision to impose the closures to their implementation.

According to information given by WSPR Kiel, the closures were complicated by the fact that some of the feeder roads extended right up to just before the bridges. This meant that the responsible RCC Middle had to deploy and coordinate a large number of personnel within a short period of time. Patrol cars were deployed to the north and south of the NOK to avoid crossing bridges. The closure of the southern side was less problematic here, as the Kiel city area is characterised by a greater "density of patrol cars". In due course, the RCC Middle informed the LBV.SH and arranged for further measures, such as an inspection by structural engineers. During the morning, the LBV.SH took over the roadblocks of the police and gradually handed them over to a traffic safety company over the course of the day. The bridges that have been hit were no longer travelled on as part of the closure measures, thereby avoiding any conceivable consequential damage.

According to information given by the LBV.SH, variable-message signs are kept at the motorway bridges over the NOK in order to initiate closures with possible diversions and the relevant instructions in accordance with Germany's highway code. These signs can be used to initiate closures at short notice via the LBV.SH.

WSA Kiel Canal's NOK alerting and reporting plan dated 17 August 2022 contains the phone number of a Deutsche Bahn [German Rail] emergency control centre. VTS NOK should call this number in the event of an allision with one of the four high railway bridges over the canal and give the control centre the following information: 'Operational hazard – hold back the trains!' This plan contains no comparable emergency number(s) for the other bridges and no general closure instruction.

Following this accident, WSA Kiel Canal revised the plan to the effect that one of the two WSPRs responsible for the canal should be called in the event of an allision with the other bridges. The telephone number of WSPR Brunsbüttel was entered for canal kilometres 0 to 49.5 and that of WSPR Kiel for canal kilometres 49.5 to 98 (alerting and reporting plan dated 23 February 2023). The numbers listed correspond to those used by VTS NOK for all other marine casualties and dialled by the NvD on watch in the MERI case.

On the one hand, these numbers are not emergency numbers whose availability is guaranteed at all times. The WSPRs can only be reached via these numbers as long as these connections are not being used for other calls and the stations are adequately staffed. At the time of the accident, the WSPR Kiel had a minimum staffing level of three people on night duty and four people on day duty. At the time of publication of the report, at least four people are planned for both – day and night duty. In individual cases, staffing levels may fall below the minimum number due to absences. The station was manned by only two people when the accident happened on 30 November 2022, for example.

On the other hand, it is not the WSPRs that are responsible for bridge closures, but rather the RCCs. The NOK lies within the area of responsibility of two RCCs. The Cooperative Regional Control Center (CRCC) West is responsible for Kkm 0 to roughly Kkm 24, otherwise the RCC Middle. The areas of responsibility are therefore not congruent with those of the WSPRs. In any case, the WSPRs would have to pass on reports about bridge approaches by telephone to the relevant RCC. In this particular case, RCC Middle had contacted the WSPR to clarify the situation following a report already received from a local resident.

4 ANALYSIS

4.1 Damage and consequences of the accident

In retrospect, the allision could even have resulted in serious personal injury. The MERI had cast off in the lock about eight minutes before the allision. However, since the deckhands working on the aft deck of the MERI had cleared and left the manoeuvring station immediately, nobody was in the crane's danger zone. Similarly, the bridges had basically withstood the allisions.

The crane remained on deck and did not have to be laboriously salvaged from the fairway of the NOK.

The consequences of the accident for road traffic as a result of the bridge closures were significant (see Chapter 2.4).

4.2 Main causes of the accident

According to the Swiss cheese model[65], this accident can be attributed to a combination of several factors. In the view of the BSU, the following material causes exist:

- the transport was planned and contractually agreed on the basis of an incorrect transport drawing;

- an accurate transport drawing was not submitted subsequently. The actual tower height was not provided;

- the crane was loaded without using the information in the stowage plan. The different attachment points to the crane that was actually to be transported could possibly have been noticed;

- a clearly visible shipping label was attached to the loaded crane, indicating an incorrect tower height;

- when the special dispensation was granted, the submitted transport drawing could only be reviewed to determine whether the drawing was correct with regard to the measurements entered;

- it was not possible to measure the height in the lock. The crane's tower height specified by the ship was not called into question for the verification.

In the following, each aspect investigated is analysed and the main causes of the accident discussed here are looked at in greater detail.

[65] See Swiss cheese model, e.g.: Swiss Cheese Model | HUMAN FACTORS HAMBURG (human-factors-hamburg.de) (2023-11-27).

4.3 Cargo (crane's manufacturer)

The LHM 600 Evo6 with a tower height of 43.2 m ordered by the Port of Esbjerg was loaded and transported. This crane model was too high for transporting through the NOK on the MERI.

4.4 Voyage and transport planning

Communication between the charterer and the ship operator was by email. It is clear from the correspondence that all parties involved in transport planning were familiar with comparable shipments. The planners at Meriaura Ltd. were at all times aware of the importance of the tower's height to the route planning. They asked the charterer about the height of the tower several times.

For the transport request to Meriaura Ltd., the charterer did not have the relevant transport drawing for the upgraded LHM 600 crane, which was from the sixth evolutionary stage. The transport drawing of an LHM 600 from the previous development stage was used as the basis for planning. Indeed, the charterer did mention to Meriaura Ltd. in email correspondence that a new crane model would have to be transported but this information was not linked to the modified crane height. Three days after this information, the charterer confirmed the incorrect crane height at 38.25 m. On 23 September, about four weeks after the last height confirmation and just over two months before shipment, the crane's manufacturer completed the transport drawing for the LHM 600 Evo6. It is not known whether this drawing was delivered to the transport planners on the crane manufacturer's side, the charterer. In any event, according to consistent information, the planners at Meriaura Ltd. did not receive it. The transport was planned and conducted on the basis of an incorrect transport drawing.

The higher costs possibly incurred by the charterer for seaward transport had no effect on the voyage planning.

4.5 The transport manual

According to the introductory notes, the transport manual contains all the activities, procedures and calculations required for transport with the MERI. It does not meet this requirement. Some of the content is

- contradictory (see annex containing transport drawing);
- not finalised (e.g. packing list);
- not up to date (e.g. stowage plan);
- incomplete (e.g. no special dispensation);
- not fit for purpose (voyage planning), and
- impermissible (route deviations only under certain conditions).

According to the documentation in the title block, the manual was not reviewed and approved. The voyage planning required on the ship does not satisfy requirements with the information contained in the manual. There was no provision for a final document release by Meriaura Ltd. for the manual.

The discrepancies discussed in the investigation section would presumably have already been noticed if Meriaura Ltd. had applied the dual control principle.

There are many indications to suggest that the master did not use this transport manual for either the loading operation or the voyage. Taking into account the included stowage plan in conjunction with the transport drawing, the deviating fastening points could possibly have been noticed during loading. However, the master had no reason to doubt the dimensions of the crane and therefore did not use the information available. The manual was not suitable for the voyage. At the latest in the lock, the master could not have used the transport manual as the basis for the special dispensation, as required and issued. By the way, the voyage plan drawn up by the ship met the requirements, so that the master did not need the information in the manual.

4.6 Loading

According to the transport drawings, the LHM 600 Evo6 crane loaded on board was not only 5.12 m higher than the LHM 600 shown in the transport manual, but with regard to the jib positioned for transport, 1.617 m shorter. These inconsistencies, as well as the structural inconsistency visible in the plan in the area of the operator's cab and the articulated point of the jib were not obvious and not noticed during loading.

From the perspective of the BSU, the known maximum horizontal crane length on deck could have been measured at the side edge of the cargo deck. This measurement might have revealed the inconsistency of 1.617 m in the drawing, despite the expected inaccuracies. Unlike a complex height measurement, the horizontal measurement control could have been carried out with a tape measure (see Annex 5.1.1 to Annex 9.3: Tape measure). If the inconsistency had been noticed, the parties responsible for the cargo should at least have enquired about the reason for the inconsistency. However, in the absence of legal or corporate requirements, there was no reason for any party involved in the loading to carry out such a measurement.

4.7 Admission for passage (special dispensation)

The NOK is used by some 27,000 ships[66] each year. In 2023, 1,414 vessels with a height of ≥ 37 m transited the canal. They included 364 vessels of ≥ 39 m in height. Vessels that use the canal several times, sometimes weekly, are counted several times. This number cannot be determined on the basis of available data. Nor can the available data be analysed to determine whether the recorded height was only reached as a result of the load. An annual average of ten vessels are higher than 40 m and therefore may only use the canal on the basis of a special dispensation in accordance with Section 42(6) SeeSchStrO with a maximum height of 40.2 m. Accordingly, dispensations are only required in exceptional cases. WSA Kiel Canal is responsible for the application procedure. The procedure is always completed before a ship enters the NOK's locks. As a general rule, only applications eligible for a special dispensation are submitted. The dispensation procedure is necessary because the SeeSchStrO confers on the canal's Administration extensive powers in respect of admission for canal passage and the height limitation is only one aspect of the overall admission

[66] Number without recreational craft. Information from WSA Kiel Canal: WSA Kiel Canal – *Schifffahrt* [shipping] (wsv.de) (2023-12-28). Another publication specifies the number of ships as being about 30,000 a year, plus some 10,000 to 15,000 recreational craft. WSA Kiel Canal – *Verkehrszentrale* [vessel traffic service] NOK (wsv.de) (2024-01-02).

procedure. The procedure practiced is extremely flexible and, in the view of the BSU, has generally proved its worth.

In light of this accident and its far-reaching consequences, administrative practice in respect of height permits must be scrutinised in order to show all parties involved, the ship operators, ship's commands and the Administration, a way of making the passage even safer where possible.

The Administration is encouraged to review and decide on applications for special dispensation within the shortest possible time. In the present case, about 1.5 working days were available for this. The regulation does not give the Administration any pointers with regard to which criteria the examination of the application should be based on. The BSU is not aware of any internal administrative review regulations that WSA Kiel Canal is required to adhere to. The dispensation was granted in the present case because the stowage plan was correct in terms of the height indicated on the drawing. This review established that the submitted plan was drawn correctly. During this procedure, the inspecting parties did not pay attention to such formalities as the title block of the submitted stowage plan. Otherwise, the Administration could have established that neither the review nor the approval were documented in the title block of the submitted plan in a way that was comprehensible to third parties.. Such a formal finding would have enabled the inspecting parties to express doubts as to the stowage plan preparation process and at least demand rectification. The originator, Meriaura Ltd., would certainly not have had any doubts about the stowage plan (see Chapter 4.4) and on request this deficiency might have been rectified and the dispensation granted.

At this point, at the latest, it becomes clear that more suitable review methods are required for the approval of such applications.

4.8 Height monitoring in the lock

The duties of lock personnel are documented in detail in internal administrative provisions for the operation of VTS NOK.

From the perspective of the BSU, the nautical assistants acted in accordance with the relevant regulations. They attempted to measure the height of the loaded crane in accordance with Annex 6 to VV-GDWS 24-7. After no measurement was possible, the information from the ship was checked for plausibility. The lock personnel used the stowage plan that had been provided for the verification, which had already been used for approving the admission for a single passage with a maximum height of 40.2 m. The result was communicated to the NvD by telephone. The NvD comprehended and essentially approved the verification. The BSU believes that according to the regulations, the measurement reports should have been sent to the NvD for verification. However, such a transmission would only be possible at the present time if, in addition to ongoing lock operation, the manually completed measurement reports are digitised in an appropriate form and transmitted to the NvD. From the perspective of the BSU, it would be helpful if each measurement, also the incorrect measurements, could be digitally recorded by the system and viewed/evaluated by both the nautical assistants and the NvD if necessary.

Annex 6 provides a recommendation for action for the verification. It recommends that VTS NOK, essentially the NvD with the help of the first nautical assistant in the lock, should be sufficiently satisfied through the presentation of appropriate ship documents, e.g. a general arrangement plan or a height certificate from a recognised classification society showing the vessel's maximum height. However, in the present case there was no height certificate available when VTS NOK had to make a decision immediately. Against this background, the verification was again made on the basis of the inadequate stowage plan. In the opinion of the BSU, the accident could have been prevented with the aid of a height certificate from a recognised classification society, as the actual height would certainly have been determined. According to the GDWS, the term "recognised classification societies" refers not only to the classes that are recognised for the German flag under Regulation (EC) No. 391/2009[67], but also to all classification societies that are members of the umbrella organisation International Association of Classification Societies (IACS). Furthermore, in the opinion of the GDWS, the term "height certificate" refers exclusively to measurements of ship heights and not to measurements of cargo heights. In the view of the BSU, height certificates or measurement reports should in any case be requested in cases to be determined in more detail. The measurement should be documented in these certificates or measurement logs in such a way that the result can be traced as part of a plausibility check. This verification should be made during the admission procedure so that the height certificate or measurements report can be obtained in good time, e.g. by the ship operator and verified by the Administration outside of lock operations with the necessary attention.

If lock personnel are unable to determine the height on the basis of a verification, then the vessel's height should be determined in accordance with Annex 6 by means of a measurement to be carried out on the vessel. Based on the findings of the investigation, such measurements in the locks will not be feasible in the short term due to a lack of sufficiently suitable options.

According to the documentation provided, the height declaration requested from the master by the first nautical assistant was missing. This was not submitted by the ship, either. From the perspective of the BSU, this was no longer essential according to the administrative provision due to the existing admission for passage. The ship had clearly stated her height in the application for this admission for passage (special dispensation) and received all the conditions to be met with the notice. Irrespective of that, the BSU believes that ship's commands should always submit concrete height declarations shortly before the canal passage, indicating the current height and any existing requirements. This declaration should ensure that the ship and VTS NOK have the same information regarding the height. It should be possible to submit the declaration in digital form.

4.9 Metrological report

The report demonstrated that based on the official vertical datum with a gauge datum of 5 m, the clearance heights of 42 m specified in the navigational charts were given

[67] Regulation (EC) No 391/2009 of the European Parliament and of the Council of 23 April 2009 on common rules and standards for ship inspection and survey organisations. Official Journal of the European Union L 131/11 of 28 May 2009.

for both bridges. Based on the determined heights of 42.50 m (Olympiabrücke bridge) and 42.55 m (Prinz-Heinrich-Brücke bridge), the published 42 m would have been given even with a gauge datum of 5.2 m, which would have been the maximum permissible for the MERI according to the granted special dispensation.

DMT calculated a crane height of 42.42 m instead of the relevant tower height of 43.35 m specified by the crane's manufacturer during the investigation of the accident. The difference of 0.93 m is plausible, as DMT had surveyed the crane on board after the accident and it was no longer standing vertically on the aft deck. Moreover, DMT had defined the underside of the forward right base plate of the jib foot as the datum level for its height specification. To compare the height with the manufacturer's information, the 0.20 m measured for the height of the bracing according to the expert report must be added.

Taking into account the crane manufacturer's updated height information, the highest point of the crane tower must be corrected upwards to 44.85 m compared to the expert report:

MV MERI	Crane height	Bracing	Freeboard	Overall height
Point 4 (fender)	42.42 m	0.20 m	1.50 m	44.12 m
	43.35 m	n/a		44.85 m

The difference to the clearance height of 42.88 m (Olympiabrücke bridge) will therefore have been just under 2 m (+1.97 m instead of 1.24 m). The difference to the second and slightly higher (42.93 m) Prinz-Heinrich-Brücke bridge will correspond approximately to the value of 1.19 m determined by DMT, as the crane had already sustained a blow at the first bridge and was no longer in its original position.

4.10 Bridge allisions on the NOK

Bridge allisions are rare accident events on the NOK. However, the NOK had to be temporarily closed in all cases. The bridge structures were always – at times severely – damaged and human lives always endangered.

During the 35-year period considered in the investigation, four different bridges (one railway bridge and three road bridges) out of a total of ten bridges[68] were struck. Only in the case of the MERI was the first bridge to be passed by a ship struck.

In the other three cases, the ships had already passed other bridges. In the cases involving the motor vessel FORT and the multi-purpose vessel WILMA, the allisions were due to shipboard cranes being put into operation without paying due attention to the limited height. The WILMA case was investigated by the flag State of Antigua and Barbuda and the BSU, the body responsible for the coastal State of the Federal Republic of Germany. Basically, the safety recommendations issued in the joint investigation report were as follows:

[68] Information on the ten bridges: *Brücken* [bridges] (nok-sh.de) (2023-08-07).

- the ship operator should make provisions for an officer to supervise the operation of the shipboard crane at all times;

- competent bodies of the Shipping Administration should examine whether deck work using shipboard cranes and jibs should be prohibited during the NOK passage.

Only in the case of the KANOK NAREE was the shipboard crane already higher than permitted without being put into operation on the canal. In terms of the MERI case, the ruling of the Maritime Board contains several noteworthy aspects. In the view of the BSU, these include the following, in particular:

a) The ship's height was not measured.
According to an official instruction of the canal's Administration, the KANOK NAREE's height calculation had to be verified on board because she had reported a height of more than 37 m. Due to heavy rainfall, the laser measuring instrument in the lock was not used because the navigational employee responsible did not expect sound, usable results. According to the master, measuring the relevant derrick with a tape measure was not an option.

b) The height information in the general arrangement plan was ambiguous.
Inter alia, the length of the heavy-lift derrick specified in the rigging plan, a detailed component of the general arrangement plan, was used as the main basis for calculation when the master and the navigational employee of the canal's Administration checked the height information. A height of 39.53 m was calculated on that basis. The master did not believe it was necessary to reduce the height as a precautionary measure, e.g. by lowering the derrick or taking on ballast water. Only during the investigations of the Maritime Board was it found that the length specification only referred to a partial length. The highest point of the ship calculated using the general arrangement plan after the accident was 42.75 m. In the opinion of the Maritime Board, the interpretation of the length information was not obvious due to insufficient marking and the dimension given not clear.

c) The KANOK NAREE only sailed into the second bridge to be passed.
Approaching from Brunsbüttel, the KANOK NAREE only sailed into the second bridge, the high railway bridge at Hochdonn. The ship had passed the first bridge, the high road bridge at Brunsbüttel, unscathed, even though the Shipping Administration specifies a clearance height of 42 m for all bridges on the Kiel Canal.[69] Upon enquiry by the BSU, WSA Kiel Canal at first confirmed an identical clearance height of 42.04 m based on the vertical datum and a water level of about zero for the bridges in question. The ruling of the Maritime Board states the clearance height of the railway bridge as 41.87 m in relation to Normalnull (NN). The report does not contain any information on the clearance height of the road bridge passed before and no statements as to why the second bridge was struck first. The change in the reference point from NN to the current vertical datum in the meantime does not explain the difference to the current height of 42.02 m, as - according to the GDWS - this change entails corrections in the

[69] WSA Kiel Canal – *Brücken und Schwebefähre* [bridges and transporter bridge] (wsv.de) (2023-08-04).

mm range, at most in the cm range and not in the dm range. In the further course of the investigation, WSA Kiel Canal informed the BSU that the bridge centre section of the railway bridge, the so-called "floating girder", was replaced by a new structure with a greater clearance height after the allision. The railway bridge was therefore lower than the road bridge at the time of the accident, as the latter had not been rebuilt in the meantime and both bridges currently have the same clearance height. It is possible that the clearance height of the railway bridge was reduced even further by the water level on the day of the accident, as - according to the Seeamtsspruch - the canal level at the time of the accident was +7 cm near the railway bridge and +/-0 cm near the road bridge. According to the ruling of the Maritime Board, the canal's water level stood at +7 cm near the railway bridge and at ~0 cm near the road bridge at the time of the accident. However, the actual water level during the road bridge passage is not known. Since the point of allision between the derrick and bridge structure was 'only' 10-12 cm below the KANOK NAREE's highest point calculated, the first bridge was only 3-5 cm below the highest point calculated. In the opinion of the BSU, the accident involving the KANOK NAREE would presumably not have occurred if the clearance height of the railway bridge had corresponded to the clearance height of the road bridge at the time of the accident.

4.11 Expert report on measuring arrangements for height monitoring

The complete metrological report is attached at Annex 9.3. The report contains a general description of various measuring arrangements, ranging from a tape measure, laser distance meters, tacheometers, laser scanners and (survey) drones, which are visually presented in the corresponding appendices and evaluated, taking into account the quality parameters defined in the report.

More complex measurement methods for monitoring height in front of the locks independently of time and continuously, such as photoelectric barriers and alternative systems, as well as radar systems, are considered in the report in an introductory manner, but in view of the alternative options available not described in detail here in the report section.

4.11.1 Current measuring arrangements in the NOK locks

According to the report, the measurement system available in the locks at Brunsbüttel and Kiel is suitable for height measurements so as to provide reliable direct height values quickly under good ambient conditions.

The experts have no clear explanation as to why the height measurements made shortly before the accident were unsuccessful. However, a variety of influencing factors were identified that could affect a reliable height measurement. The following are mentioned:

- visual obstructions to the object (ship);
- (restricted) visual targeting of the measuring points with the (existing) sight optics;
- no height measurement due to absent distance measurements to the measuring points because of insufficient reflective properties;

- weather-related obstruction of visual targeting in heavy rain, fog and drifting snow;
- (unfavourable) position of the ships during lockage operations;
- device settings on the measuring instrument (default values);
- insufficient power supply (internal and/or external);
- no automated registration of the original measuring elements or reproducibility of the height measurement carried out;
- strain on the operators, especially in stressful situations that arise during lockage operations and unexpected failure of the measuring equipment.

With regard to the last bullet point, the BSU believes that stress is not only caused by the failure of the measuring equipment. Unexpected measurements are likely to have comparable consequences according to human judgement.

While retaining the measuring arrangement and modernisation in line with the state of the art, the following improvements should be examined according to the expert report:

- use of a modern surveying instrument with crosshair illumination and reliable distance measurement in difficult conditions (tacheometer);
- testing of an instrument combination with an implemented infrared camera and connection of the system configuration to a field computer (tablet);
- development of a flow chart for height measurement and logging;
- programming of data exchange interfaces;
- establishment of base-related measuring arrangements for non-executable distance measurements to the high points to be measured (tower height measurement).

4.11.2 Traceable shipboard height monitoring

The expert report describes and evaluates the determination of the height of the tower as an alternative measurement method. In the opinion of the experts, this procedure can be a suitable method for having the height determined by a third party and verifying the result before the planned lockage.

4.12 Emergency management: Bridge safety

The RCC Middle was sufficiently informed three minutes after the allisions to initiate the closures for reasons of responsibility There was no delay in the flow of information from the ship (pilot) to VTS NOK, from there to WSPR Kiel and RCC Middle. The fact that WSPR Kiel's telephone number was not blocked by another call and that a local

resident had already alerted RCC Middle to a possible allision with the bridge before the WSPR was able to relay VTS NOK's message was to the benefit of the parties involved.

Irrespective of this positive sequence of events, the BSU believes that VTS NOK should call the relevant RCC for all bridge allisions and thus arrange for closures, unless it concerns a railway bridge or a bridge with a variable-message sign.

It took 35 minutes to actually implement the closures, in particular due to the spatial conditions and the personnel required at short notice. According to the LBV.SH, there was a genuine risk that one of the two structures might collapse as a result of the allision. The BSU believes that such a theoretical hazard will exist after every allision with a bridge.

Despite all the measures taken on ships and the canal, bridge allisions cannot be ruled out. In the view of the BSU, variable-message signs similar to those already seen on motorway bridges should therefore be installed on selected bridges. Such signs should be installed on those bridges that a ship would pass first after moving from a lock into the canal. These include the high bridge at Brunsbüttel and the two high bridges at Holtenau. Inadmissible heights should always become apparent there first.
Vessels whose height can be changed at any time above the maximum permitted height certainly continue to pose a higher residual risk than vessels with a fixed height. To reduce this risk, please refer to the safety recommendations mentioned in chapter 4.10.

5 CONCLUSIONS

5.1 Cargo (crane's manufacturer)

At the crane's manufacturer, numerous people from several departments are involved in preparing for transport and loading many different products. The processes should be controlled such that transport operations are always carried out on the basis of an up to date, correct and accurate transport drawing.

To avoid similar accidents in the future, ship operators, masters and the canal's Administration should each take their own appropriate measures for their own areas of responsibility, regardless of the overall legal responsibility.

5.2 The transport manual

Transport manuals should be developed as intended at Meriaura Ltd. and meet the company's internal standards. The information contained should be complete, accurate and up to date. The process should conclude with the originator approving the document.

Similar transport operations should only be carried out on the basis of approved transport manuals. Irrespective of the lack of legal necessity, these should be used so that less obvious deviations, such as the incorrect crane height in this case, can be recognised.

5.3 Loading

In the view of the BSU, the deviation from the existing transport drawing should have been noticeable during a horizontal measurement of the loaded crane. An identified deviation would have led the shippers responsible to ask why the deviation existed. It may then have been recognised that a different crane than that planned for had been loaded.

In any case, all information available for loading should be used to check the loading operation in respect of planning, even if there is no special reason to do so. As a matter of principle, loading should only be carried out on the basis of approved transport manuals.

5.4 Admission for passage (special dispensation)

From the perspective of the BSU, WSA Kiel Canal should be guided by the recommendation for action for VTS NOK when reviewing applications for a one-off height permit and always obtain a comprehensible height certificate (approved measurement report) for the object in question (ship/cargo). Ship general arrangement plans are generally only suitable to a limited extent, as they are often not adapted to the individual and current ship in the case of series construction or subsequent modifications. Traceable measurement reports can be created on the basis of a tower height determination. Information on determining tower heights can be found in the expert's report in Annex 9.3. WSA Kiel Canal should publish corresponding information in advance so that ship operators can request suitable height measurements and submit approved measurement reports in a timely fashion.

The probability is high that accidents, such as in the case of the MERI, can be prevented on the basis of traceable measurement reports. The previous administrative provision of VTS NOK provides for corresponding records for measurements in locks of 39 m and higher, but also allows for alternative verifications. Since suitable measurement reports are not readily available in the locks when required, alternative verifications are carried out as planned and in the case of the MERI. From the perspective of the BSU, traceable measurement reports should become a part of standard practice for vessels with a height of 40 metres and higher and for vessels with a (project) load (overall height) of 37 metres and higher. These should be requested in advance from WSA Kiel Canal, as part of an application for one passage up to and including a height of 40.2 m and checked for plausibility.

5.5 Height monitoring in the lock

In the lock, the height should be remeasured while retaining the current measuring arrangement and always referring to existing regulations.

However, the measuring arrangement should be optimised, taking into account the recommendations mentioned in Chapter 4.11.1. All (digitally) recorded measurements should always be made available to the NvD as a basis for decision-making.

As before, ship's commands should always submit a height declaration to VTS NOK for heights of ≥ 37 m. The latter should be in digital form if possible.

Verifications should only be carried out by the NvD. *Inter alia*, the verification should be made on the basis of all (digitally) recorded measurements of the lock, as well as – if available – on the basis of a special dispensation from WSA Kiel Canal with the associated measurement report (see Chapter 5.4).

Clearance for canal passage should only be given after

- the basic requirements for canal passage have been met, whereby a special dispensation will be required for a (project) load height (overall height) of 37.00 m and higher and a vehicle height of 40 m and higher;

- from 37 m and higher, a height declaration from the master has been submitted;

- from 37 m and higher, the height could be measured in the lock or the NvD carried out a verification, and

- the NvD has issued clearance.

The current administrative provisions should be specified accordingly.

5.6 Emergency management: Bridge safety measures

The BSU takes the view that WSA Kiel Canal should amend the alerting and contingency plan so that the relevant RCC is called in the event of a bridge allision that does not involve a railway bridge. In the case of bridges with variable-message signs, the LBV.SH should be called. Telephone numbers must be agreed with the RCCs and the LBV.SH that can be reached at all times.

Given that the LBV.SH has advised that there was a theoretical danger to users of the structures – i.e. to the life and limb of people – until the bridge was completely closed, the investigators believe that the time span of 38 minutes from notification to implementation of the closure is very long. It would be worth considering whether a simpler procedure that requires less time and manpower could be implemented for the high bridge at Brunsbüttel and the two high bridges at Holtenau so as to be able to initiate closures at short notice. The installation of remote-controlled variable-message signs would be conceivable, for example.

6 ACTIONS TAKEN

6.1 Crane's manufacturer

The crane's manufacturer has taken the following action to prevent similar accidents in the future:

- technical drawings are produced only on the basis of a formal requirement made within the company;

- transport drawings are created according to the dual control principle, with the assistance of an external service provider;

- transport drawings are provided with a cover sheet that includes the basic data of the cargo, such as the height. The connection between cargo and transport drawing is established by the inclusion of a serial number;

- transport drawings are reviewed before being sent to the logistics company concerned, and approved if the result is positive;

- the height of erected cranes is measured and the result documented.

The BSU believes that the action taken is credible and sound. Based on the information provided, the BSU suggested that the principle of dual control should be documented in the title blocks of the transport drawing/cover sheet. In addition to the originator, the name of the reviewer and date of the review should be given.

Based on the measures taken, the BSU refrains from making corresponding safety recommendations to the crane's manufacturer.

6.2 Federal Waterways and Shipping Agency (GDWS) / Schleswig-Holstein's regional authority for roads and transport (LBV.SH)

The GDWS and the LBV.SH have been in regular dialogue since the bridge allisions, which will continue after the publication of this investigation report and any adjustments to the emergency management for bridge safety.

6.3 Ship operator Meriaura Ltd.

Right after the incident Meriaura Ltd. decided to demand measurement certificates from shippers/charterers for each and every cargo with potentially critical dimensions. This safety measure generally applies as soon there are height restrictions on the intended route for instance due to bridges or power lines and when the height of the cargo exceeds the air draft of the vessel.

Furthermore Meriaura Ltd. have revised the process of drafting and reviewing transport manuals. For instance: About one week prior to departure of each shipment of cargo an internal meeting including members of the departments planning, operations and

commercial will be held to review all relevant stages of the respective journey including loading and discharge.

7 SAFETY RECOMMENDATIONS

The following safety recommendations do not constitute a presumption of blame or liability in respect of type, number or sequence.

7.1 Federal Waterways and Shipping Administration (WSV)

The BSU makes the following recommendation to the WSV:

7.1.1 Federal Waterways and Shipping Agency (GDWS)

The maximum permissible height above water level for navigating the Kiel Canal without a special dispensation should be reduced for vessels with a (project) load (overall height) from 40 m to 37 m.

7.1.2 WSA Kiel Canal

7.1.2.1 Special dispensations

Applications for a single transit of the NOK for vessels with an overall height of up to and including 40.2 metres should only be granted on the basis of a comprehensible measurement report approved by the Administration.

7.1.2.2 Alerting and contingency plan

The alerting and contingency plan should be amended so that the relevant RCCs (CRCC West ab initio Kkm 0, RCC Middle from about Kkm 24) are called in the event of a bridge allision that does not involve a railway bridge. In the case of bridges with variable-message signs, the LBV.SH should be called. Telephone numbers should be agreed with the RCCs and the LBV.SH that can be reached at all times.

7.1.2.3 Height monitoring in the locks

The measuring arrangement should be optimised, taking into account the recommendations made in Chapter 4.11.1. All (digitally) recorded measurements should be made available to the NvD as a basis for decision-making.

7.2 Ship operator MERIAURA Ltd.

The BSU recommends that Meriaura Ltd. always provides complete, correct and up-to-date information in transport manuals. Approval and subsequent updates should be clearly documented on the manual in a suitable manner.

7.3 Ship's command MERI

The BSU recommends that the ship's command use approved transport manuals and point out any recognised inadequacies to the originator.

7.4 Schleswig-Holstein regional authority for roads and transport (LBV.SH)

The BSU recommends that the LBV.SH establish suitable procedures for closing the high bridge at Brunsbüttel and the two high bridges at Holtenau at short notice.

8 SOURCES

- Enquiries of the waterway police (WSP)
- Written explanations/submissions
  - Ship's command MERI
  - Ship operator MERIAURA Ltd.
  - Charterer Liebherr
  - Crane manufacturer Liebherr
  - Consignee Port of Esbjerg
  - Pilot
  - United Canal Agency GmbH (UCA)
  - The canal's Administration (WSA Kiel Canal, VTS NOK)
  - WSPR Kiel
  - Schleswig-Holstein regional authority for roads and transport (LBV.SH)
- Witness testimony (master, pilot, VTS NOK (canal controllers, lock personnel))
- VDR recording
- VHF radiotelephone recordings
- AIS data
- Administrative provisions of the GDWS
- Two expert reports attached as annexes
- Navigational charts
  - Kiel Canal, BSH DE42
  - Kiel Fjord navigational chart, BSH DE34
- Legislation
  - International Regulations for Preventing Collisions at Sea of 13 June 1977 (Federal Law Gazette I p. 816), as amended by Article 1 of the Regulation of 7 December 2021 (Federal Law Gazette I p. 5188).
  - German Traffic Regulations for Navigable Maritime Waterways, as amended and promulgated on 22 October 1998 (Federal Law Gazette I p. 3209; 1999 I p. 193), as amended by Article 2 of the Regulation of 11 May 2023 (Federal Law Gazette 2023 I No 127). Notice of the Federal Waterways and Shipping Agency, Outstation North, of 28 January 2014 concerning the German Traffic Regulations for Navigable Maritime Waterways (Federal Gazette AT 31.01.2014 B7).
  - Ordinance on the Safety of Shipping of 27 July 1993 (Federal Law Gazette I p. 1417), last amended by Article 544 of the Ordinance of 31 August 2015 (Federal Law Gazette I p. 1474).
- Comments/papers on legislation
- Investigation report: Federal Bureau of Maritime Casualty Investigation – Investigation Reports – Investigation Report 607/06 (bsu-bund.de) (2023-05-23).
- Ruling of the Maritime Board on the KANOK NAREE (Ref.: SeeA1-DI 8/94 K), archived at the Federal Archives under Ref. B 175/737
- Miscellaneous (pamphlets/magazine articles/internet)
  - *Brücken* [bridges] (nok-sh.de) (2023-08-07)
  - A legible version of the SeeSchStrO in conjunction with all Notices in the Federal Gazette: ELWIS – Section 42 (2023-06-19)

- *Geschichte Holtenaus – Die Prinz-Heinrich-Brücke* [Holtenau's history – Prinz-Heinrich-Brücke bridge] (apt-holtenau.de) (2023-05-23).
- Swiss Cheese Model | HUMAN FACTORS HAMBURG (human-factors-hamburg.de) (2023-11-27)
- WSA Kiel Canal – *Schifffahrt* [shipping] (wsv.de) (2023-12-28).
- WSA Kiel Canal – *Verkehrszentrale* [vessel traffic service] NOK (wsv.de) (2024-01-02).
- WSA-Nord-Ostsee-Kanal – *Brücken und Schwebefähre* [bridges and transporter bridge] (wsv.de) (2023-08-04)

9 ANNEXES

9.1 Application for special dispensation: Stowage plan

9.2 Metrological report. Reconstruction and documentation of the prevailing conditions at the time of the damage event[70]

9.3 Metrological report. Analysis of measuring arrangements

[70] German version only.