FINAL REPORT
of Preliminary Assessment of New Findings on MV ESTONIA Accident

Tallinn 2025

Republic of Estonia
Safety Investigation Bureau

Safety Investigation Authority

Statens haverikommission

Estonian Safety Investigation Bureau | Safety Investigation Authority, Finland | Swedish Accident Investigation Authority

Final Report of Preliminary Assessment of New Findings on MV ESTONIA Accident

Ohutusjuurdluse Keskus
Statens haverikommission
Onnettomuustutkintakeskus / Olycksutredningscentralen

Tallinn
2025

In case of discrepancies between the PDF edition and the print edition, the PDF edition is to be considered the authoritative version.

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Summary

The report here presented is not a regular accident investigation report. It is drafted to make activities carried out and analysed many years ago accessible to the reader. Thus, it also includes parts/activities that are not usually incorporated in a safety investigation report. Thereto, all the work results are not primarily presented in the report, instead a number of stand-alone documents have been produced, covering subjects that not really are within the scope of the objectives of the Preliminary Assessment. However, this report includes the results of all the investigative activities done, either presented here, or with a reference to the relevant document.

Some parts of the report have a technical ponderosity or substance, while other parts are more reasoning, all depending of the character and the context of the activity. Most results of any value are presented in this summary. Thus, anyone wanting a fairly quick overview of the investigative activities and their result could start off with a read-through of the report in summarized form. It should be noted, however, that to have a more detailed description of the work, an approach to the relevant section in the main report is necessary.

Objectives

Ro-ro passenger ferry MV ESTONIA sank on 28 September 1994 during a voyage from Tallinn, Estonia, to Stockholm, Sweden. Of the 989 people on board, 852 died. The accident was investigated by an ad hoc commission, The Joint Accident Investigation Commission of Estonia, Finland, and Sweden (JAIC). New video footage, not available during the work of JAIC (1994–1997), was published in Sep-2020 which revealed a breach in the starboard side of the hull. Based on this new evidence, the Estonian Safety Investigation Bureau (*Ohutusjuurdluse Keskus*, OJK) initiated this Preliminary Assessment (which is a certain legislative degree of investigative activity) of the new information along with its counterparts in Finland and Sweden.

The objectives of the Preliminary Assessment were:

- to identify the cause of penetrating deformation(s) to the hull of MV ESTONIA, seen in the new video footage aired in Sep-2020 by Monster Media Group Limited;
- to assess whether the new information gives reason to revise the conclusions presented in the JAIC Final Report;
- to assess which new investigative measures should be taken, if any; and
- to assess whether the safety investigation of the sinking of MV ESTONIA should be re-opened.

Preparatory Work

It was clear from the beginning that national legislation needed to be amended both in Finland and Sweden to allow any seabed activities at site. Thus, a request of such amendments was initiated, and went into force 1 July 2021 (permanent amendments for Sweden, temporary for Finland). An overview of earlier performed investigation activities, studies and reports was also done.

It was clear that the work had to be divided into different phases, with the result from one phase influencing the planning of the next phase. This made, to a high extent, parallel activities impracticable and inefficient. It was subsequently decided to start with a detailed seabed survey in combination with an overview of the hull of the vessel. Whilst the planning of this was ongoing, preparatory activities at site were performed to find out circumstances at the site, e.g., the visibility (turbidity), salinity, and currents at the seabed. The result was, i.a., that any activity at site, requiring visibility at seabed and stable weather conditions, should be performed in the period late May to early July.

This is described in Chapter 1, Chapter 2, and Section 3.1.

At Site Activities

The first site operations commenced on 8 July 2021 with three participating vessels. Several seabed survey methods were used, and synoptic Remotely Operated Vehicle (ROV)-filming of the wreck was done.

Summer 2022, a comprehensive and detailed footage of the wreck was made, consisting of almost 45 000 photos. The footage resulted in a 3D photogrammetric model.

Summer 2023, ROV-filming inside the car-deck was done. In addition, some supplementary samples were collected. A number of site activities, not depending so much on conditions at site, were also performed. They include location and examination of items on the seabed in the area.

The Seabed

The seabed surveys showed that the area is varying both in depth and seabed consistence. Most areas are consisting of various layer of clay, amongst which outcropping bedrock is occurring frequently. MV ESTONIA is laying on a bedrock ridge, consisting of 1800 My-old gneiss. A little less than 0.9 nm distance, a seabed imprint shows where the bow visor landed after falling off the vessel.

A survey of the surrounding area shows items on the seabed, that originate from MV ESTONIA. The location of these items shows a probable route for the vessel, after the bow visor fell off. The route is somewhat more extensive than the one suggested in the 1997 JAIC Final Report (Figure 0.1).

The results are described in Section 3.2 and Section 4.1.3.

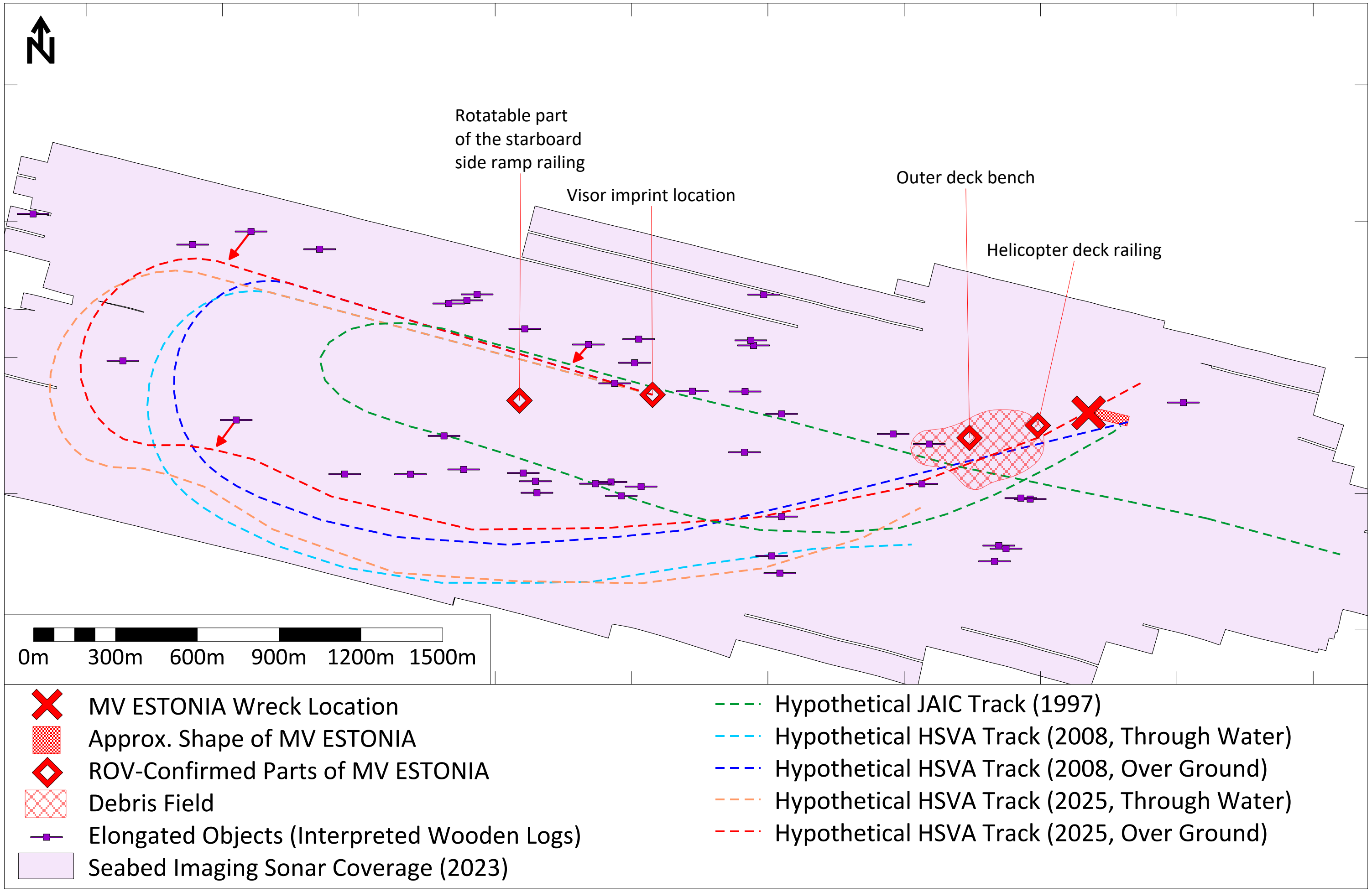

FIG. 0.1: Proposed tracks during the flooding and sinking of MV ESTONIA by JAIC, Valanto, and Kim et al.[1], [2], [3] The main reference points of the vessel's track reconstructions are shown.

The Wreck

MV ESTONIA was when surveyed laying on a slope and has been exposed for considerable movement during the years. A number of landslides have occurred, and it is evident that the wreck has not been steadily resting. To what extent she is stabilized now, is not known.

The ROV footage showed that the wreck had extensive damage. The starboard side, previously hidden towards the seabed, now showed an indentation, approx. 25 m of length, which at each end form a breach through the hull into the vessel's interior. The indentation followed the bedrock ridge well. Amongst other damage, the most obvious were a bending, partly a rupture, reaching from the aft part of the vessel's port side towards almost half of the vessel's length; the navigation bridge on port side heavily pushed down to the deck below; and the forward car deck ramp loosened from the remaining two (out of four) hinges and fallen down into the clay at the vessel's side.

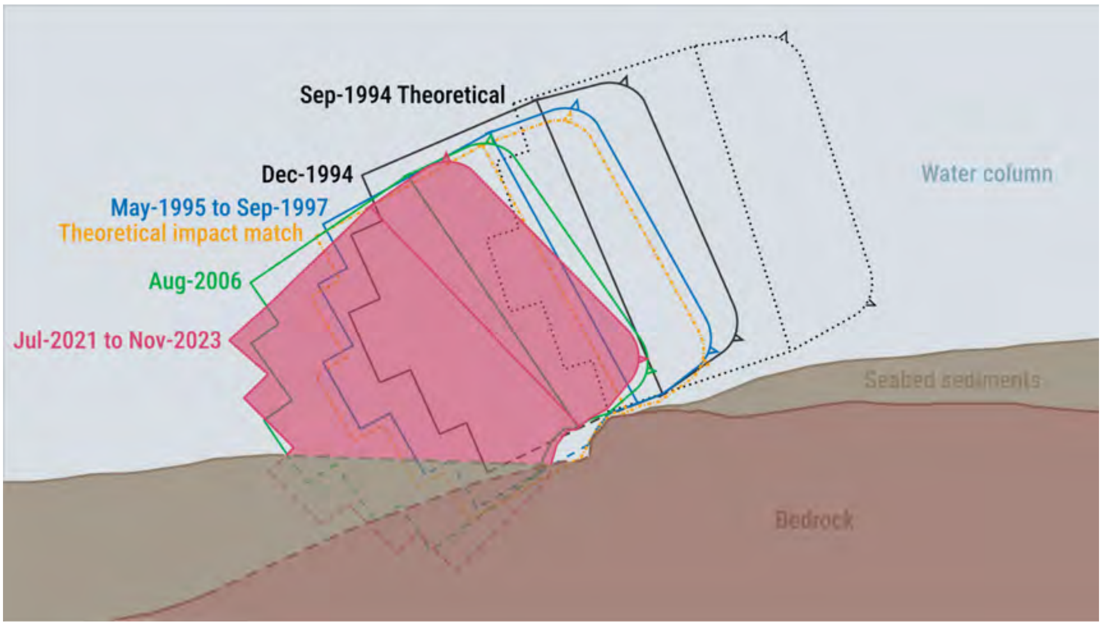

FIG. 0.2: A sectional cut at midships, near the forward penetrating damage, illustrates the wreck's movement over the decades.

The results are described in Section 3.3.

Results from Samples and Salvaged Items

From the wreck site, a number of items have been brought ashore. Amongst these are a piece of the bow ramp railing, and the bow ramp itself. Both show that the railings came off by physical force. The damage of the bow ramp fits with the structure of the small top of the fore peak, forming a triangle shaped deck in front of the bow ramp, when in place.

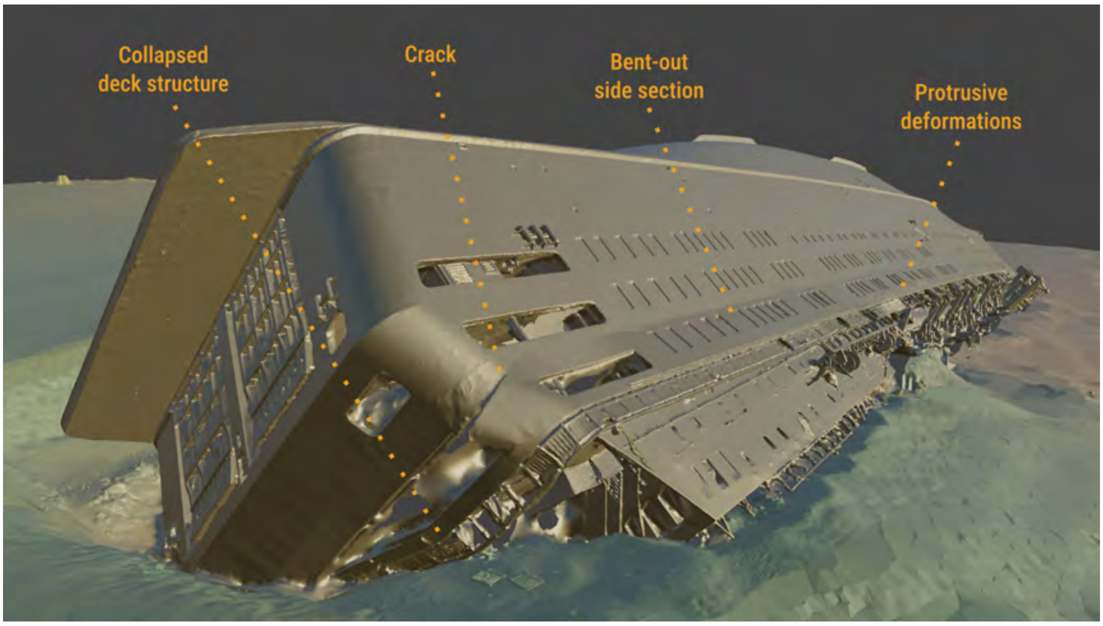

FIG. 0.3: Stern view of the photogrammetric model of the wreck illustrating the observed structural damage.

Samples from the vessel's hull at the forward end of the damage on starboard side showed that the damage has not been caused by any collision or explosives. Samples from the vessel's hull itself showed that black or dark shade or colouring was originating from natural growth.

One of the two preventer wires, belonging to bow ramp rig, showed that it was snapped by physical force.

Sinking Process Calculations

Several theoretical calculations have been done, indicating that water ingress in other ways than via the opened bow ramp would have led to another sinking scenario, e.g., the immediate and heavy list should not have developed if the water ingress had come from below car deck. Another finding is that the initiation of the water ingress is likely to have started somewhat earlier than indicated in the 1997 JAIC Final Report.

The results are described in Section 4.

Witness Interviews

Of the 137 survivors, 134 were interviewed by the police in 1994. Based on these statements, the JAIC investigators selected some people for further interviews.

Altogether, 68 survivors have been interviewed in connection to the on-going Preliminary Assessment. Of these, one survivor has never been interviewed before. In addition, other witnesses, who were not onboard during the journey but who were involved in other ways, have given evidence. Some of these people have not been interviewed before.

Analysis of the interviews resulted in witness support of no damage to the hull of MV ESTONIA while it was on surface. Most witness statements deny any loading of military vehicles; only a few support this. Further, several statements show that the witnesses have not read the 1997 JAIC Final Report, but that most witnesses still support or approve of the results of the JAIC Final Report. However, there are strong feelings amongst the witnesses on the decisions of the salvaging of the vessel, of the recovery of the deceased, and of the covering of the wreck.

The result is in more detail described in Chapter 5.

Conclusions

It can be concluded that MV ESTONIA sank due to the failure of the bow structure, and that the new damage on the starboard side resulted from contact with the seabed. Therefore, there is no need to reopen the safety investigation of the accident of MV ESTONIA.

Further details are found in Chapter 6, Chapter 7, and Chapter 8.

Other Findings, Not Directly Connected to the Accident

During the work with the Preliminary Assessment, investigative activities concerning other matters connected to MV ESTONIA have been performed. In case such matters are not directly connected to the accident, the results may be accounted for in separate documents.

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Definitions

CONCEPT	DEFINITION
Preliminary assessment	The professional and independent assessment of all the evidence relating to an accident or serious incident in the maritime sector with the purpose of determining whether a safety investigation should be opened or re-opened.
Safety investigation	An investigation to identify the circumstances, causes, and consequences of a marine casualty or marine incident, and if necessary, to provide recommendations to prevent such marine casualty or marine incident in the future and to improve maritime safety, without appointing blame or liability.

Glossary of Abbreviations

AB	Able Seaman
ADCP	Acoustic Doppler Current Profiler
AIS	Automatic Identification System
BSB	below seabed
CAD	Computer Aided Design
CCTV	Closed Circuit TV
CET	Central European Time
CoG	center of gravity
CPT	Cone Penetrometer Test
CTD	Conductivity, Temperature, Depth
EET	Eastern European Time
EEZ	Exclusive Economic Zone
EU	European Union
FEM	Finite Element Method
FFPV	Flexible Fallpipe Vessel
GTS	Gas Turbine Ship
HMS	*Hans Majestäts Skepp*, i.e., His Majesty's Ship
HSVA	Hamburgische Schiffbau-Versuchsanstalt GmbH
IACS	International Association of Classification Societies
JONSWAP	Joint North Sea Wave Project
LC	liquid chromatography
MAS	Multi-Aperture Sonar
MBES	Multi-Beam Echo Sounder
MetOcean	Meteorological & Oceanographic
MRCC	Maritime Rescue Co-ordination Centre
MV	Motor Vessel
OPV	Offshore Patrol Vessel
OSV	Offshore Supply Vessel
PA	Public Address
PCPT	Piezocone Penetrometer Test
PSC	Port State Control
PSV	Platform Supply Vessel
ROLS	Remote Offloading System
ROV	Remotely Operated Vehicle
RV	Research Vessel
SBES	Single Beam Echo Sounder
SBP	Sub-Bottom Profiler
SOLAS	International Convention for the Safety of Life at Sea

(Continued)

SS	Screw Steamer
SSS	Side Scan Sonar
SVP	Sound Velocity Profiler
T/S	Temperature/Salinity
TLC	thin layer chromatography
TSHD	Trailing Suction Hopper Dredger
UNCLOS	United Nations Convention on the Law of the Sea
UTC	Coordinated Universal Time
VDR	Voyage Data Recorder

Glossary of Organizations

EGT	Geological Survey of Estonia (*Eesti Geoloogiateenistus*)
EKEI	Estonian Forensic Science Institute (*Eesti Kohtuekspertiisi Instituut*)
EMI	Estonian Marine Institute (*Eesti Mereinstituut*)
EMSA	European Maritime Safety Agency
EVA	Estonian National Maritime Board (*Veeteede Amet*)
FM	Swedish Armed Forces (*Försvarsmakten*)
IMO	International Maritime Organization
JAIC	The Joint Accident Investigation Commission of Estonia, Finland, and Sweden
MerivTL	Finnish Naval Research Institute (*Merivoimien tutkimuslaitos / Mariners forskningsanstalt*)
MKH	Finnish Maritime Administration (*Merenkulkuhallitus / Sjöfartsverket*)
MKL	Finnish Maritime Administration (*Merenkulkulaitos / Sjöfartsverket*)
NGI	Norwegian Geotechnical Institute (*Norges Geotekniske Institutt*)
OJK	Estonian Safety Investigation Bureau (*Ohutusjuurdluse Keskus*)
PPA	Estonian Police and Border Guard Board (*Politsei- ja Piirivalveamet*)
RIL	Estonian State Fleet (*Riigilaevastik*)
RVL	Finnish Border Guard (*Rajavartiolaitos / Gränsbevakningsväsendet*)
SHK	Swedish Accident Investigation Authority (*Statens haverikommission*)
SIAF	Safety Investigation Authority, Finland (*Onnettomuustutkintakeskus / Olycksutredningscentralen*)
SjöV	Swedish Maritime Administration (*Sjöfartsverket*)
SPF	Swedish National Board for Psychological Defence (*Styrelsen för Psykologiskt Försvar*)
SYKE	Finnish Environment Institute (*Suomen ympäristökeskus*)
TRAM	Estonian Transport Administration (*Transpordiamet*)
Vinnova	Swedish Agency for Innovation Systems (*Verket för innovationssystem*)
YM	Finnish Ministry of the Environment (*Ympäristöministeriö / Miljöministeriet*)

Glossary of Units

UNIT	NAME
a	Year.
cal y BP	Calibrated years before present, i.e., calendar years before 1950.
°C	Degrees Celsius.
h	Hour.
g	Gram.
kn	Knot.
L	Litre.
m	Metre.
min	Minute.
nm	Nautical mile.
NTU	Nephelometric Turbidity Unit.
S	Siemens.
t	Tonne.

SI PREFIXES

PREFIX	SYMBOL	MULTIPLICATION FACTOR	... IN SCIENTIFIC NOTATION
mega	M	1 000 000	10^{6}
kilo	k	1000	10^{3}
–	–	1	10^{0}
deci	d	0.1	10^{-1}
centi	c	0.01	10^{-2}
milli	m	0.001	10^{-3}
micro	µ	0.000 001	10^{-6}

1 Introduction & Background

1.1 Background

The passenger ferry MV ESTONIA sank on 28 September 1994 during a voyage from Tallinn, Estonia, to Stockholm, Sweden. Of the 989 people on board, 852 died.

In accordance with an agreement between the prime ministers of Estonia, Finland, and Sweden, a The Joint Accident Investigation Commission of Estonia, Finland, and Sweden (JAIC) was formed to investigate the accident in 1994. JAIC published a part-report in Apr-1995 [4]; their final report was published on 3 December 1997.[3]

New video footage was published by Monster Media Group Limited in Sep-2020 which revealed a penetrating damage, characterized as a 'hole', in the starboard side of the hull (Figure 1.1).

FIG. 1.1: The hole that was displayed in the TV documentary in 2020, as seen in 2021 Remotely Operated Vehicle (ROV) footage.

The Estonian safety investigation authority, Estonian Safety Investigation Bureau (*Ohutusjuurdluse Keskus*, OJK) initiated a Preliminary Assessment of the new information and requested assistance from its corresponding authorities in both Finland and Sweden. Both the Safety Investigation Authority, Finland (*Onnettomuustutkintakeskus / Olycksutredningscentralen*, SIAF) and the Swedish Accident Investigation Authority

(*Statens haverikommission*, SHK) decided to assist OJK in carrying out the Preliminary Assessment.

The general purpose of a preliminary assessment after a maritime accident is to consider whether a safety investigation should be initiated.

1.2 Objectives of the Preliminary Assessment

The objectives of the Preliminary Assessment were:

- to identify the cause of penetrating deformation(s) to the hull of MV ESTONIA, seen in the new video footage aired in Sep-2020 by Monster Media Group Limited;
- to assess whether the new information gives reason to revise the conclusions presented in the JAIC Final Report;
- to assess which new investigative measures should be taken, if any; and
- to assess whether the safety investigation of the sinking of MV ESTONIA should be re-opened.

The scope of investigative activities has expanded over time. The JAIC conducted a stability analysis and concluded that a few thousand tonnes of water on the car deck would cause the vessel to heel sufficiently submerging additional openings for water ingress. The JAIC Final Report did not proceed beyond this stage, an understandable approach in the general context of a marine accident investigation.

Public criticism and questions regarding the later phase of MV ESTONIA's sinking led to additional scientific studies in the 2000s, procured by Swedish National Board for Psychological Defence (*Styrelsen för Psykologiskt Försvar*, SPF) and Swedish Agency for Innovation Systems (*Verket för innovationssystem*, Vinnova) in which the sinking sequence was modelled and explained up to the vessel's capsizing.

During the Preliminary Assessment, launched in 2020, the scope of investigation expanded even further. The main focus became the interaction between the vessel and the seabed. Planned investigative measures were split into phases, starting with preparatory surveys, which included a seabed survey and a general overview of the condition of the wreck. The purpose of these surveys was to collect data to target subsequent works most efficiently. Subsequent wreck surveys were used to measure and photograph the hull of the wreck and its deformations. Further, the sub-seabed layers in the immediate vicinity of the wreck were imaged to better understand stratigraphy in the vicinity of the wreck.

The inputs from marine surveys were used to simulate scenarios of the vessel's seabed contact. Results from such modelling projects were compared against the measured deformations on the wreck as well as the imaged subsea geology. This allowed the Preliminary Assessment to check whether any deformations were created by the contact of the vessel with the seabed and its later downslope movement or if they may have stemmed from other causes.

A programme of interviews with survivors and persons associated with the catastrophe was also carried out. These interviews were undertaken alongside collecting, systematizing, and reviewing existing interview material.

1.3 Roles of Participating States

In this Preliminary Assessment, the three authorities worked together under the lead of the Estonian authority. Estonia and Sweden carried out investigative activities while Finland, as a coastal state, facilitated access to the wreck in its Exclusive Economic Zone (EEZ) as well as observed the process of all work.

1.3.1 Estonia, Flag State

Article 94 of the United Nations Convention on the Law of the Sea (UNCLOS) states that the flag state is responsible for ships flying its flag in regards of, *inter alia*: construction, equipment, manning, and seaworthiness of ships. In case an accident or incident takes place, the flag state is responsible for conducting an inquiry to determine the cause(s) of the accident or incident.

Estonian Maritime Safety Act § 69[2] stipulates that the safety investigation of marine casualties and marine incidents shall be held, *inter alia*, if the ship flies the national flag of Estonia. The investigation is to be held purely with the purpose of improving maritime safety and without appointing any blame or liability.

At the time of the accident, the flag state of MV ESTONIA was the Republic of Estonia. Hence the obligation to conduct an inquiry into the causes of the accident lay with Estonia. The flag state may invite other countries to participate in the inquiry, who, in this case, were Finland (the coastal state) and Sweden (a substantially interested state).

Estonia led the Preliminary Assessment and coordinated activities in close cooperation with Finland and Sweden. The Estonian safety authority, OJK, initiated the Preliminary Assessment in 2020 and requested assistance from their corresponding authorities in the two other states that had been involved in the JAIC investigation.

1.3.2 Finland, Coastal State & Substantially Interested State

The wreck of MV ESTONIA is located in the Finnish EEZ, outside of Finnish Territorial Waters. The UNCLOS is an international agreement that establishes a legal framework for all marine and maritime activities.

MV ESTONIA is considered a maritime grave site, protected by both national and international legislation. Sanctity over the site has thus been declared. The Finnish Border Guard (*Rajavartiolaitos / Gränsbevakningsväsendet*, RVL) is responsible for grave peace surveillance in the area covered by the Finnish national grave peace legislation. Of the 852 fatalities, 10 were Finnish.

Upon the decision of the flag state Estonia, underwater operations in the vicinity of MV ESTONIA were considered necessary to conduct the Preliminary Assessment.

Finland is a signatory state of the UNCLOS agreement and holds the prerogatives of a coastal state in the Preliminary Assessment. Finland's role in the Preliminary Assessment was to facilitate investigative activities on site. Coastal states have sovereign rights in the EEZ with respect to natural resources and certain economic and scientific activities. Coastal states also exercise jurisdiction over environmental protection, and all marine research in the EEZ is subject to the coastal state's consent.

The facilitation of the Preliminary Assessment required the expertise, cooperation, and coordination of different Finnish authorities, organisations, and companies. These included the Ministry for Foreign Affairs, the Ministry of Justice, the Ministry of the Interior, the Ministry of Defence, the Ministry of Economic Affairs and Employment, and the Ministry of Traffic and Communications.

While SIAF participated in the Preliminary Assessment, it did not participate in the marine surveys conducted by its Estonian and Swedish counterparts.

1.3.3 Sweden, Substantially Interested State

According to the European Union (EU) Directive 2009/18/EC, there is an obligation for the flag state, the coastal state, and substantially interested states to carry out a safety investigation of very serious marine casualties. The expression "substantially interested states" refers to a definition in the International Maritime Organization (IMO) Casualty Investigation Code. One of the alternative criteria that can be the basis for being considered as a substantially interested state is where, as a result of a marine casualty, nationals of that state lost their lives or received serious injuries.

The IMO Casualty Investigation Code as well as the mentioned EU directive came into effect after the accident.

MV ESTONIA was travelling a route between Estonia and Sweden when the accident occurred. Of the 852 fatalities, 501 were Swedish.

Sweden took part in the JAIC investigation, together with the flag state and the coastal state, due to the high number of lost nationals, the effect on the society of such a catastrophe, and because Sweden participated in the rescue operations.

SHK fully participated in the Preliminary Assessment.

1.4 Public Affairs

Press conferences have been carried out after the achievement of milestones during the Preliminary Assessment with the primary objective of introducing interim results to the public.

A new website[1] was designed to comprehensively detail both the original catastrophe and its subsequent investigations. Similarly, all information gathered during the Preliminary Assessment is being published on this website.

Regular meetings have been carried out with the Estonian organization Memento Mare MTÜ, which represents some of the catastrophe's survivors, their next of kin, and the next-of-kin of casualties. Likewise, meetings have been held with Swedish survivors and next-of-kin.

Representatives from media as well as survivors have been present during surveys at site.

1.5 Legal Situation

1.5.1 Legal Framework

Regulation I/21 of the International Convention for the Safety of Life at Sea (SOLAS) lay down the responsibilities of flag states to conduct casualty investigations and to supply the International Maritime Organisation with relevant findings.

Article 94 of the UNCLOS establishes that each state shall cause an inquiry to be held by or before a suitably qualified person or persons into every marine casualty or incident of navigation on the high seas involving a ship flying its flag.

The IMO Casualty Investigation Code (Code of International Standards and Recommended Practices for a Safety Investigation into a Marine Casualty or Marine Incident) was adopted on 16 May 2008. The Code was preceded by the Code for the Investigation of Marine Casualties and Incidents adopted on 27 November 1997.

The Casualty Investigation Code establishes obligations of accident investigation authorities to investigate marine casualties (Chapter 6) as well as rights to acquire evidential material (Chapter 8).

EU Directive 2009/18/EC establishing fundamental principles governing the investigation of accidents in the maritime transport sector expresses the obligation of investigation authorities to investigate marine casualties (Article 5) as well as the right to free access to any relevant area or casualty site and to any ship or wreck (Article 8).

[1] The website URL is https://estonia1994.ee/en.

1.5.2 Protection of the Vessel

On 23 February 1995, the Governments of Estonia, Finland, and Sweden agreed to protect the wreck site of MV ESTONIA, as a final place of rest for victims of the disaster, from any disturbing activities.

The contracting parties stated in Article 3 of the agreement that the vessel would not be raised. In Article 4, the contracting parties undertook to institute legislation aiming at the criminalization of any activities which would disturb the peace of the final place of rest. It was explicitly stated that this criminalization should include any diving or other activities with the purpose of recovering victims or property from the wreck or the seabed.

This international agreement has been implemented in national legislations in various ways. Additional states have ratified the agreement as well. The contracting parties are Estonia, Denmark, Finland, Latvia, Lithuania, Poland, Russia, Sweden, and the United Kingdom.

1.5.3 Amendments of National Legislation

National legislation, implemented due to the international agreement to protect the wreck as a grave site, prohibited certain investigative activities. The legislation in Sweden and Finland specifically criminalized diving and other underwater activities at the accident site.

The respective accident investigation authorities requested amendments to the national legislation, which were passed by the parliaments of Sweden and Finland during 2021. The Finnish amendment was in effect to the end of 2024.

1.5.4 Legal Basis

The Casualty Investigation Code and the EU Directive 2009/18/EC were both adopted after the accident of MV ESTONIA. Neither of them contains any transitional provisions.

However, Chapter 26 of the Casualty Investigation Code establishes that each state, which has completed a marine safety investigation, should reconsider their findings and consider re-opening the investigation when new evidence is presented which may materially alter the analysis and conclusions reached. When significant new evidence relating to any marine casualty or marine incident is presented regarding a completed marine safety investigation, the evidence should be fully assessed for appropriate input.

The Preliminary Assessment set out to examine whether these criteria are met.

1.6 Report Status & Structure

The purpose of this report is to outline the Preliminary Assessment's conclusions with respect to the objectives of the Preliminary Assessment (Section 1.2) and to answer the most frequent questions asked about the sinking of MV ESTONIA.

Since the safety investigation of the sinking of MV ESTONIA has not been reopened and the present process constitutes a preliminary assessment of new information related to the accident, this report does not follow the conventional structure of a safety investigation report.

The report is divided into four main parts, defined in the context of this report as follows:

- **Chronological Overviews** (Chapter 2): this covers in a tabular format all input information for the Preliminary Assessment, connecting various analyses and investigative activities into a coherent logical whole.
- **Pre-Foundering Analysis & Results** (Chapter 4): this covers all events and aspects of the accident that occurred before the vessel came into contact with the seabed, including the vessel's condition prior to the accident, her final voyage, structural failures, and the flooding and sinking.
- **Post-Foundering Analysis & Results** (Chapter 3): this covers all events and aspects of the accident from the moment the vessel came into contact with the seabed, including the interaction between the vessel and the seabed as well as changes in the condition of the wreck and the seabed from the 1990s to the present.
- **Survivors' Interviews** (Chapter 5): this covers the analysis and discussions of the interviews conducted with the survivors during the Preliminary Assessment, including their previous statements.

Chronological overviews are presented to provide a concise overview of all input information, incl. marine operations, reports, and deliverables. This explains why certain actions were taken and how they contribute to the overall analysis. A familiarization with Chapter 2 is not a prerequisite for understanding the analysis and conclusions presented through Chapter 4 to Chapter 7.

The post-foundering chapter is presented next, as it addresses the Preliminary Assessment's primary objective: to explain the causes of the previously unknown damage. Since the JAIC Final Report described the seabed around the wreck only briefly, and no detailed overview has previously been published on how the wreck covering operations were technically conducted, this chapter also provides an overview of these subjects.

The pre-foundering chapter combines previous information and newly collected data from the Preliminary Assessment into a coherent, subject-based overview of the accident. Different stages and factors of the accident are described in chronological order together with the context needed to understand the subjects without substantial prior knowledge.

Sub-conclusions are presented in the beginning of each sub-section and followed by the discussion to simplify reading the report.

All times in the report, except where stated otherwise, are given in Eastern European Time (EET) (Coordinated Universal Time (UTC) +2 h).

Table 1.1 defines the locations of the wreck of MV ESTONIA and the seabed imprint of the visor as defined during the Preliminary Assessment.

TABLE 1.1: Coordinates of the wreck of MV ESTONIA and the visor imprint on the seabed as determined during the Preliminary Assessment.

DESCRIPTION	LATITUDE	LONGITUDE
Wreck	59°22.9192′ N	021°40.8451′ N
Visor Seabed Imprint	59°22.9696′ E	021°39.1571′ E

2 Chronological Overviews

2.1 Marine Operations

2.1.1 Initial Surveys, 1994

O 2.1

Wreck Locating Survey, 29-Sep-1994 to 30-Sep-1994	
Survey Contractor	MKH
Survey Vessel	MKH's hydrographic survey vessel SUUNTA
Contracting Authority	—
Main Objective	To locate the wreck.
Survey Equipment	SSS & MBES.
Main Results	The wreck was found.
Results Availability	No raw data available. Some faxed sonar images available.

O 2.2

Wreck Video Survey, 02-Oct-1994	
Survey Contractor	Finnish Navy
Survey Vessel	YM's oil pollution control vessel HALLI, operated by the Finnish Navy
Contracting Authority	JAIC.
Main Objective	To examine the wreck, its general condition, and whether the bow visor had become detached.
Survey Equipment	ROV.
Main Results	The wreck and its bow area were filmed.
Results Availability	ROV videos.

O 2.3

Additional Wreck Video Survey, 09-Oct-1994 to 10-Oct-1994	
Survey Contractor	RVL
Survey Vessel	RVL's OPV TURSAS
Contracting Authority	JAIC.
Main Objective	To receive detailed information of the damage in the bow area, as per JAIC's decision from meeting of 03-Oct-1994 to 04-Oct-1994.
Survey Equipment	ROV.
Main Results	Bow area of the wreck was filmed.
Results Availability	ROV videos.

O 2.4

Visor Locating Survey, 05-Oct-1994 to 18-Oct-1994	
Survey Contractor	RVL & EVA
Survey Vessel	RVL's OPV TURSAS & EVA's coast guard vessel EVA-200
Contracting Authority	JAIC.
Main Objective	To search for the bow visor, as per JAIC's decision from meeting of 03-Oct-1994 to 04-Oct-1994.
Survey Equipment	Low frequency echo sounder, SSS, & ROV.
Main Results	Visor was found 18-Oct-1994 approx. 1600 m west of the wreck; identification confirmed by ROV.
Results Availability	No raw data is available except for the ROV videos. Report.

O 2.5

Visor Recovery Operation, 12-Nov-1994 to 19-Nov-1994	
Survey Contractor	MKH & Swedish Navy
Survey Vessel	MKH' multi-purpose icebreaker NORDICA & Swedish Navy's HMS FURUSUND
Contracting Authority	JAIC.
Main Objective	To recover the visor for a detailed survey.
Survey Equipment	ROV.
Main Results	The visor was recovered on 18-Nov-1994, and taken to Hanko, Finland for further examination and studies.
Results Availability	No raw data is available. The visor is located and accessible in Musköbasen, Sweden. Several reports about examination and testing of visor parts.

2.1.2 Wreck Status Surveys & Covering Operations, 1994 to 1997

O 2.6

Condition Survey, 21-Nov-1994 to 08-Dec-1994	
Survey Contractor	Rockwater A/S & Smit Tak B.V., subcontracted UDI-Wimpol Limited (Fugro Group)
Survey Vessel	Rockwater A/S' semi-submersible platform ROCKWATER SEMI 1 & K/S Sira PSV's (Brødrene Klovnings Rederi A/S) PSV SIRA SUPPORTER
Contracting Authority	SjöV.
Main Objective	To gather information in considering further actions regarding the wreck, by establishing the condition of its interior and evaluating the feasibility of lifting the entire wreck or recovering individual victims.
Survey Equipment	Saturation divers, two ROVs, echo sounder, combined SSS and SBP, & vibracorer.
Main Results	The wreck was assessed to be salvageable but operation complicated. The wreck's position, orientation, and condition were documented. The seabed consists of silt and soft clay with a slope around the wreck of 3° to 9°. The seabed in the wider area is highly variable with numerous local valleys.
Results Availability	Reports (by Rockwater A/S, ter Haar, & Shaw). Only data referenced in reports, dive logs, & ROV videos.

O 2.7

Seabed Investigation, 21-May-1995 to 30-May-1995

Survey Contractor	Rockwater A/S, subcontracted UDI-Wimpol Limited (Fugro Group)
Survey Vessel	Det Søndenfjelds-Norske DS's drilling vessel BUCENTAUR
Contracting Authority	SjöV, represented by VBB VIAK AB (Sweco Group).
Main Objective	To carry out seabed investigations around the wreck to establish the geotechnical and geochemical characteristics of the seabed necessary for the design of the wreck covering solution.
Survey Equipment	SBES, ROV, sector scanning sonar, T/S probe, PCPT, borehole sampler, gravity corer, box corer, & water sampler.
Main Results	Bathymetric map of the site made using ROV data as the basis; geotechnical information acquired with some CPTs penetrating up to 30 m below seabed.
Results Availability	No raw data. Only reported data available in print & two ROV / survey screen video clips. Report.

O 2.8

Complementary Surveys, 29-Dec-1995 to 03-Jan-1996

Survey Contractor	Nordic Marine Contractors J.V. (consortium of NCC AB & NCC Eeg-Henriksen A/S & A/S Jebsens-ACZ & Smit Tak B.V.), subcontracted Delft Geotechnics & Fugro Engineers B.V.
Survey Vessel	Van Oord ACZ Materieel B.V.'s FFPV ROCKY GIANT
Contracting Authority	SjöV, represented by VBB VIAK AB (Sweco Group).
Main Objective	To prepare for the wreck covering works by confirming existing data; establishing more confidence in soil status at the wreck site and at the sand borrow pit offshore Helsinki; installing pilot forced penetration strings.
Survey Equipment	Sonar system, ROV, sector scanning sonar, large diameter sample corer, & vane tests.
Main Results	Indications were found that a mud slide occurred to the south of the wreck; occasional items noted in the vicinity of the wreck; pilot forced penetration string installed.
Results Availability	Only reported data available in print & four ROV video clips. Report.

O 2.9

Oil Removal Operation, 09-Apr-1996 to 20-Jun-1996	
Survey Contractor	Frank Mohn A/S & Northern Engineering A/S & Taifun Engineering Oy Ltd & Alfons Håkans Oy Ab & RVL & Finnish Navy
Survey Vessel	YM's oil pollution control vessel HALLI, operated by the Finnish Navy, as the main platform & YM's oil pollution control vessel HYLJE, operated by the Finnish Navy, as a stand-by vessel
Contracting Authority	YM.
Main Objective	To minimize the risk of future environmental pollution by emptying the wreck's fuel tanks before it was covered. The minimum goal was to remove at least 200 m^3 of oil (of an estimated 418 m^3) by fully emptying the bottom tanks containing light oil as far as practicable, and removing 70 % to 80 % from the tanks containing heavy fuel oil.
Survey Equipment	ROLS operated by the vessel's crane, assisting ROVs, vacuum pump system, surveillance airplanes, & satellites.
Main Results	Approx. 230 m^3 to 250 m^3 of various oils were removed from the wreck and 8 m^3 from the sea surface. The bow of the wreck was filmed at the request of the JAIC on 19-Jun-1996.
Results Availability	Work log, ROV videos & some operational videos (total length of digitized video 215 h 55 min). Report.

O 2.10

Wreck Covering Works, 19-Apr-1996 to 27-Jul-1996	
Survey Contractor	Nordic Marine Contractors J.V., subcontracted Delft Geotechnics & NGI
Survey Vessel	Van Oord ACZ Marine Services B.V.'s semi-closed FFPV TERTNES & Van Oord ACZ Materieel B.V.'s TSHD VOLVOX IBERIA & EMI's RV LIVONIA
Contracting Authority	SjöV, represented by VBB VIAK AB (Sweco Group).
Main Objective	To protect the wreck from intrusion by covering it with a double layer of block mattresses and granular material fillings at the bow and stern.
Survey Equipment	MBES, scanning sonar, SBP (pinger), ROVs, soil samplers, & wreck position measuring system.
Main Results	Forced penetration strings were installed in the southern part of the counterfill. Around the wreck, 26 geotextiles were installed and stabilized with a gravel layer. Sandfilling was placed but not to the originally planned extent. On 21-Jul-1996 large scale sandfill deformation were discovered south of the wreck. Approx. 300 000 m^3 of sand had been placed by then. The work was continued, but was soon suspended due to ongoing movement. At demobilisation, a total amount of approx. 380 000 m^3 of sand had been placed in the area. The wreck's position was monitored by the transponders and remained stable at its original position.
Results Availability	Only reported data available in print. Large but incomplete dataset consisting of several reports from design (by Heijboer & Heijboer), as-built, and re-design phases.

O 2.11

Seismic Survey, 08-Sep-1997 to 10-Sep-1997	
Survey Contractor	Nordic Marine Contractors J.V., subcontracted Nederlands Instituut voor Toegepaste Geowetenschappen TNO
Survey Vessel	SjöV's icebreaker ALE
Contracting Authority	SjöV, represented by VBB VIAK AB (Sweco Group).
Main Objective	To determine the sand layer thickness and to obtain a more detailed quantification of the contact area between the wreck and the seabed, based on which the alternative protection (wreck covering) design could be finalised.
Survey Equipment	Towed SBP (chirp).
Main Results	The wreck is resting sufficiently on the glacial till and the stability of the anti-intrusion protection design is confirmed by the results of this investigation. No change in the position of the wreck relative to the surrounding seabed has occurred since the site has been abandoned at the end of Jul-1996.
Results Availability	Only reported data available in print. Reports (by Velde & Mesdag).

2.1.3 Hydrographic Surveys, 2006

O 2.12

Hydrographic Survey, 18-Aug-2006 to 22-Aug-2006	
Survey Contractor	OSAE GmbH
Survey Vessel	OSAE GmbH's RV MERIDIAN
Contracting Authority	MKL.
Main Objective	To conduct general hydrographic surveying.
Survey Equipment	MBES.
Main Results	Hydrographic survey completed over 3780 km^2.
Results Availability	Cleaned soundings.

2.1.4 Preliminary Assessment, 2021 to 2024

O 2.13

Video Survey, 14-Jul-2021 to 15-Jul-2021	
Survey Contractor	Tuukritööde OÜ
Survey Vessel	Tuukritööde OÜ's workboat VLT-089
Contracting Authority	OJK for the Preliminary Assessment.
Main Objective	To obtain the visual information of the wreck and the mudline; to visually inspect areas of interest which had been recorded on the sector-scanning sonar.
Survey Equipment	Observation-class & drone-class ROVs.
Main Results	Good quality video imagery acquired across the mudline of the wreck, documenting damage and condition of the wreck.
Results Availability	Raw video and post-processed (watermarked) videos. Report.

O 2.14

Geophysical Reconnaissance, 08-Jul-2021 to 15-Jul-2021	
Survey Contractor	Stockholms universitet
Survey Vessel	Stockholms universitet's RV ELECTRA AF ASKÖ
Contracting Authority	SHK for the Preliminary Assessment.
Main Objective	To map the wreck's position on the seabed as well as the seabed topography (bathymetry) and geology of the wreck site for the purpose of establishing a base dataset to be used for further assessments of the accident as well for the preparation of additional investigations.
Survey Equipment	MBES, SBP, mid-water sonar, SSS, SVP, CTD, two ADCPs, environmental camera, grab sampler, & piston corer.
Main Results	Mapping of exposed bedrock at surface, confirmation of sediments around the wreck, and position assessment of the wreck.
Results Availability	Raw data. Report.

O 2.15

Seismo-Acoustic Survey, 14-Jul-2021	
Survey Contractor	EGT
Survey Vessel	Stockholms universitet's RV ELECTRA AF ASKÖ
Contracting Authority	OJK for the Preliminary Assessment.
Main Objective	To enhance penetration of sediments and to map the bedrock surface along with the thickness of glacial till.
Survey Equipment	Towed seismic system (boomer) with a hydrophone.
Main Results	Tentative bedrock surface identified with numerous outcrops in the survey area.
Results Availability	Raw data. Report.

O 2.16

Sector Scanning Sonar Survey, 11-Jul-2021 to 16-Jul-2021	
Survey Contractor	Abbott Underwater Acoustics, LLC
Survey Vessel	TRAM's multi-purpose icebreaker EVA-316
Contracting Authority	OJK for the Preliminary Assessment.
Main Objective	To obtain information on the conditions of the wreck and the surrounding seabed by sonar imaging.
Survey Equipment	Sector scanning sonar.
Main Results	Mapping of the wreck and seabed features in detail.
Results Availability	Raw data. Report.

O 2.17

Oceanographic Surveys, 10-Jul-2021 to 21-Mar-2022	
Survey Contractor	Tallinna Tehnikaülikool
Survey Vessel	TRAM's multi-purpose icebreaker EVA-316 (first launch); PPA's multi-purpose oil pollution control vessel KINDRAL KURVITS (first recovery); PPA's multi-purpose oil pollution control vessel RAJU (second launch); Tallinna Tehnikaülikool's RV SALME (second recovery)
Contracting Authority	OJK for the Preliminary Assessment.
Main Objective	To understand water column conditions by measuring pressure, conductivity, temperature, and oxygen content.
Survey Equipment	Moored ADCP.
Main Results	Understanding of water column conditions in summer, autumn, and winter.
Results Availability	Raw data. Reports (by Kikas et al. & Kikas et al.).

O 2.18

Seawater Turbidity Survey, 13-Apr-2022 to 01-Jun-2022	
Survey Contractor	Tallinna Tehnikaülikool
Survey Vessel	TRAM's RV JAKOB PREI (launch); Tallinna Tehnikaülikool's RV SALME (maintenance); Tuukritööde OÜ's workboat VKC-346 (recovery)
Contracting Authority	OJK for the Preliminary Assessment.
Main Objective	To measure seawater turbidity as an input to the laser scanning survey.
Survey Equipment	Autonomous underwater glider.
Main Results	Understanding of turbidity conditions in late spring.
Results Availability	Raw data. Report.

O 2.19

Laser Scanning Survey, 20-May-2022 to 28-May-2022	
Survey Contractor	ESC Risk Management OÜ, subcontracted Baltic Taucherei- und Bergungsbetrieb Rostock GmbH & Kraken Robotik GmbH
Survey Vessel	Vroon Offshore Services BV's OSV VOS SWEET
Contracting Authority	OJK for the Preliminary Assessment.
Main Objective	To generate an accurate 3D digital point cloud of the wreck and the adjacent seabed using laser scanning, focussing on all deformations and openings.
Survey Equipment	Light work-class ROV with laser scanner.
Main Results	No results obtained due to the loss of the primary ROV and its onboard equipment. The contract was terminated on 31-Dec-2022.
Results Availability	None.

O 2.20

Photogrammetry and Other Marine Surveys, 04-Jun-2022 to 24-Jun-2022	
Survey Contractor	Ocean Discovery AB, subcontracted JD-Contractor A/S
Survey Vessel	Vroon Offshore Services BV's OSV VOS SWEET
Contracting Authority	SHK for the Preliminary Assessment.
Main Objective	To create a 3D digital model of the wreck and the adjacent seabed using photogrammetry; to map the geology in the vicinity of the wreck using sub-bottom profiling to improve the geologic model around the wreck; and to collect biological samples from the wreck for further analysis.
Survey Equipment	Two observation-class ROVs, light work-class ROV with SBP, drone-class ROV, & biological sampler.
Main Results	Approx. 45 000 high resolution still images were taken to create photogrammetric model. The SBP data were used to improve the geologic model around the wreck. No biological samples were collected.
Results Availability	Raw video and image data & raw SBP data. Report. Photogrammetric model of the wreck and adjacent seabed & three orthomosaic charts.

O 2.21

Marine Surveys and Works, 17-Jul-2023 to 25-Jul-2023	
Survey Contractor	Reach Subsea AS, subcontracted JM Robotics AS
Survey Vessel	Eidesvik Reach AS' RV VIKING REACH
Contracting Authority	SHK for the Preliminary Assessment.
Main Objective	To collect and recover different samples from the wreck (including the bow ramp) and the seabed for further analysis; to inspect the condition of the vehicle deck.
Survey Equipment	Work class-ROV with various tools & two observation class-ROVs.
Main Results	Successfully conducted bedrock sampling, hull fouling sampling, recovery of shell plating cut-outs, recovery of window samples, starboard side damage shell plating sampling, visual inspection of the vehicle deck, and recovery of the bow ramp.
Results Availability	Raw video and survey screen data & recovered samples. Reports (by Skelton, Dupraz et al., Toomet, Laanet, & Juhe). Digital twin of the bow ramp.

O 2.22

High-Resolution Seabed Imaging Survey, 23-Nov-2023 to 29-Nov-2023	
Survey Contractor	Reach Subsea AS
Survey Vessel	Göteborgs universitet's RV SKAGERAK, operated by Northern Offshore Services AB
Contracting Authority	OJK for the Preliminary Assessment.
Main Objective	To gain a better understanding of the flooded vessel's track during the accident and to document the seabed around the wreck in detail.
Survey Equipment	MBES, MAS, & CTD.
Main Results	Mapping of the seabed carried out successfully along the anticipated track of the vessel. Debris from MV ESTONIA mapped.
Results Availability	Raw data and processed outputs. Report.

O 2.23

Seabed Target Video Inspection, 01-Jul-2024 to 04-Jul-2024	
Survey Contractor	RIL & EMSA, subcontracted ACSM Shipping CO SLU
Survey Vessel	RIL's multi-purpose icebreaker EVA-316
Contracting Authority	OJK for the Preliminary Assessment.
Main Objective	To identify some of the interpreted objects from the high-resolution seabed imaging survey, and to verify whether these originate on MV ESTONIA and if so, from which part of the vessel.
Survey Equipment	Observation-class ROV.
Main Results	Altogether 17 dives were carried out with video identification of mapped MAS targets. The rotatable part of the starboard side ramp railing was found 485 m west from the visor location on the seabed and was recovered.
Results Availability	Raw video data and post-processed (watermarked) videos. Report.

2.2 Reports & Deliverables

2.2.1 Wreck Site & Wreck

Prior to the Preliminary Assessment

[18]

RAPPORT angående de tekniska och legala förutsättningarna att återfinna och omhänderta omkomna från färjan Estonia.	
Publisher	Sjöfartsverket
Author(s)	
Date	1994-10-11
Contracting Authority	SjöV
Main Objective	To review technical and legal conditions to find and take care of victims from MV ESTONIA.
Type of Report	Technical Report; Supplement No. 502[19] to JAIC Final Report
Language	Swedish
Field Work Status	Desk-based.
Main Results	There were no legal obstacles or obligations for anyone to search for and recover the deceased after a maritime accident. It was not known how many deceased were inside or outside the ship, but search and recovery of the deceased outside the ship could be carried out using various techniques.

[5]

Surveyreport m.v. "Estonia". Our project nr. 94/7.060.

Publisher	Smit Tak B.V.
Author(s)	ter Haar
Date	1994-12-8
Contracting Authority	Rockwater A/S
Main Objective	To assess the condition of the wreck of MV ESTONIA post-sinking and provide information for governmental decision-making on further interventions.
Type of Report	Survey Report as Add-On to Survey Report
Language	English
Field Work Status	Field-based (O 2.6).
Main Results	Detailed inspections were conducted using ROVs and saturation divers, though much of the starboard side remained inaccessible.

[20]

Condition Survey of Ferry "Estonia". Survey Report

Publisher	Rockwater A/S
Author(s)	
Date	1994-12-12
Contracting Authority	SjöV
Main Objective	To assess the condition of the wreck of MV ESTONIA post-sinking and provide information for governmental decision-making on further interventions.
Type of Report	Survey Report; Supplement No. 503[19] to JAIC Final Report
Language	English
Field Work Status	Field-based (O 2.6).
Main Results	A total of 125 victims were located inside the wreck during the survey, primarily in accessible port-side areas. The condition of the wreck was documented extensively, and it was concluded that technical salvage was feasible, though accompanied by ethical and logistical complexities.

[6]

Rockwater A/S. Estonia Ferry Survey. 26 November - 8 December 1994

Publisher	UDI-Wimpol Ltd
Author(s)	Shaw
Date	1994-12-13
Contracting Authority	SjöV
Main Objective	To conduct a geophysical and geotechnical survey at the MV ESTONIA wreck site to characterize seabed and sub-seabed conditions, evaluate potential hazards, and prepare for planned diving operations.
Type of Report	Survey Report
Language	English
Field Work Status	Field-based (O 2.6).
Main Results	MV ESTONIA wreck lay on a slope at 80 m to 85 m depth over very soft sediments and some gas-charged areas. Bathymetry revealed channels filled with laminated clays and silts up to 22 m thick. No debris or hazards were found. Anchoring conditions were deemed difficult.

[21]

Övertäckning Estonia

Publisher	Sjöfartsverket
Author(s)	
Date	1995-2-10
Contracting Authority	SjöV
Main Objective	To evaluate the feasibility of covering the wreck of MV ESTONIA with materials (e.g., rocks or concrete elements) to ensure long-term protection and integrity.
Type of Report	Technical feasibility and geotechnical assessment report
Language	Swedish
Field Work Status	Desk-based.
Main Results	Full coverage using rockfill or concrete elements was theoretically feasible, but required extensive technical planning: concerns included slope stability, sediment conditions, logistics, and potential risks to divers and equipment.

[22]

m/s ESTONIAN hylyn ympäristösta laadittujen merenpohjakarttojen selitys

Publisher	Merivoimien tutkimuslaitos
Author(s)	Nuorteva
Date	1995-3-28
Contracting Authority	JAIC
Main Objective	To document and interpret the seabed maps produced from sonar data collected during the 1994 search for the bow visor, including bathymetry, sediment layers, and seabed properties.
Type of Report	Survey Report; Supplement No. 501[19] to JAIC Final Report
Language	Finnish
Field Work Status	Field-based (O 2.4).
Main Results	A detailed classification of seabed types (rock, moraine, glacial/post-glacial clays) was created based on sonar interpretation. Depths ranged from 51 m to 121 m. No sand formations were detected. Post-glacial clays may exceed 50 m to 70 m in thickness. Wreck orientation, slope conditions, and debris fields were mapped acoustically.

[23]

ESTONIA - SEABED INVESTIGATION. RW/NMA/EST/REP/001, Rev C.

Publisher	Rockwater A/S
Author(s)	
Date	1995-7-11
Contracting Authority	SjöV
Main Objective	To perform a geophysical and geotechnical seabed investigation to support the potential design of a protective embankment over the wreck site.
Type of Report	Survey Report
Language	English
Field Work Status	Field-based (O 2.7).
Main Results	The seabed was composed primarily of glacial and post-glacial clays overlying till. Sediments near the wreck were sampled and found to be soft to very soft. Recommendations included further surveys, incl. seismic refraction and sand dumping trials to support embankment design.

[24]

Engineering Field Report on Complementary Investigations. ACZ-REP-DES-001, Rev 01.

Publisher	Jebsens A.C.Z.
Author(s)	Heijboer
Date	1996-1-26
Contracting Authority	SjöV
Main Objective	To perform additional geotechnical investigations near the wreck of MV ESTONIA, including CPT, vibracoring, and bathymetric surveys, to supplement earlier findings and inform planning for a protective embankment.
Type of Report	Field Report
Language	English
Field Work Status	Field-based (O 2.8).
Main Results	The seabed consisted mainly of post-glacial clays with some areas of glacial clay and till. CPT and core samples confirmed weak surface layers over firmer substrate. Data supported design assumptions for potential protective works.

[7]

Preliminary Design Report on Forced Penetration Strings. ACZ-REP-DES-004, Draft.

Publisher	Nordic Marine Contractors J.V.
Author(s)	Heijboer
Date	1996-1-26
Contracting Authority	SjöV
Main Objective	To provide a preliminary design of forced penetration strings intended to enhance the stability of fill material placed around the wreck of MV ESTONIA, by increasing shear resistance over weak clay subsoil.
Type of Report	Preliminary Design Report
Language	English
Field Work Status	Desk-based.
Main Results	Forced penetration strings, spaced approx. 30 m apart and driven 1.5 m to 2.0 m deep, were proposed to reinforce the seabed around the wreck. Simulations showed a 32 % to 50 % increase in stability.

[8]

Preliminary Design Report on Geotextiles. ACZ-REP-DES-005, Draft

Publisher	Nordic Marine Contractors J.V.
Author(s)	Heijboer
Date	1996-1-26
Contracting Authority	SjöV
Main Objective	To propose and design a geotextile layer beneath the planned sand fill to enhance stability and mitigate seabed failure near the wreck of MV ESTONIA.
Type of Report	Preliminary Design Report
Language	English
Field Work Status	Desk-based.
Main Results	The report proposed using high-tensile polyester geotextiles (PETP 500/50) anchored to forced penetration strings and ballasted with gravel. Functions include stabilizing weak clays, reducing settlement, and distributing loads. Estimated coverage was approx. 100 875 m^2.

[25]

Report on Sand Borrow Pit Helsinki. ACZ-REP-DES-002, Rev 2.

Publisher	Nordic Marine Contractors J.V.
Author(s)	Heijboer
Date	1996-4-12
Contracting Authority	SjöV
Main Objective	To evaluate the suitability of a sand borrow site offshore Helsinki for use in the planned protection works at the MV ESTONIA wreck site.
Type of Report	Field Report
Language	English
Field Work Status	Field-based.
Main Results	Bathymetric and vibracoring surveys confirmed the presence of suitable sand that could be dredged (200 µm and larger) in a 500 m × 150 m area. Finer sand, present elsewhere in the pit, was considered acceptable for counter-fills. A total of approx. 300 000 m^3 of sand was needed.

[26]

Penetration String Inspection. NMC-PRO-OUA-008, Rev 1.

Publisher	Nordic Marine Contractors J.V.
Author(s)	Myers
Date	1996-4-25
Contracting Authority	SjöV
Main Objective	To define and implement procedures for inspecting the upper surfaces of forced penetration strings to ensure clean contact with geotextile and sandfill layers.
Type of Report	Procedure
Language	English
Field Work Status	Field-based (O 2.10).
Main Results	Clean contact surfaces were ensured through ROV-based video inspections. Where clay contamination was observed, corrective sand dump runs were planned to restore clean interfaces, critical for proper load transfer.

[27]

Protection of the M/S Estonia, laboratory testing sandfill material. BO-361680/145, Version 02.

Publisher	Delft Geotechnics
Author(s)	Grashuis
Date	1996-9-20
Contracting Authority	Nordic Marine Contractors J.V.
Main Objective	To determine the geotechnical properties of sandfill material sampled from Helsinki's borrow area, in support of seabed protection measures around the wreck of MV ESTONIA.
Type of Report	Laboratory Report as Annex to report
Language	English
Field Work Status	Field-based (analysis of samples collected during O 2.10).
Main Results	The sandfill material showed low plasticity and good grading, with high permeability and low compressibility, suitable for intended fill use. Shear strength and density parameters were within expected ranges.

[28]

Protection of the M/S Estonia, seabed soil sampling. BO-361680/161.

Publisher	Delft Geotechnics
Author(s)	Grashuis
Date	1996-9-20
Contracting Authority	Nordic Marine Contractors J.V.
Main Objective	To analyse geotechnical properties of seabed soils near the wreck of MV ESTONIA to inform the design and stability of protective structures.
Type of Report	Laboratory Report as Annex to report
Language	English
Field Work Status	Field-based (analysis of samples collected during O 2.10).
Main Results	Soils consisted mainly of soft clays with low undrained shear strength and high moisture content, presenting challenges for load-bearing capacity. Consolidation and strength data were derived to inform FEM modelling.

[29]

Protection of the M/S Estonia, Interpretation of seismic surveys. BO-361680/160.

Publisher	Delft Geotechnics
Author(s)	Kruse
Date	1996-9-20
Contracting Authority	Nordic Marine Contractors J.V.
Main Objective	To interpret SBP profiles from Jul-1996 to assess sandfill thickness, seabed changes, and underlying soil conditions following a slump near MV ESTONIA.
Type of Report	Seismic interpretation report as Annex to report
Language	English
Field Work Status	Field-based (analysis of seismic data collected during O 2.10).
Main Results	Sandfill thickness before the slump was generally ≤4 m, with one point reaching 5.9 m. The post-deformation deposits reached up to 9.1 m thick. MV ESTONIA was interpreted to rest in firm contact with glacial till; data showed deformations in surficial deposits and possible remoulding south of the wreck.

[30]

Protection of M/S Estonia, Geotechnical report on sandfill deformation. BO-361680/159. Revision 01.

Publisher	Delft Geotechnics
Author(s)	Luger
Date	1996-9-27
Contracting Authority	Nordic Marine Contractors J.V.
Main Objective	To evaluate the causes and mechanics of the Jul-1996 sandfill deformation near the wreck of MV ESTONIA using numerical modelling and site data.
Type of Report	Geotechnical analysis report as Annex to report
Language	English
Field Work Status	Desk-based.
Main Results	FEM modelling showed that the deformation was likely due to a combination of excess pore pressure from the rapid sand dumping and weak clay subsoil. A slope failure was simulated that matched observed conditions. Recommendations included revised dumping methods and preloading strategies.

[31]

The removal of oil in the wreck of the MS Estonia

Publisher	Suomen ympäristökeskus
Author(s)	Jolma and Mykkänen
Date	1996-10-25
Contracting Authority	SYKE
Main Objective	To remove as much oil as reasonably possible from the wreck of MV ESTONIA before it was covered, minimizing future environmental risk.
Type of Report	Operations Report
Language	English
Field Work Status	Field-based (O 2.9).
Main Results	Approx. 230 m^3 to 250 m^3 of oil were successfully removed using robotic systems without divers. Despite equipment issues and delays, the operation demonstrated that remote-controlled extraction of heavy oil is feasible under suitable conditions.

[32]

Detailed Report on Deformation during Sandfilling. ACZ-REP-DES-026, Rev 03.

Publisher	Nordic Marine Contractors J.V.
Author(s)	Heijboer
Date	1996-11-17
Contracting Authority	SjöV
Main Objective	To document and analyse structural deformations observed during the sandfilling operations and to form a basis for a conceptual design of the remedial actions to be taken in order to complete the original design.
Type of Report	Factual Report
Language	English
Field Work Status	Field-based (O 2.10).
Main Results	The position of the wreck had not changed and was more stable than previously anticipated. The exact reason for the occurred deformations cannot be determined, but possible causes are the mobilisation of combined forces, the presence of sediment layers thicker and/or softer than applied in design calculations, local slides, progressive failure, the sliding of geotextiles, and local punching of sandfilling.

[33]

Re-Definition of Design Basis. ACZ-REP-DES-030, Rev 1.

Publisher	Nordic Marine Contractors J.V.
Author(s)	Velde
Date	1997-5-15
Contracting Authority	SjöV
Main Objective	To reassess the engineering design parameters and construction strategy for the seabed protection around MV ESTONIA in response to deformation observed in 1996.
Type of Report	Engineering design reassessment
Language	English
Field Work Status	Desk-based.
Main Results	The design basis was updated to account for lower shear strength in underlying clay and increased deformation risk. Adjustments included modified fill geometry, preloading options, and placement sequence revisions. Recommendations were based on FEM results and geotechnical re-evaluation.

[34]

Concrete Block Mattress Solution. ACZ-REP-DES-033, Rev 3.

Publisher	Nordic Marine Contractors J.V.
Author(s)	Velde
Date	1997-8-29
Contracting Authority	SjöV
Main Objective	To propose a technically viable alternative to the sandfill embankment using a flexible concrete block mattress system for covering the wreck of MV ESTONIA.
Type of Report	Preliminary design proposal
Language	English
Field Work Status	Desk-based.
Main Results	The concrete block mattress solution was found to be technically feasible and adaptable to seabed conditions. Benefits included modularity, flexibility, and reduced need for seabed preparation. Estimated coverage of approx. $10\,500\,m^2$ with fill quantities approx. $45\,000\,m^3$.

[10]

Seismic Survey at Estonia Site. NITG 97-187-B.

Publisher	Netherlands Institute of Applied Geoscience TNO
Author(s)	Mesdag
Date	1997-9-1
Contracting Authority	Jebsens ACZ A/S
Main Objective	To determine the seabed configuration and position of MV ESTONIA relative to glacial till for coverage design planning.
Type of Report	Survey Report as Annex to report
Language	English
Field Work Status	Field-based (O 2.11).
Main Results	The survey successfully mapped the seabed and glacial till surface beneath the wreck. Results indicated that the vessel likely contacts glacial till in some areas. Mud thickness maps and seismic reflectors provided high confidence in till depth assessment.

[9]

Investigation Report on Estonia Contact with Glacial Till. ACZ-REP-DES-034, Rev 01.

Publisher	Nordic Marine Contractors J.V.
Author(s)	Velde
Date	1997-10-31
Contracting Authority	SjöV
Main Objective	To determine whether the hull of MV ESTONIA is in direct contact with glacial till and assess implications for wreck stability.
Type of Report	Geotechnical investigation report
Language	English
Field Work Status	Field-based (O 2.9).
Main Results	The investigation concluded that the midsection of the wreck lies directly on glacial till. This contact provided structural support and explained reduced deformation in that area. Bedrock was not present under the wreck. The findings informed future stabilization strategies.

[35]

Historiebeskriving from geoteknisk synpunkt	
Publisher	VBB VIAK AB
Author(s)	Engström
Date	1999-3-10
Contracting Authority	SjöV
Main Objective	To provide a chronological technical summary of the works carried out at the MV ESTONIA wreck site from 1994 to 1998, and to assess their reliability and conclusions.
Type of Report	Summary Overview
Language	Swedish
Field Work Status	Desk-based.
Main Results	The report reviewed the surveys conducted from 1994 to 1998, affirming their general consistency and technical soundness, along with progress meetings and technical reviews held.

Preliminary Assessment

[36]

Parvlaeva Estonia allvee robotuuringute kokkuvõte 14-15.07.2021	
Publisher	Tuukritööde OÜ
Author(s)	Peremees
Date	2021-7-20
Contracting Authority	OJK for the Preliminary Assessment.
Main Objective	To verify sonar imagery and identified objects at the wreck site of MV ESTONIA.
Type of Report	Survey Report
Language	Estonian
Field Work Status	Field-based (O 2.13).
Main Results	The investigation found the stern ramps to be closed and undamaged, with no visible damage to the propellers or rudders. Several structural deformations were observed, particularly around the bow ramp and car deck areas. ROV access was occasionally limited due to visibility issues and cable constraints. The surrounding seabed was also examined, revealing minor external objects near the wreck.

[37]

A Preliminary Assessment of the MS Estonia Shipwreck Using the MS 1000 Scanning Sonar

Publisher	Abbott Underwater Acoustics, LLC
Author(s)	Abbott
Date	2021-8-21
Contracting Authority	OJK for the Preliminary Assessment.
Main Objective	To conduct a preliminary underwater sonar survey of the wreck of MV ESTONIA and the surrounding seabed to establish a data baseline for future investigations.
Type of Report	Survey Report
Language	English
Field Work Status	Field-based (O 2.16).
Main Results	The ship rests on her starboard side at a list of 132° to 138°. A trench lies along the hull's north side; structural damage, hull cracks, and displaced elements were observed. A baseline sonar mosaic of the wreck and seabed was created.

[38]

Fartyget M/S Estonia – Genomgång av geotekniskt underlag

Publisher	Swedish Geotechnical Institute
Author(s)	Rudebeck and Kennedy
Date	2021-9-14
Contracting Authority	SHK for the Preliminary Assessment.
Main Objective	To review existing geotechnical data at the wreck site of MV ESTONIA, assess possible geological explanations for the vessel's rotation and observed hull breaches, and support planning of future investigations.
Type of Report	Geotechnical desktop study
Language	Swedish
Field Work Status	Desk-based (review of existing investigations).
Main Results	The vessel rests on soft post-glacial clay with prior slope failures documented. Two hull breaches and rotational movement are discussed, but causality remains inconclusive. The report calls for further field studies to clarify the vessel's interaction with subsoil, especially contact with glacial till.

[39]

EL21-Estonia : Report of the MS Estonia shipwreck site survey with RV Electra

Publisher	Stockholm University, Department of Geological Sciences
Author(s)	Jakobsson et al.
Date	2021-11-3
Contracting Authority	SHK for the Preliminary Assessment.
Main Objective	To map MV ESTONIA's present position on the seabed as well as the wreck site's topography (bathymetry) and geology.
Type of Report	Survey Report
Language	English
Field Work Status	Field-based (O 2.14).
Main Results	Earlier findings were confirmed while more detailed sediment boundaries, exposed bedrock, and mass-wasting features around the wreck of MV ESTONIA were mapped. A slide scarp west of the vessel indicated past downslope movement of dumped sand; exposed bedrock near major hull breaches may have contributed to deformation. The midship rested on firm seabed, but the bow was poorly supported, increasing the risk of structural stress. The wreck lay at a starboard list of approx. 133°, with signs of gradual hull deformation toward the bow. A trench up to 8 m wide and 7 m deep extended along the stern and northern side. Several metal frames and seabed imprints of the bow visor were identified. Oceanographic data showed weak upper-layer currents but strong bottom currents up to 1 m/s, likely affecting sediment stability. A halocline and anoxic conditions were present below 75 m, meaning the wreck spanned both oxic and anoxic zones, which may have influenced its corrosion.

[11]

ADCP mõõtmised hoovuste profiilide ja põhjalähedase soolsuse ning hapniku sisalduse andmete kogumiseks parvlaev „Estonia“ vraki piirkonnas (juuli-november 2021). Aruanne

Publisher	Tallinna Tehnikaülikool
Author(s)	Kikas et al.
Date	2022-1-20
Contracting Authority	OJK for the Preliminary Assessment.
Main Objective	To collect vertical current profiles and bottom-layer salinity, temperature, and oxygen data near the wreck of MV ESTONIA between Jul-2021 and Nov-2021 to support environmental modelling and historical comparison.
Type of Report	MetOcean Report
Language	Estonian
Field Work Status	Field-based (O 2.17).
Main Results	The strongest bottom currents reached up to 0.35 m/s and coincided with stormy weather. Demersal anoxic conditions alternated with periods of higher oxygen, closely tied to salinity changes. Increased salinity was associated with oxygen depletion, indicating advection of saltier, low-oxygen water masses from the south. Oxygen levels improved in Oct-2021 due to vertical mixing driven by wind and cooling.

[12]

ADCP mõõtmised hoovuste profiilide ja põhjalähedase soolsuse ning hapniku sisalduse andmete kogumiseks parvlaev „Estonia“ vraki piirkonnas (detsember 2021 – märts 2022). Aruanne

Publisher	Tallinna Tehnikaülikool
Author(s)	Kikas et al.
Date	2022-5-20
Contracting Authority	OJK for the Preliminary Assessment.
Main Objective	To collect vertical current profiles and bottom-layer salinity, temperature, and oxygen data near the wreck of MV ESTONIA between Dec-2021 and Mar-2022 to support environmental modelling and historical comparison.
Type of Report	MetOcean Report
Language	Estonian
Field Work Status	Field-based (O 2.17).
Main Results	The strongest bottom currents reached up to 0.37 m/s. Demersal anoxic conditions prevailed to the middle of Feb-2022 when a high-oxygen concentration water mass entered the area. Oxygen levels decreased towards Mar-2022 due to wind-driven vertical mixing.

[40]

Seismo-acoustic survey of the MS Estonia shipwreck site with a boomer-type sound source transmitter

Publisher	Geological Survey of Estonia
Author(s)	Tuuling et al.
Date	2022-6-14
Contracting Authority	OJK for the Preliminary Assessment.
Main Objective	To investigate the geological structure beneath the wreck of MV ESTONIA using a boomer-type seismo-acoustic source, focusing on sediment layering and the depth to bedrock.
Type of Report	Survey Report
Language	English
Field Work Status	Field-based (O 2.15).
Main Results	Improved penetration was achieved into soft Quaternary sediments, though interpretation remained challenging due to noise and complex geological conditions. The wreck rested on a steeply sloped elevation of Precambrian crystalline basement, spanning both a flat basement crest and its steeper eastern slope. The Quaternary consisted mainly of late glacial and post-glacial clays, reaching occasionally over 15 m thickness.

[41]

Field Report - Photogrammetry Survey of the M/S ESTONIA

Publisher	Ocean Discovery AB
Author(s)	
Date	2022-7-25
Contracting Authority	SHK for the Preliminary Assessment.
Main Objective	To create a 3D model of the wreck and seabed to document new damage, aid future investigations, and inform the public.
Type of Report	Operations Report
Language	English
Field Work Status	Field-based (O 2.20).
Main Results	Over 45 000 high-resolution images were captured covering approx. 95 % of the wreck; new damage was observed; partial seabed coverage due to visibility limits.

[42]

Merevee hägususe mõõtmine. Lõpparuanne

Publisher	Tallinna Tehnikaülikool
Author(s)	Salm et al.
Date	2022-7-27
Contracting Authority	OJK for the Preliminary Assessment.
Main Objective	To monitor underwater turbidity and other seawater parameters in the vicinity of the wreck of MV ESTONIA between Apr-2022 and Jun-2022, in support of the laser surveys.
Type of Report	MetOcean Report
Language	Estonian.
Field Work Status	Field-based (O 2.18).
Main Results	A near-bottom turbid layer developed after late Apr-2022, driven by the intrusion of saltier, low-oxygen water masses. The highest turbidity values exceeded 4 NTU around 80 m depth. Stronger stratification increased turbidity near the bottom. These conditions would hinder optical investigations from spring to autumn.

[13]

Petrographic analysis of Sample ES1

Publisher	Stockholm University
Author(s)	Skelton
Date	2023-1-1
Contracting Authority	SHK for the Preliminary Assessment.
Main Objective	To perform a petrographic analysis of a rock sample, ES1, collected from the seabed at the MV ESTONIA wreck site to identify its mineral composition and geological classification.
Type of Report	Rock Analysis Report
Language	English
Field Work Status	Field-based (O 2.20).
Main Results	Sample ES1 was identified as gneiss, a high-grade metamorphic rock typical of Scandinavian bedrock. The analysis revealed interlocking crystals of quartz, feldspar, biotite, and garnet, and showed micro-textures like undulous extinction and grain boundary migration, indicative of deformation at elevated temperatures.

[43]

Bathymetry and sediment thickness at the MV Estonia shipwreck site	
Publisher	—
Author(s)	Jakobsson
Date	2023-1-24
Contracting Authority	SHK for the Preliminary Assessment.
Main Objective	To update the sediment thickness model and restore the seabed morphology to pre-impact conditions at the MV ESTONIA wreck site, providing input data for future numerical simulations of the ship's impact with the seabed.
Type of Report	Geophysical Interpretation Report
Language	English
Field Work Status	Field-based (O 2.20).
Main Results	The wreck rests on a ridge composed of exposed bedrock and soft sediments, with a reconstructed sediment thickness model showing thick post-glacial clay on the flanks and thinner sections midship. ROV inspections confirmed outcropping bedrock near hull damage. Bathymetry was digitally restored to simulate pre-impact conditions.

[15]

Uuringuakt nr 23U-AR0075. Metalliuuring	
Publisher	Eesti Kohtuekspertiisi Instituut
Author(s)	Toomet
Date	2023-8-10
Contracting Authority	OJK for the Preliminary Assessment.
Main Objective	To determine whether a metal fragment cut from the hull fracture of MV ESTONIA shows signs of contact or collision with a metallic object.
Type of Report	Forensic metallurgical inspection
Language	Estonian
Field Work Status	Desk-based (laboratory analysis of a recovered component).
Main Results	The metal fragment showed no mechanical signs of collision with another metal object. Surfaces were uniformly corroded, with no scratch or impact traces; possible minor contact marks were likely erased by corrosion.

[16]

Uuringuakt nr 23U-AL0002. Lõhkeaine uuring	
Publisher	Eesti Kohtuekspertiisi Instituut
Author(s)	Laanet
Date	2023-8-15
Contracting Authority	OJK
Main Objective	To determine whether explosive residues are present on a corroded metal fragment recovered from the MV ESTONIA wreck site.
Type of Report	Forensic explosive trace analysis
Language	Estonian
Field Work Status	Desk-based (laboratory analysis of a recovered component).
Main Results	No explosive residues were found on the examined surface of the metal fragment. Only one side of the object was tested, based on agreement with the investigation authority.

[44]

Numerical Assessment of Bottom Contact of MV ESTONIA	
Publisher	Tallinna Tehnikaülikool
Author(s)	Tabri et al.
Date	2023-9-20
Contracting Authority	OJK for the Preliminary Assessment.
Main Objective	To simulate and analyse the dynamic behaviour of the MV ESTONIA hull upon seabed impact, using numerical modelling to test different impact angles, velocities, and soil interactions.
Type of Report	Engineering simulation and impact modelling report. Summary published as [45].
Language	English
Field Work Status	Desk-based.
Main Results	Simulations showed that the hull could have sustained damage consistent with observed deformations under plausible impact angles and velocities. Damage patterns depended on sediment composition and internal structural modelling assumptions.

[17]

Uuringuakt nr 23U-PL0001. Lõhkeseadeldise ja plahvatuse uuring

Publisher	Eesti Kohtuekspertiisi Instituut
Author(s)	Juhe
Date	2023-10-13
Contracting Authority	OJK for the Preliminary Assessment.
Main Objective	To determine whether a hull fragment, the bow ramp, and associated video and photo materials show evidence of explosive impact.
Type of Report	Forensic explosion trace investigation
Language	Estonian
Field Work Status	Desk-based (laboratory analysis of a recovered component).
Main Results	No explosive effects were detected on the hull fragment, bow ramp, or submitted media. No traces indicative of a blast, explosive centre, or charge mass (TNT equivalent) could be confirmed.

[46]

Final Report MV ESTONIA High Resolution Seabed Imaging Survey. REACH-6629-SR-001. Revision 2

Publisher	Reach Subsea AS
Author(s)	TS
Date	2024-1-19
Contracting Authority	OJK for the Preliminary Assessment.
Main Objective	To conduct high-resolution seabed imaging at the MV ESTONIA wreck site to support debris mapping for trajectory reconstruction and to locate anchoring wires from the 1996 geotextile installation.
Type of Report	Survey Report
Language	English
Field Work Status	Field-based (O 2.22).
Main Results	A total of 296 seabed targets were identified, including known wreck debris and new objects potentially related to the sinking. Anchor wires from the 1996 geotextile installation were not detected.

[14]

2023/24-Estonia - Analysis of material deposited near a fracture on the MS Estonia shipwreck

Publisher	Stockholm University, Department of Geological Sciences
Author(s)	Dupraz et al.
Date	2024-3-24
Contracting Authority	SHK for the Preliminary Assessment.
Main Objective	To determine the component sources for 13 samples based on a detailed characterization of elemental and mineralogical content, particle morphology, and microbial community composition.
Type of Report	Chemical Analysis Report
Language	English
Field Work Status	Field-based (O 2.20).
Main Results	Samples from hull fractures, nearby sediment, and steel were examined using chemical, mineralogical, and microbiological techniques. The deposits were found to result from natural processes, including marine corrosion, sediment accumulation, and bio-fouling. All components could be traced to known sources: the steel hull, surrounding sediments, seawater, and colonizing microorganisms. Deposits were grouped based on dominant materials—ranging from pristine steel surfaces to corrosion-rich and sediment-laden layers. Corrosion products formed layered structures varying with oxygen exposure, often involving green rust and iron sulphides. Microbial activity, particularly related to sulphur cycling, played a key role in corrosion behaviour. Elevated trace elements originated primarily from the steel and paint pigments, influenced by corrosion and microbial processes.

[47]

PAR.2401.R.01.01. MV ESTONIA Wreck Site Bathymetric Comparison Seabed Changes from 1994–2024

Publisher	Paralos Geo OÜ
Author(s)	Rikson
Date	2024-7-30
Contracting Authority	OJK for the Preliminary Assessment.
Main Objective	To assess historical bathymetric changes at the wreck site of MV ESTONIA by georeferencing and reconstructing 1990s-era charts, comparing the reconstructed 1994–1996 bathymetry to present day models, and digitizing ancillary details to enhance understanding of the wreck's historical condition.
Type of Report	Desk Study
Language	English
Field Work Status	Desk-based (review of existing data).
Main Results	Reconstructed bathymetry is deeper than the previous reconstruction. The wreck seems to have moved between 1994 and 1996, and there are signs that some sediments slumps had already occurred prior to the installation of the pilot forced penetration string.

[48]

ROV Video Survey of the Selected Sonar Targets on the Sinking Track of MV Estonia. Factual Report. Revision 2

Publisher	Ohutusjuurdluse Keskus
Author(s)	Roosipuu and Rikson
Date	2024-10-1
Contracting Authority	Preliminary Assessment.
Main Objective	To conduct an ROV-based video survey to visually identify selected MAS targets detected along the presumed track of MV ESTONIA, and to verify whether the targets are related to the wreck.
Type of Report	Factual Report
Language	English
Field Work Status	Field-based (O 2.23).
Main Results	17 ROV dives were conducted along the presumed sinking track; objects included wood logs, boulders, parts of the ramp railing (one of which was recovered), and metallic debris. The survey contributed visual confirmations of several sonar targets including potentially ship-related debris.

[49]

MV Estonia: numerical assessment of the mid-ship damages with revised material properties, vessel position and orientation. Rev 1

Publisher	Tallinna Tehnikaülikool
Author(s)	Tabri and Heinvee
Date	2025-8-28
Contracting Authority	OJK for the Preliminary Assessment.
Main Objective	To update the 2023 modelling with new material properties and vessel position and orientation.
Type of Report	Engineering simulation and modelling report
Language	English
Field Work Status	Desk-based
Main Results	The simulation results consistently identified the mid-ship region as the location of maximum deformation, thereby confirming that the protruding bedrock ridge governed the structural interaction responsible for the observed damage mechanism.

[50]

Geological Units at the MV Estonia Wreck Site. Report. Revision 1

Publisher	Ohutusjuurdluse Keskus
Author(s)	Rikson
Date	2025-10-27
Contracting Authority	Preliminary Assessment.
Main Objective	To draft an overview of the geological background of the wreck site of MV ESTONIA, and to illustrate these layers using geophysical data.
Type of Report	Desk Study
Language	English
Field Work Status	Field-based (O 2.11, O 2.14, O 2.15, and O 2.20).
Main Results	Examples from all SBPs used at the wreck site were shown and compared. Data analysis confirmed the expected natural geological layers (muds and bedrock), although glacial till was difficult to identify. An anthropogenic unit, interpreted as sand deposited during the 1996 wreck covering operation, along with a possible sub-unit were detailed.

[51]

Bow Visor of MV Estonia. Report. Revision 2

Publisher	Ohutusjuurdluse Keskus
Author(s)	Rikson and Zachau
Date	2025-11-24
Contracting Authority	Preliminary Assessment.
Main Objective	To provide an overview of the known information relating to the visor of MV ESTONIA after its detachment.
Type of Report	Desk Study
Language	English
Field Work Status	Field-based (O 2.4, O 2.5, O 2.12, O 2.14, O 2.22, and O 2.23).
Main Results	Different coordinates for the visor's seabed location were evaluated and assessed. The distance between the visor and the wreck was re-computed. Examples of the visor's seabed imprint were given based on different datasets.

[52]

MV Estonia Wreck Site Environmental Data. Report. Revision 1	
Publisher	Ohutusjuurdluse Keskus
Author(s)	Rikson
Date	2025-12-3
Contracting Authority	Preliminary Assessment.
Main Objective	To provide an overview of the known environmental data from the wreck site of MV ESTONIA.
Type of Report	Desk Study
Language	English
Field Work Status	Field-based (O 2.7, O 2.14, O 2.17, O 2.18, and O 2.22).
Main Results	Comprehensive continuous data for various environmental properties was presented, comparing data from different field operations. A brief theoretical assessment of the wreck's future deterioration due to corrosion was made.

2.2.2 Bow Construction

Prior to the Preliminary Assessment

[53]

M/V ESTONIA Bow arrangement collapse – Sequence of events	
Publisher	MacGREGOR (SWE) AB
Author(s)	Carlsson
Date	2007-11-1
Contracting Authority	—
Main Objective	To outline the sequence of events leading to the bow arrangement collapse and to the vessel sinking.
Type of Report	Technical Report
Language	English
Field Work Status	Desk- and Laboratory-based
Main Results	Bow visor locking devices and hinges broke due to forces exerted from severe sea-loads. Visor detached from vessel prior to substantial vessel heel developing. During visor detachment, the bow ramp was struck and remained open inside of the visor for a period of time until the visor fell from the ship. When the visor detached completely the ramp fully opened and waves were free to enter the car deck through an unrestricted 5.5 m × 5.3 m clear opening. Existing construction drawings were re-drawn in CAD format, a 1:20 bow scale model and ramp steel model were made (both not preserved), and a video summary created.

[54]

Investigations for indications of deliberate blasting on the front bulkhead of the ro-ro ferry MV ESTONIA

Publisher	Engineering Failure Analysis
Author(s)	Klingbeil et al.
Date	2014-8-1
Contracting Authority	—
Main Objective	To analyse two palm-sized specimens recovered in 2000 by the divers from the front bulkhead of the wreck to determine whether there were any indications of deliberate blasting.
Type of Report	Published Article
Language	English
Field Work Status	Laboratory-based
Main Results	The comparative tests comprised mechanical tests, shot peening tests and blasting tests using different explosives. Testing demonstrated that blasting always formed twinned ferrite grains in the microstructure over the whole cross-section of each of the 8 mm thick comparative plates. Although one of the original test pieces of MV ESTONIA showed deformation twins, this was only confined up to 0.4 mm underneath the surfaces and not spread over the whole cross-section. Comparative shot peening tests produced the very same pattern of subsurface deformation twins. Therefore, the twins detected in the micro-section of the test pieces of the wreck of MV ESTONIA traced back to the shot peening process performed by the shipyard in 1979–1980 and not to a deliberate blast.

Preliminary Assessment

Visor 3D Laser Scanning

Publisher	—
Author(s)	Swe-teknik AB
Date	2021-09, 2022-02, and 2022-03
Contracting Authority	SHK for the Preliminary Assessment.
Main Objective	To create accurate digital model of the bow visor for further digital analysis.
Type of Report	Digital Data Delivery
Language	—
Field Work Status	Field-based.
Main Results	3D point cloud of the visor and separated parts, reverse engineered to CAD model.

Visor Weighing

Publisher	—
Author(s)	INOMEC AB and Tunga Lyft i Sverige AB
Date	2021-11, 2022-02, and 2022-03
Contracting Authority	SHK for the Preliminary Assessment.
Main Objective	To determine the actual weight of the visor for comparison with calculated weight.
Type of Report	Digital Data Delivery
Language	—
Field Work Status	Field-based.
Main Results	Visor weight without the port side hydraulic cylinder, both side lock lugs, and cut-off test specimens: 65.58 t. Hydraulic cylinder of MV MARE BALTICUM: 1.35 t. Loose parts: 1.10 t. Visor total weight without two side lock lugs (estimated 0.09 t together) that remained to the wreck: 68 t.

[55]

MS Estonia Bow Visor: Calculation of Weight and Volume. R667-01

Publisher	SALTECH Consultants AB
Author(s)	Zachrisson
Date	2021-12-15
Contracting Authority	SHK for the Preliminary Assessment.
Main Objective	To calculate the total weight and volume of the bow visor of MV ESTONIA to assess how well the visor could have floated.
Type of Report	Technical report
Language	English
Field Work Status	Desk-based (CAD analysis).
Main Results	The bow visor's weight with one hydraulic cylinder (estimated 0.5 t) was calculated at approx. 64.0 t. Based on the CoG of the visor and the volume of possible air pockets, it is not possible to dismiss that the visor could float under certain circumstances. It cannot be determined whether an air pocket would occur and it is not possible to say with accuracy for how long a time an air pocket would delay the sinking of the visor.

[56]

Metallurgical Investigation of a Plate from the Bow Visor from M/S Estonia	
Publisher	Norwegian University of Science and Technology
Author(s)	Westermann
Date	2022-6-29
Contracting Authority	*Not explicitly stated.*
Main Objective	To examine the metallurgical and structural characteristics of a plate removed from the bow visor to assess deformation, thermal exposure, and possible welding or failure mechanisms.
Type of Report	Technical metallurgical analysis
Language	English
Field Work Status	Desk-based (laboratory analysis of a recovered component).
Main Results	The plate was severely deformed and showed signs of localized heating above 1200 °C, melted intermetallic phases, and complex fracture features. Ridge formations and pores contained intermetallic inclusions. However, no conclusive signs of explosive force or deformation twins (Neumann bands) were detected.

[57]

Interpretation and Commenting on Metallurgical Report. TEK22-2154

Publisher	Element Materials Technology AB
Author(s)	Hjertsén
Date	2022-12-20
Contracting Authority	SHK for the Preliminary Assessment.
Main Objective	To interpret and clarify metallurgical findings in a prior report concerning a plate from the bow visor of MV ESTONIA, and to verify specific structural features through additional sample analysis.
Type of Report	Technical interpretation and metallographic validation report
Language	English
Field Work Status	Desk-based (laboratory analysis of a recovered sample).
Main Results	The samples showed no signs of high-temperature quenching; microstructures were consistent with multi-pass welds using covered electrodes. Poor weld quality and extensive heat-affected zones were confirmed. Findings supported previous interpretations without indicating explosive effects.

Ramp 3D Laser Scanning and Photogrammetry

Publisher	—
Author(s)	Vertz3D Studios OÜ
Date	2023-10
Contracting Authority	OJK for the Preliminary Assessment.
Main Objective	To create an accurate digital model of the bow ramp for further analysis.
Type of Report	Digital Data Delivery
Language	—
Field Work Status	Field-based.
Main Results	3D triangulated mesh of the ramp with photogrammetric texture.

Digital Twin of the Bow Construction

Publisher	—
Author(s)	MEC Insenerilahendused OÜ
Date	2023-11
Contracting Authority	OJK for the Preliminary Assessment.
Main Objective	To create an accurate digital model of the as-designed bow construction.
Type of Report	Digital Data Delivery
Language	—
Field Work Status	Field-based.
Main Results	3D solid and surface models of the bow construction.

[58]

Undersökning av bärgad bogramp, m/s Estonia

Publisher	Element Materials Technology AB
Author(s)	Hjertsén
Date	2024-1-10
Contracting Authority	SHK for the Preliminary Assessment.
Main Objective	To visually inspect the recovered bow ramp and assess whether its damage and separation are consistent with the documented sequence of failure described in the 2007 technical report on the bow arrangement collapse.
Type of Report	Technical inspection report
Language	Swedish
Field Work Status	Field-based (O 2.21).
Main Results	The observed damage on the bow ramp and railing matched the sequence described in the 2007 report. No evidence of cutting or thermal separation was found. Deformations and fractures were consistent with structural failure during the sinking, not with post-recovery intervention.

[59]

MV Estonia: numerical modelling of bow arrangement failure sequence. Rev 2

Publisher	Tallinna Tehnikaülikool
Author(s)	Tabri et al.
Date	2025-11-14
Contracting Authority	OJK for the Preliminary Assessment.
Main Objective	To analyse, model, and visualize the sequence of bow arrangement collapse and explain the mechanics of deformations not described before.
Type of Report	Engineering simulation and modelling report
Language	English
Field Work Status	Desk-based
Main Results	The hypothesis that wave loads in a realistic configuration alone could have initiated the collapse of the bow structure was reinforced. Deformations and their mechanism clearly indicate that the visor detached from the ship when it was in upright position and the ramp has been fully open. Using the numerical assessment, even the causes of the previously unexplained or discussed deformations can be explained by the natural collapse process. No contact with the external object is required to initiate the collapse process and there are no obvious signs of such contact. The visor locking system did not have any structural safety margin for the realistically expected wave conditions.

2.2.3 Flooding & Sinking

Prior to the Preliminary Assessment

[60]

Estonia. Sjunkförloppsstudie. Rapport förstudie. 15 bilagor	
Publisher	—
Author(s)	Rosenius and Sjöling
Date	2003-3-28
Contracting Authority	SPF
Main Objective	To include in SPF's database material that explains how MV ESTONIA may have flooded in the final stages of the accident and to create a basis for the further preparation of the Swedish government's assignment regarding this topic.
Type of Report	Technical Report of Pre-Study
Language	Swedish
Field Work Status	Desk-based
Main Results	In the presented examples, the sinking sequence of MV ESTONIA develops largely in the manner described in the JAIC Final Report. The crucial difference between the JAIC Final Report and this report lies in the fact that the working group has demonstrated a natural route for water to reach Decks 1 and 0 (the engine room area, etc.) through ventilation ducts located along the ship's sides when the list exceeds approx. 40°. This provides a reasonable explanation for how MV ESTONIA could have sunk as described in the accident report. Five recommendations were made for future studies.

[61]

Final Report - Research Study on the Sinking Sequence of MV Estonia. No 134, 2008

Publisher	SSPA Sweden AB
Author(s)	Källström et al.
Date	2008-5-5
Contracting Authority	Vinnova
Main Objective	To understand the sequence and explain the underlying causes of the loss of MV ESTONIA and to derive suitable recommendations on design and operation of passenger vessels in order to prevent such tragedy from happening again.
Type of Report	Final Report of the Research Study
Language	English
Field Work Status	Desk- and Laboratory-based
Main Results	In view of the conclusion on the most likely sinking sequence of MV ESTONIA, it can confidently be stated that the lack of compliance with minimum SOLAS requirements on forward collision bulkhead by MV ESTONIA on the night of 27–28 September 1994, was the main reason for unobstructed ingress of sea water into the car deck spaces and, therefore, that this was the main cause of the ship loss in the light of international maritime law. 17 sub-reports and video material were delivered.

[1]

Research Study on the Sinking Sequence and Evacuation of the MV Estonia - Final Report. No. 1663	
Publisher	Hamburgische Schiffbau-Versuchsanstalt GmbH
Author(s)	Valanto
Date	2008-5-5
Contracting Authority	Vinnova
Main Objective	To shed light on the sequence of the sinking of MV ESTONIA and to develop knowledge to improve maritime safety for ships in Swedish waters and internationally.
Type of Report	Final Report of the Research Study
Language	English
Field Work Status	Desk- and Laboratory-based
Main Results	Altogether the results of the analysis carried out show a similar sinking sequence to the one worked out already by the official investigation after the accident. Some more details could be added in, and explanations provided for, the most probable presently known course of events during the accident. Four sub-reports were compiled.

[62]

A Fast and Explicit Method for Simulating Flooding and Sinkage Scenarios of Ships

Publisher	—
Author(s)	Dankowski
Date	2013-3-13
Contracting Authority	—
Main Objective	To develop a fast, stable and reasonably accurate numerical simulation method to predict and revisit flooding scenarios in the time domain. A comparison with the results of a standard benchmark model test and a re-investigation of the accidents of MV EUROPEAN GATEWAY, SS HERAKLION, and MV ESTONIA were performed for validation.
Type of Report	Doctoral Thesis
Language	English
Field Work Status	Desk-based
Main Results	A new numerical flooding simulation method within the ship design system E4 was developed and successfully validated. For the case of MV ESTONIA accident, the general flooding sequence was well reproduced by the newly developed method, even though dynamic motions of the flood water and the vessel were neglected. A sensitivity analysis was performed with regard to the increased breaking load of windows, increased discharge coefficient for the bow door opening, the complete closure of all watertight doors and the closure of the bow ramp beyond 90° heel.

Preliminary Assessment

[63]

Numerical and experimental assessment of the collapse loads of the windows of MS Estonia. C2422.100.1, Rev 1	
Publisher	MEC Insenerilahendused OÜ
Author(s)	Heinvee and Mäesalu
Date	2024-10-16
Contracting Authority	OJK for the Preliminary Assessment.
Main Objective	To determine collapse loads of the windows located on the passenger decks of MV ESTONIA, using series of numerical calculations and full scale experiments.
Type of Report	Technical Report
Language	English
Field Work Status	Desk- and Laboratory-based
Main Results	The collapse loads of small windows obtained from numerical simulations and full-scale experiments are several times larger than the largest collapse load given in previous reports. Corresponding collapse loads of large windows match the highest predictions given in previous reports.

[2]

Numerical Simulation and Analysis of the Sinking Scenarios of MV Estonia. HSVA-2025-004, RevA	
Publisher	Hamburgische Schiffbau-Versuchsanstalt GmbH
Author(s)	Kim et al.
Date	2025-7-28
Contracting Authority	OJK for the Preliminary Assessment.
Main Objective	To assess the possibility of various hypothetical sinking scenarios of MV ESTONIA and, if possible, to exclude scenarios that do not correspond to existing evidence.
Type of Report	Research Study Report
Language	English
Field Work Status	Desk-based
Main Results	It seems reasonable to assume that the new side damage was not present during the ship's heeling and capsize process on the reconstructed track, based on seabed debris and other known facts on the sinking. New side damage only without the bow damage is altogether an extremely unlikely damage case.

2.2.4 Other

Prior to the Preliminary Assessment

[4]

Part report, covering technical issues on the capsizing on 28 September, 1994 in the Baltic Sea of the ro-ro passenger vessel MV ESTONIA	
Publisher	The Joint Accident Investigation Commission of Estonia, Finland, and Sweden
Author(s)	The Joint Accident Investigation Commission of Estonia, Finland, and Sweden
Date	1995-4-7
Contracting Authority	—
Main Objective	To cover the main interim technical findings and conclusions from the accident investigation.
Type of Report	Interim Accident Investigation Report
Language	English
Field Work Status	Desk-based.
Main Results	The accident was initiated "by the locking devices for the bow visor being unable to withstand the loads imposed during the prevailing speed, heading and sea conditions".[4, p. 5]

[3]

Final report on the capsizing on 28 September 1994 in the Baltic Sea of the ro-ro passenger vessel MV ESTONIA

Publisher	The Joint Accident Investigation Commission of Estonia, Finland, and Sweden and Edita Ltd
Author(s)	The Joint Accident Investigation Commission of Estonia, Finland, and Sweden
Date	1997-12-3
Contracting Authority	—
Main Objective	To determine the circumstances and causes of the accident, with the aim of improving the safety of life at sea and avoiding further accidents.
Type of Report	Accident Investigation Report
Language	English
Field Work Status	Desk-based.
Main Results	Summary of results, including results from numerical assessments, physical experiments, and some field operations with two supplements ([19], [64]). MV ESTONIA's bow visor locking devices failed due to wave-induced impact loads creating opening moments about the deck hinges. MV ESTONIA capsized due to large amounts of water entering the car deck, loss of stability, and subsequent flooding of the accommodation decks.

[65]

Negotiated risks: the Estonia accident and the stream of bow visor failures in the Baltic ferry traffic	
Publisher	—
Author(s)	Hänninen
Date	2007-5-16
Contracting Authority	—
Main Objective	To explore the social and systemic processes that led to the capsizing of MV ESTONIA.
Type of Report	Doctoral Thesis
Language	English
Field Work Status	Desk-based
Main Results	The accident of MV ESTONIA was found to be a systemic failure. It was explained how the established roles of the shipowners, the shipbuilders, the mariners, and the regulatory agencies promoted the free flow of traffic, affected the perception and handling of the bow visor risk, and prevented a wider negotiation of this risk within the shipping industry. More, it is explained how the customs of shipbuilding, the general tolerance for failure, and the customs of the vessel trade promoted local negotiation of the visor risk, thus preventing learning and regulatory development at the industry level. The new interpretation of the tragedy of MV ESTONIA and its background broadens the current understanding of the development of organizational and technological failures.

Preliminary Assessment

[66]

The Swedish Armed Forces' response to the Swedish Accident Investigation Authority	
Publisher	Swedish Armed Forces
Author(s)	Stach
Date	2022-12-30
Contracting Authority	SHK for the Preliminary Assessment.
Main Objective	To reply to an inquiry about vessels, including Swedish submarines, near the accident site and the transport of military materiel on-board MV ESTONIA.
Type of Report	Response to inquiry
Language	English
Field Work Status	Desk-based
Main Results	The FM did not have any sensors that could have registered when MV ESTONIA hit the seabed. The FM do not have any knowledge of other vessels' movements in the area of the sinking. No Swedish submarine was in the area when the accident occurred. Electronic equipment, unconnected to weapons, had been shipped on MV ESTONIA using civilian vehicles, but no such shipment was made on the night of the accident.

[67]

Intermediate Report of the Preliminary Assessment of MV ESTONIA

Publisher	Ohutusjuurdluse Keskus, Statens haverikommission and Onnettomuustutkintakeskus
Author(s)	—
Date	2023-1-23
Contracting Authority	Preliminary Assessment.
Main Objective	To summarize the main findings from all surveys completed in 2021 and 2022 during the Preliminary Assessment.
Type of Report	Interim Report by the Preliminary Assessment
Language	English
Field Work Status	Desk-based
Main Results	The wreck of MV ESTONIA is in a poor condition with severe structural damage. The location of the outcropping bedrock under the hull matches the location of the deformation on the hull. Based on the evidence gathered so far, there is no indication of a collision with a vessel or a floating object nor indication of an explosion in the bow area.

[68]

Official note regarding 'unknown vessels' in an illustration in the report into the loss of ESTONIA

Publisher	Statens haverikommission
Author(s)	Zachau
Date	2024-9-23
Contracting Authority	Preliminary Assessment.
Main Objective	To investigate whether it is possible to identify two vessels labelled 'unknown vessel' in Figure 17.1 of the JAIC Final Report.
Type of Report	Memo
Language	English
Field Work Status	Desk-based
Main Results	The investigation has shown that these unidentified ships were most likely GTS FINNJET and MV FINNMERCHANT, which the JAIC Final Report also lists as amongst the first six vessels to arrive to assist in rescue operations.

[69]

Port State Control Training on MV ESTONIA	
Publisher	Statens haverikommission
Author(s)	Zachau
Date	2025-8-20
Contracting Authority	Preliminary Assessment.
Main Objective	To disclose known facts about the PSC training, the result of on-hand examination of all available copies of the report form, and provide an analysis and conclusions based on these facts.
Type of Report	Memo
Language	English
Field Work Status	Desk-based
Main Results	The reason for the inspectors to be onboard MV ESTONIA was only training. No deficiency gave cause for a detention or to stop the vessel from departing. There was no attempt to detain the vessel or stop her from sailing. The dissimilarities in the copies of the PSC protocol can all be explained naturally. It is considered incongruous for the inspectors to have found any deficiency that caused the accident during the PSC training, and it not reasonable to expect that any PSC could have prevented the accident.

[70]

Notes, observations and findings regarding ro-ro passenger vessel MV ESTONIA

Publisher	Statens haverikommission
Author(s)	Zachau
Date	2025-12-9
Contracting Authority	Preliminary Assessment.
Main Objective	To reduce the uncertainty in connection to the accident by explaining different aspects.
Type of Report	Memo
Language	English
Field Work Status	Desk-based
Main Results	MV ESTONIA never had a fully weathertight front bulkhead with ability to resist water ingress. This obviously does not correspond to drawings or legislative requirements at the time she was built. Nothing indicates or suggests that any extra-ordinary activity to prevent damage or accidents due to the coming weather situation was made on MV ESTONIA on her last journey, except for the speed reduction. Several conclusions about other observations are made.

3 Post-Foundering Analysis & Results

Results from 2021–2023 surveys have shown that the seabed and the condition of the wreck have changed in the period from the sinking to the present day. To better understand these changes, the datasets highlighted in Section 2.1 are analysed below.

The data collected after the sinking of MV ESTONIA have not maintained uniform coverage across the wreck site. This is because the field operations were generally not related to understanding the sequence of the accident (the surveys were mostly not organized by JAIC), but instead were focussed on figuring out what to do with the wreck and how to do it. Because of this, each survey focussed on a slightly different area around the wreck and used different equipment.

Therefore, the information presented below does not describe all data acquired as part of the surveys related to the catastrophe of MV ESTONIA, but a (relatively) consistent subset of these. This means that the below analysis focusses on a relatively small area that is immediately important in understanding the conditions that affected the course of the accident and the subsequent fate of the ship.

3.1 Environmental Conditions

The environmental data (SVP and CTD casts, etc.) acquired during the surveys does not provide ancillary information about the possible course of the accident. However, environmental data can be used to understand how the wreck has been affected since its sinking. Alongside the structural damage incurred on MV ESTONIA during the initial sinking and the wreck's movement and deformation on the seabed, stress factors relating to changing environmental conditions have been the primary contributor that has exacerbated structural damage.

Measured environmental conditions were assessed separately after each survey.[11], [12], [23], [39], [42], [46] In addition, a summary report of the extant data was compiled for the Preliminary Assessment.[52]

For reference, the wreck lies approx. 58 m to 87 m below sea level.

Annual averages of selected properties of the seawater in the depth range of the wreck are shown as Table 3.1. The same properties are also quantified with their minimum, maximum, and average in Section 3.1.2, Section 3.1.3, and Section 3.1.4.

3.1.1 Sub-Conclusions

The following subsidiary conclusions are made on the environmental conditions of the wreck site:

- The condition of the wreck is affected by changes in temperature, conductivity, oxygen content, and salinity.
- Hypoxic and anoxic conditions occur variably in the depth range of 50 m to 90 m.
- The rate at which marine-grade steels fatigue is affected by various environmental factors.
- The measured current velocities suggest that seabed erosion is likely to be minimal.
- The measured current velocities do not support a movement of the wreck due to currents.

3.1.2 Physical Properties

Seawater, at the wreck site, has the following general physical properties:

- Its temperature range (Figure 3.1) was 2.3 °C to 23.8 °C, with an average of 4.6 °C.[52]
- Its conductivity range was 0.71 S/m to 1.19 S/m, with an average of 0.94 S/m.[52]
- Its density range was 998.7 kg/m^3 to 1014.1 kg/m^3, with an average of 1008.2 kg/m^3.[52]
- Its specific conductance range was 1.02 S/m to 2.07 S/m, with an average of 1.65 S/m.[52]

The rate of steel corrosion in seawater depends on temperature and the water's chemical properties.

3.1.3 Chemical Properties

Seawater, at the wreck site, has the following general chemical properties:

- Its dissolved oxygen range (Figure 3.2) was 0.01 mL/L to 10.32 mL/L, with an average of 6.92 mL/L.[52]
- Its salinity range was 0.02 to 15.26, with an average of 8.89.[52]

The rate of corrosion in seawater depends on oxygen concentration, pH, and salinity as well as the physical properties of the water. Further, corrosion, as well

TABLE 3.1: Annual averages for selected physical, chemical, and optical properties in the depth range of the wreck of MV ESTONIA.[52] "TEMP.": temperature; "COND.": conductivity; "SPEC. COND.": specific conductance.

DEPTH RANGE	PHYSICAL PROPERTIES				CHEMICAL PROPERTIES		OPTICAL PROPERTIES
	TEMP.	COND.	DENSITY	SPEC. COND.	DISSOLVED OXYGEN	SALINITY	TURBIDITY
m	°C	S/m	kg/m^3	S/m	mL/L		NTU
55 to 60	3.41	0.82	1009.0	1.57	7.56	7.73	0.07
60 to 65	3.78	0.88	1009.4	1.65	6.85	8.02	0.08
65 to 70	4.37	0.99	1010.1	1.80	5.20	8.57	0.09
70 to 75	4.99	1.07	1010.8	1.90	3.12	9.23	0.20
75 to 80	5.57	1.13	1011.5	1.99	1.39	9.87	0.69
80 to 85	5.94	0.98	1011.9	1.78	0.71	10.46	1.28
85 to 90	6.01	1.02	1011.8	1.84	0.64	10.36	1.47

as other physical stresses, can have different effects in oxic conditions compared to in hypoxic and anoxic conditions.[1]

3.1.4 Optical Properties

Seawater, at the wreck site, has the following general optical properties:

- Its turbidity range was 0.03 NTU to 8.49 NTU, with an average of 0.23 NTU.[52]

3.1.5 Currents

Current velocities were measured at the wreck site in 2021 and 2022 (O 2.14 and O 2.17). Recorded basal water layer velocities were less than 0.10 m/s in the 50 m to 60 m depth range with measured maxima approx. 0.08 m/s and the mean velocity approx. 0.02 m/s.[39] In water depths deeper than 60 m, measured median velocities were 0.04 m/s to 0.07 m/s while velocity maxima were 0.31 m/s to 0.37 m/s.[11], [12]

The strength of the current, i.e., its velocity, determines which particles are suspended (carried) with the flow and which sediments settle. The median velocities measured at the wreck site were too slow to transport sands, though smaller grains (clays and silts) would have remained suspended. However, sand would have mostly settled even at the measured velocity maxima.

The measured velocities are not capable of moving the wreck.

[1] In an oceanographic context, hypoxic conditions are defined as oxygen levels below 2.0 mg/L (≊1.40 mL/L) and anoxic conditions as oxygen levels below 0.5 mg/L (≊0.35 mL/L).[71]

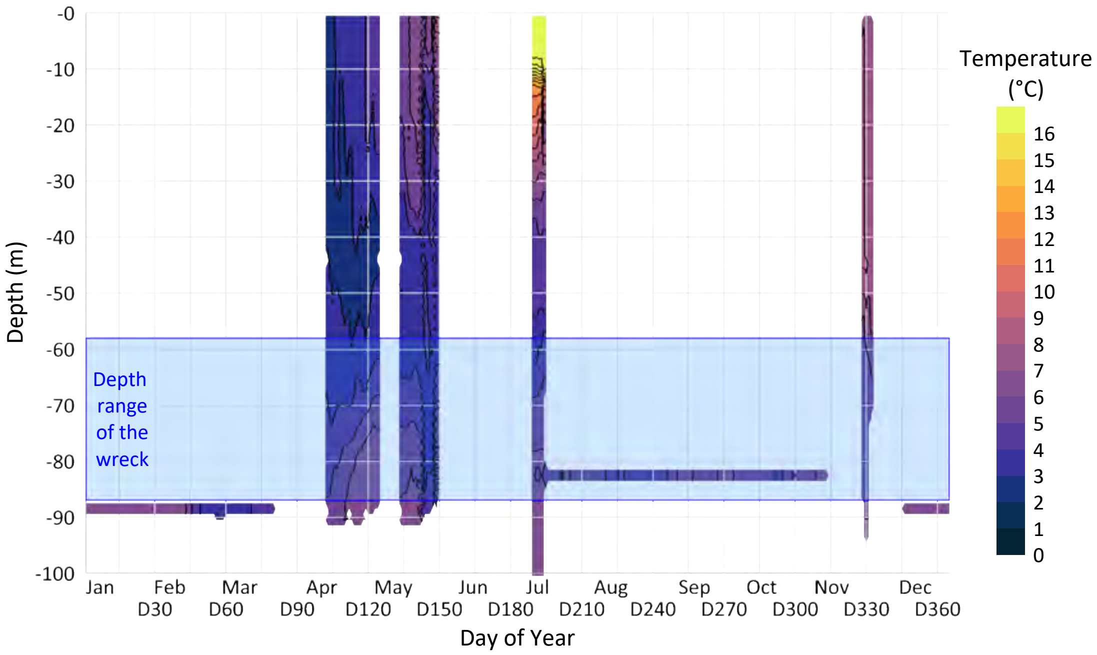

FIG. 3.1: Intra-annual daily temperature at the wreck site of MV ESTONIA based on all known and extant measurements.[52]

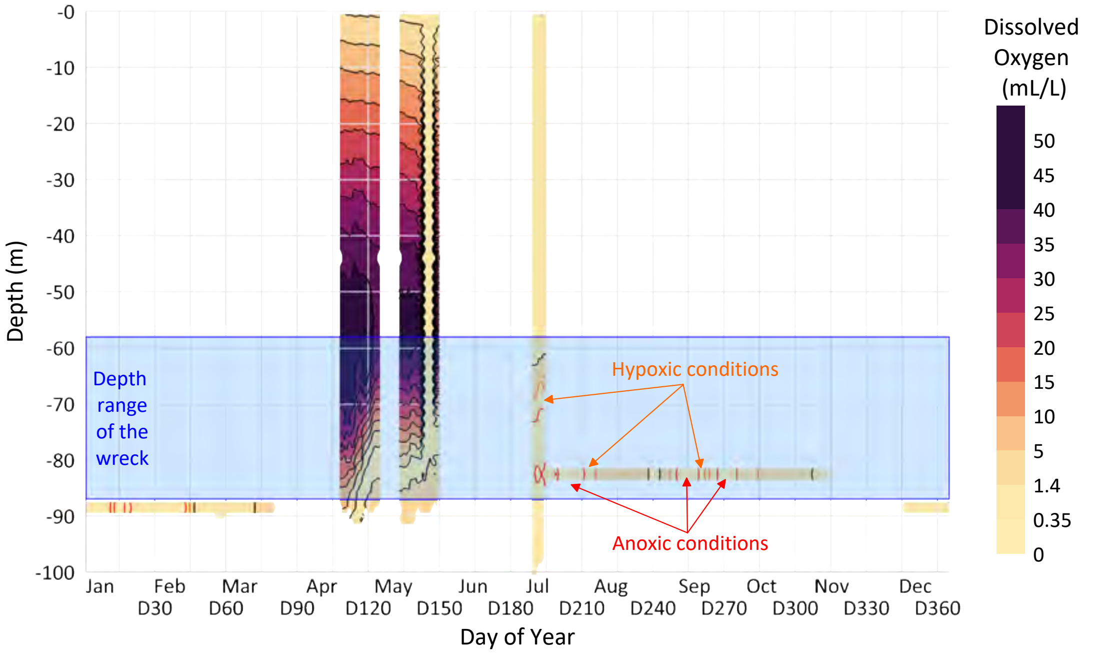

FIG. 3.2: Intra-annual daily oxygen content at the wreck site of MV ESTONIA based on all known and extant measurements.[52]

3.2 Geological Conditions

The ambient conditions on the site and their interaction with MV ESTONIA can be described in three main phases.

1. Prior to the accident, site conditions were natural.
2. From the moment the stern of MV ESTONIA physically crashed into the seabed, the ship began to affect the accident location just as this location affected the manner in which the ship sank, the damage she suffered during the sinking, and how the vessel settled on the seabed. These effects, though arbitrary, cannot be wholly discounted because had the ship sunk in a different location, the course of the accident from the moment she touched the seabed would have been different. Extant survey data from 1994–1995 allows insights into this period which are further described below.
3. Lastly, various engineering operations were carried out around the wreck, including the installation of equipment on the seabed and the pumping of sand around the wreck. These operations inadvertently caused the wreck site to change in ways that its original reconstruction is not possible with perfect accuracy.

Where it is possible to reconstruct or recognize effects on the seabed and on the wreck from specific operations, this has been done to present a comprehensive sequence of events.

3.2.1 Sub-Conclusions

The following subsidiary conclusions are made on the geological conditions of the wreck site:

- Bedrock outcrops are generally frequent in this area.
- The bedrock is currently outcropping on the northern side of the wreck, near the documented damage on the hull. The outcropping bedrock near the hull is a wholly natural formation.
- The midships of the wreck of MV ESTONIA currently rests on a bedrock ridge.
- The area in the vicinity of the wreck has been considerably deformed by operations undertaken in 1996.

3.2.2 Geological Overview

The accident site is located in the Central Baltic Sea. In general, the natural geological sequence in this area can be divided into four main units: Proterozoic Rocks

(Unit 1), Glacial Till (Unit 2), Glacial Clays (Unit 3), and Marine Clays (Unit 4). In addition to the naturally occurring units, an anthropogenic layer, i.e., a layer which originates in human activity, is also present in the vicinity of the wreck (Unit 5).[50]

Unit 1: Proterozoic Rocks

Background literature describes the bedrock in the vicinity of the survey area as comprised of Proterozoic (2500 Ma to 538.8 Ma) igneous rocks: granodiorite and basalt (Paleoproterozoic, 2500 Ma to 1600 Ma) and granite (Paleoproterozoic to Mesoproterozoic, 2500 Ma to 1000 Ma).[72] Generally, the top of this rock surface is highly rugged with numerous incision features.

No geotechnical boreholes have been drilled within 50 km of the accident site. However, a small sample of rock was cut in 2023 at the wreck site (O 2.21). Laboratory testing determined that the extracted rock is gneiss, a metamorphic rock.

The bedrock was filmed in 2021 (O 2.13), 2022 (O 2.20), and 2023 (O 2.21). The footage helps define the character of the bedrock around the wreck. As the bedrock is visible in the photogrammetric model, depths to the bedrock could also be measured in that dataset.

A model of the bedrock elevation and depth below seabed (BSB) with respect to the time of the accident were created. These are illustrated as Figures 3.3 and 3.5.

Unit 2: Glacial Till

The first sedimentary layer dates to the Pleistocene and relates to the deposition of glacial till during the Last Glacial Maximum, i.e., the Late Weichselian Glaciation, known in Estonia as the Võrtsjärve Glaciation[2]. The till was deposited by the ice sheet when it flowed over the bedrock. The retreat of the ice sheet caused (partial) erosion of the till layers with a counter-intuitive result—quite often the remaining till is thicker on top of the topographic highs of the underlying bedrock. Till is unsorted and comprised of an even mixture of clay, sand, gravel, and boulders.

In literature, the thickness of the till in this area is quoted as anything from a couple of meters to tens of meters, i.e., it should be considered highly locally variable.[39], [40], [50] Till can be difficult to penetrate with SBPs or geotechnical sampling equipment, but localized sampling can sometimes have high rates of recovery.

Sand, gravel, or both were observed at the bases of samples from boreholes B21, B23, B34, and B36.[23] Interpreted till was encountered at the following depth intervals: in B21, from 8.3 m BSB to 9.5 m BSB as very dense sand with

[2]The Late Weichselian Glaciation is commonly dated in Estonia to have occurred from 22 ka to 12.7 ka.[73] Glacial advance would have occurred somewhat earlier in the more northerly Central Baltic Sea while its retreat would have taken place later.

gravel; in B23, from 18.0 m BSB to 18.2 m BSB as gravel; in B34, from 9.0 m BSB to 10.4 m BSB as gravel; and in B36, as gravel from 2.7 m BSB to 3.1 m BSB.[23]

Geophysical data from the wreck site does not allow confirming definitively that these samples represent a till layer extant across the entire site.[50] Partially, this could be due to the resolution of the acquired data; additionally, this can be explained if the acoustic character of the till at the wreck site is void, i.e., if there are almost no internal echoes in the data, and the only easily differentiable surface is the top of the underlying rock.[50]

Unit 3: Glacial Clays

The second sedimentary layer in this area comprises glacial clays, deposited in a glaciolacustrine environment, i.e., in an early developmental stage of the Baltic Sea, known as the Baltic Ice Lake (lasted up to 11 700 cal y BP). These clays are varved, with finer grains deposited in the winter and coarser in the summer.

Unit 4: Marine Clays

The most recent sedimentary layer to occur in the survey area comprises Holocene clays that have been deposited during the development of the Baltic Sea, from approx. 11 700 cal y BP to the present. These clays occasionally have high biological components which may result in acoustic blanking due to gas charged intervals.

The reconstructed depth BSB to bedrock (Unit 1) indicates that there was a thin layer of sediment overlying the rock ridge. As rock is currently exposed in this area, it indicates that the overlying veneer was removed during the sinking and wreck settlement.

Unit 5: Anthropogenically Affected Sediments

After the accident, a decision was made by the Swedish Government on 15 December 1994 to cover the wreck.[74] The wreck covering operations began in 1996 (O 2.10). On 19 June 1996, the works were ordered to be halted once pressure embankments and necessary reinforcements were finished.[75] The engineering works that were carried out included the installation of forced penetration strings and geotextiles and the placement of sand (Figure 3.6):

- The forced penetration strings[3] were planned to reinforce the seabed to support the placement of sand and the filling to cover the bow and stern of MV ESTONIA (the latter were never installed). Altogether, eight (one trial and seven

[3] A forced penetration string is a long, rigid element driven into the seabed. Rocks, with an average grain size of 5 cm to 20 cm, were used as the rigid element in the case of MV ESTONIA.

design or planned) forced penetration strings were installed. Generally, the achieved penetration was greater than anticipated and soil heaps developed either side of strings where underlying sediment was pushed out.

- The geotextiles were also planned to reinforce the seabed and assist in the transfer of loads to maintain stability. The geotextiles were ballasted by a thin layer of gravel. Altogether, 26 geotextiles of 250 m length were installed. One geotextile slipped during installation, so its final location was not its design location. Post-installation evaluation of the other geotextiles found that seven of them were partially folded (deployed in shorter length than planned).
- The sand was planned to stabilize the wreck, to support geotextiles for load transfer, and to assist covering the wreck under concrete (act as counter-filling). The sand was taken from a pit near Helsinki, Finland. A total quantity of approx. 380 000 m^3 was sprayed. 14 samples of the sand were taken prior to its deposition with 1 sample comprising slightly gravelly sand [(g)S], 7 gravelly sand [gS], and 6 sandy gravel [sG].

However, the added weight of the sand contributed to landslides which reworked surficial sediment layers around the wreck and principally to the south of the wreck. The slump features comprise a mixture of deposited sand, occasional gravel, and clays. Additionally, the deposited sand also occurs in small patches on the wreck itself. A model of the depth BSB (i.e., thickness) of these sediments is illustrated as Figures 3.7 and 3.8.

This unit's volume (excluding the sub-unit mentioned below) was calculated during the Preliminary Assessment by computing the volume enclosed between its contours. The calculated volume is approx. 376 000 m^3, indicating good correlation with the operational background information.

A basal sub-unit of this layer is recognisable in the immediate vicinity of the wreck. The thickness of this sub-unit is illustrated as Figure 3.9. This sub-unit is interpreted to reflect a remnant of the original sediment movement caused by the accident when the ship sunk into the seabed. Other traces of this original sediment displacement were likely carried away with the sediment slumps that were caused by sand deposition in 1996.

3.2.3 Seabed Sediments

Seabed sediments are generally related to the underlying geological units. The "Folk 5" classification system, used widely in European seabed sediment classifications, was used to describe seabed sediments.[76] Altogether, five different sediment classes were interpreted alongside the area that the wreck covers up on the seabed:

- **Rock**: Surficial expression of Unit 1, occurring at seabed where the bedrock outcrops.
- **Coarse sediment**: Surficial expression of Unit 2, comprising sands and clays at seabed with interspersed gravel and boulders.
- **Mixed sediment**: Mixed sands and clays which occur on the lower slopes of the topographic highs of the bathymetry. In contrast to the coarse sediment, there is almost no gravel or boulders within these areas. These areas stand out particularly well on the high resolution seabed imaging sonar data.
- **Mud**: Surficial expression of Unit 4, occurring principally in the topographic lows of the bathymetry where recent sedimentation has been thickest.
- **Sand**: Surficial expression of Unit 5, representing predominantly anthropogenic sand which was deposited on and around the wreck as well as the slumped mixed sediments which occur principally to the south of the wreck.

Seabed sediments around the wreck are illustrated as Figure 3.10.

3.2.4 Bathymetry

The bathymetry at the wreck site undulates with numerous topographic lows and highs. The topographic variation of the bathymetry is directly related to the underlying sediments, with outcrops of bedrock (Unit 1) forming the most significant protrusions compared to the surrounding seabed.

The bathymetry of the site has been reconstructed based on surveys carried out in 1995 (O 2.8) and 1996 (O 2.10) which pre-date the significant sediment slides to the south of the wreck.[47] These reconstructions show that the wreck lay on a bedrock-supported slope with a veneer of seabed sediments. An alternative reconstruction was also created, but is not shown herein.[43]

Bathymetry is illustrated below for 1994 (Figure 3.11), 1996 (Figure 3.12), and the present (Figure 3.13).

Figures showing the 1994 bathymetry and total depth of the bedrock are shown as Figures 3.14 and 3.15. The corresponding depth BSB of the bedrock is shown as Figure 3.16. The interpreted depth BSB of the bedrock at the wreck site prior to the accident was <1 m to 25 m BSB.

Figures showing the change in the bathymetry which resulted from the sediment deposition of 1996 are shown as Figures 3.17 and 3.18.

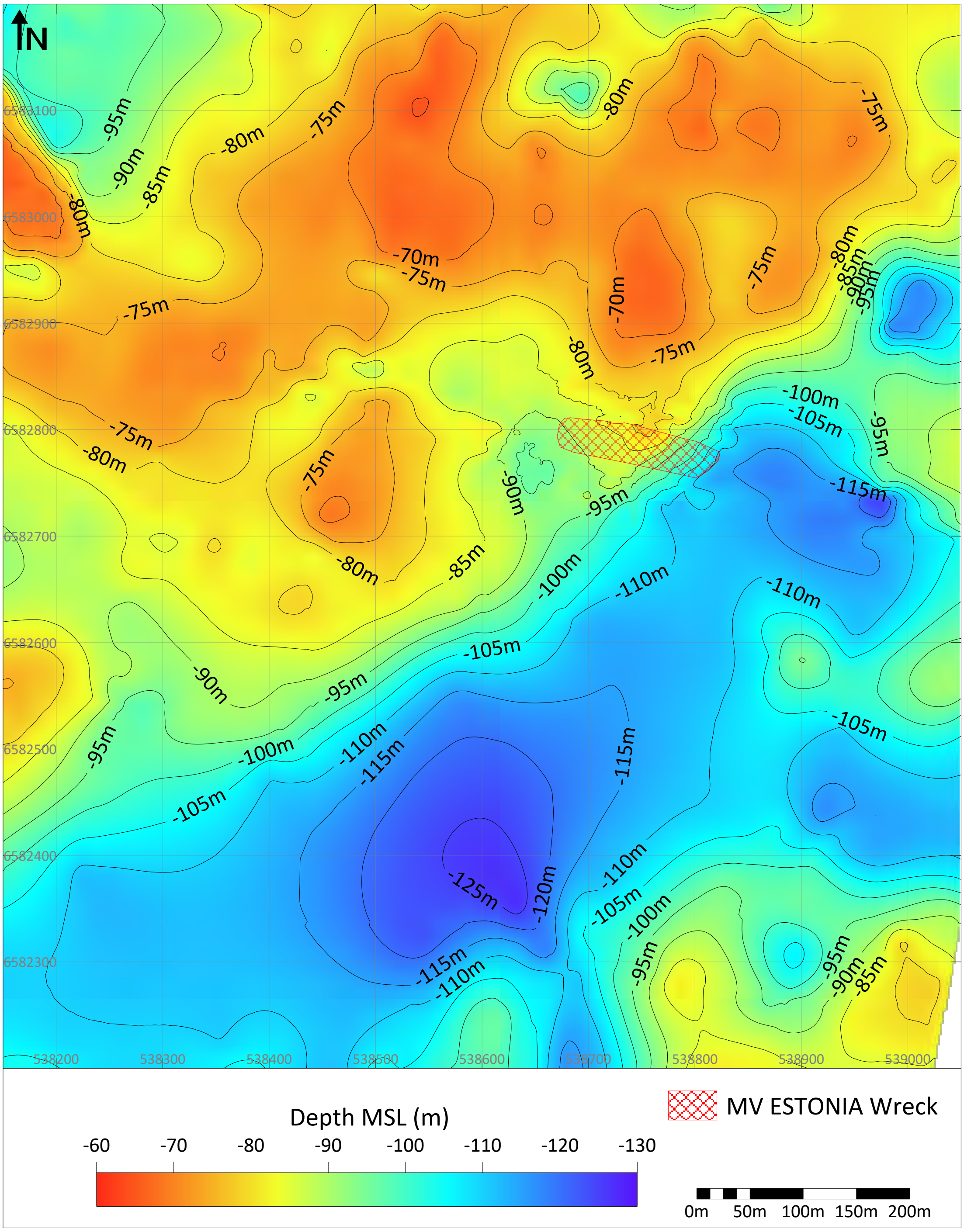

FIG. 3.3: Total Depth from Sea Level to Bedrock in 1994

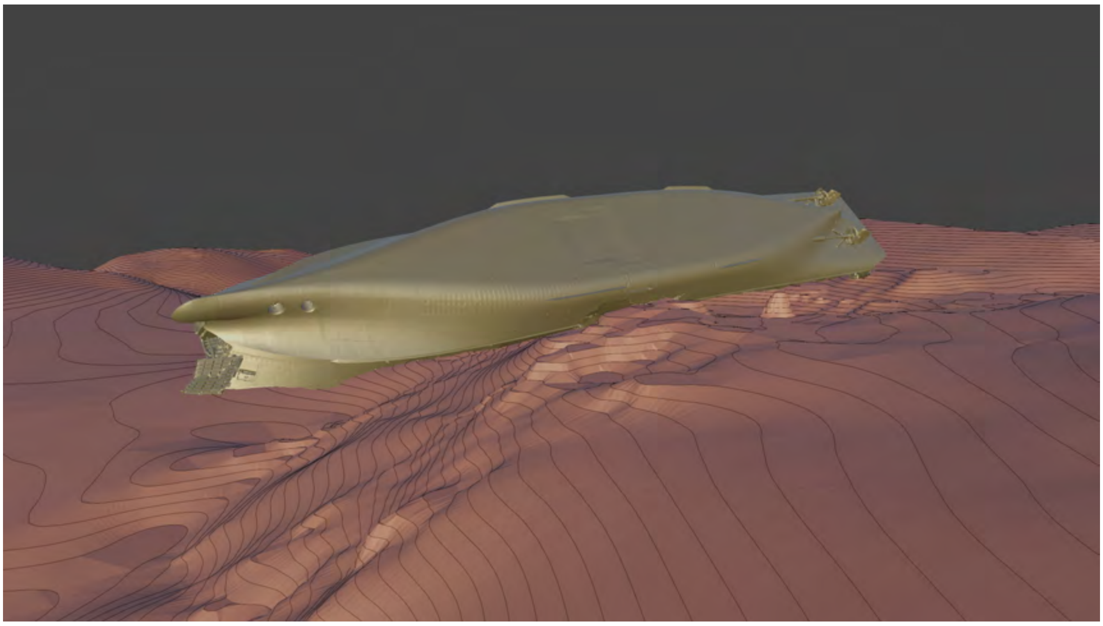

FIG. 3.4: Reconstructed top bedrock surface with a partial model of the wreck. The bedrock surface is based on the 2024 reconstruction.[47] The layers between the seabed and the bedrock are not shown. The wreck is shown primarily as measured during the photogrammetry survey (O 2.20); as the photogrammetry did not image below the seabed layer (not shown here), the parts of the wreck currently extending below the seabed are not shown.

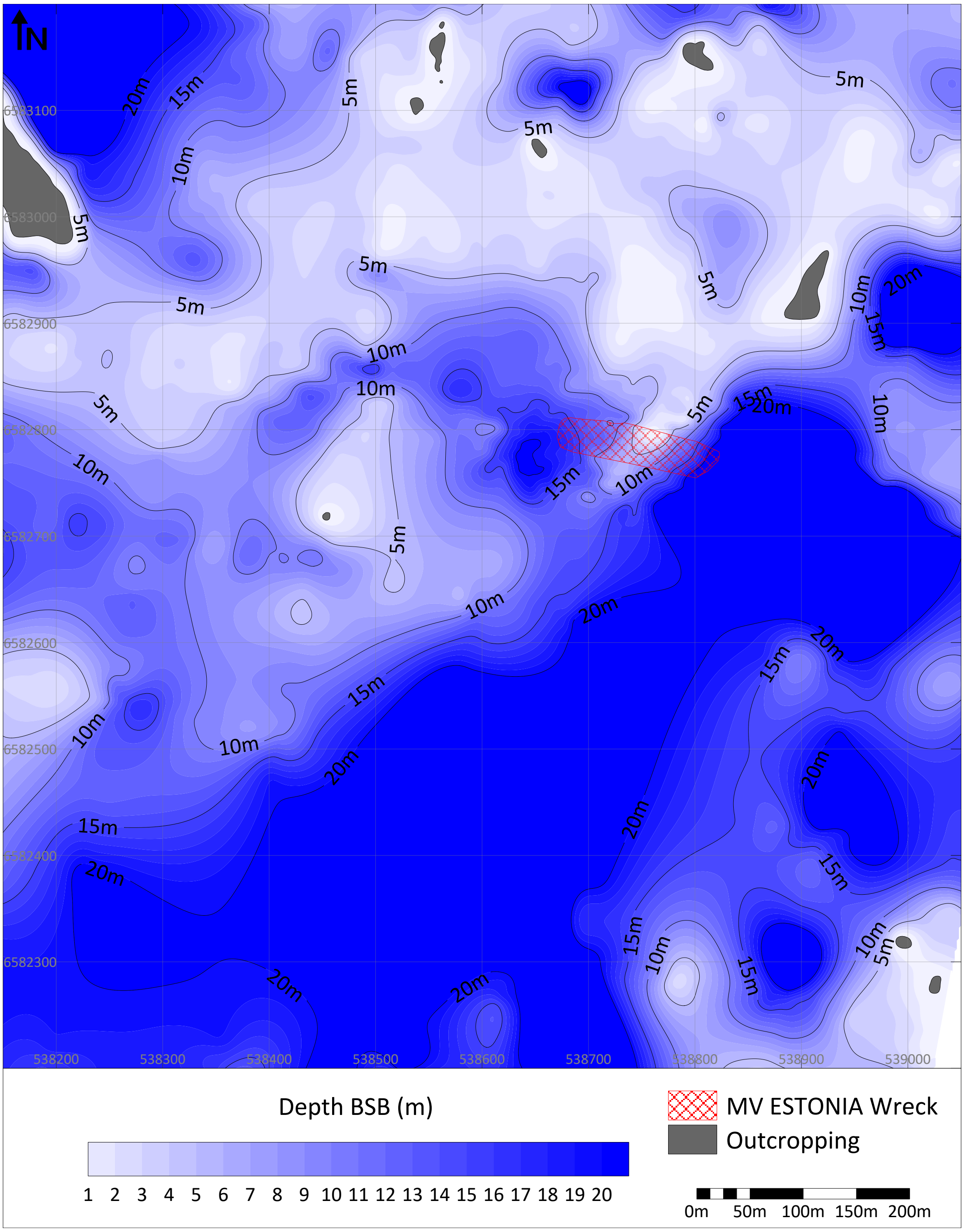

FIG. 3.5: Depth Below Seabed to Bedrock in 1994. The reconstruction results in a probable veneer of sediments overlying the bedrock, based on the difference between the current measured, known, and interpreted bedrock positions with respect to the reconstructed seabed of Sep-1994.

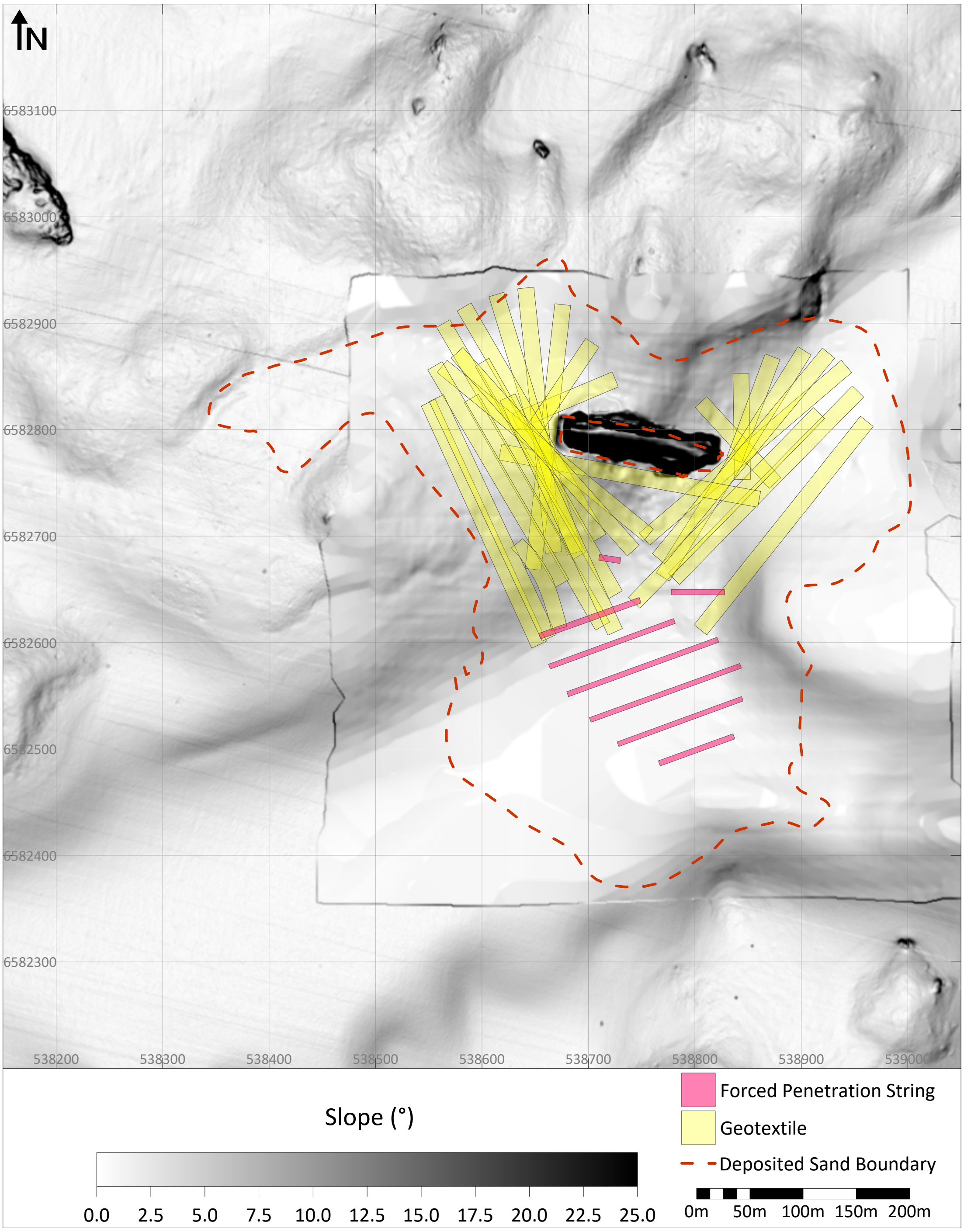

FIG. 3.6: Installed Forced Penetration Strings and Geotextiles

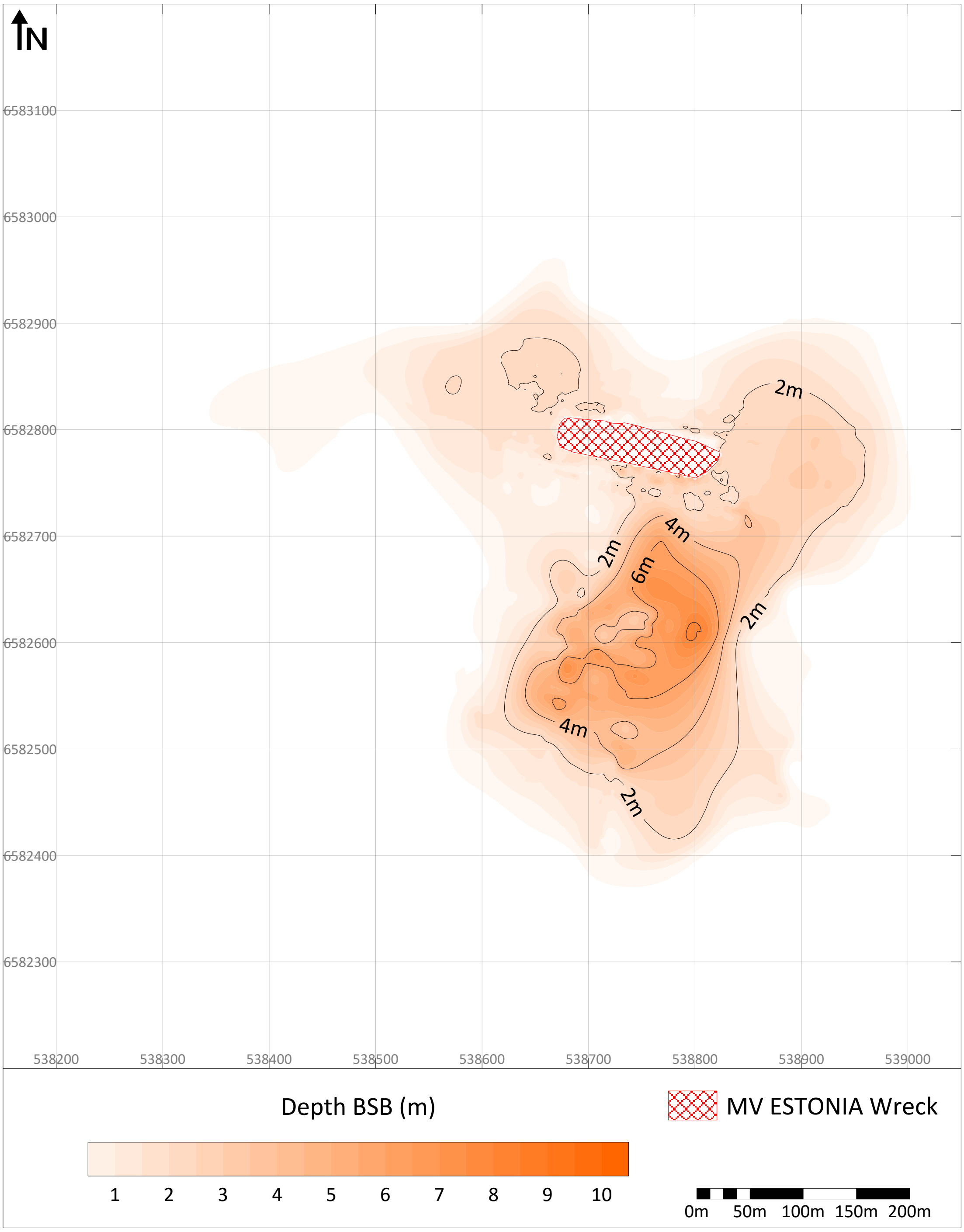

FIG. 3.7: Thickness of Anthropogenically Affected Sediments. These sediments were dumped around the wreck during the wreck covering works in 1996 (O 2.10).

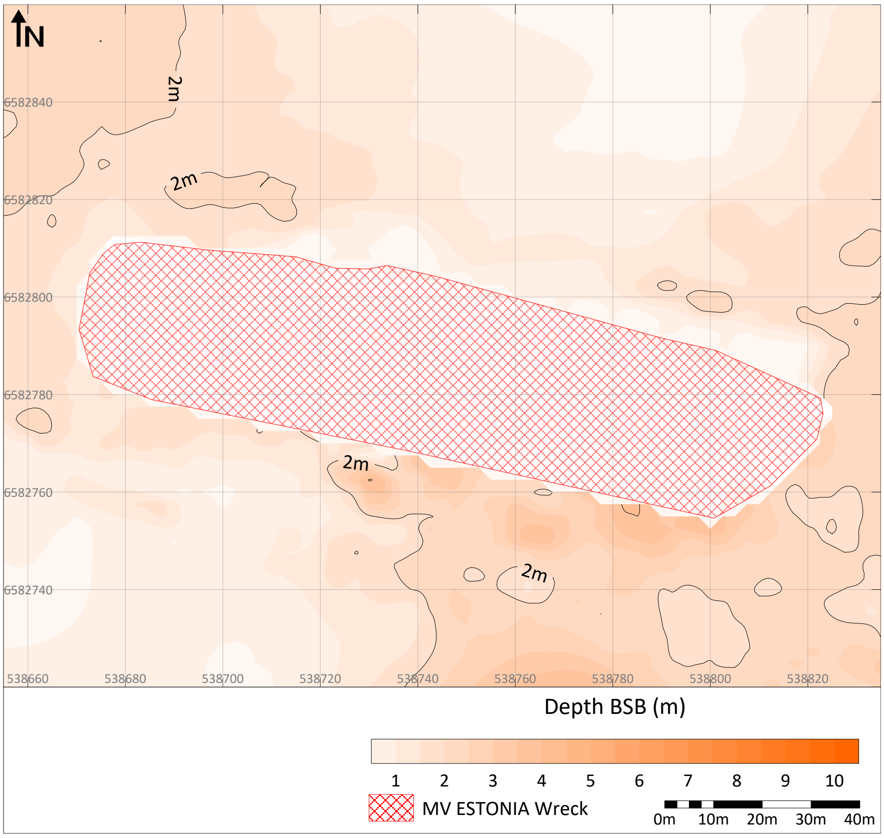

FIG. 3.8: Thickness of Anthropogenically Affected Sediments in the Vicinity of the Wreck. These sediments were dumped around the wreck during the wreck covering works in 1996 (O 2.10).

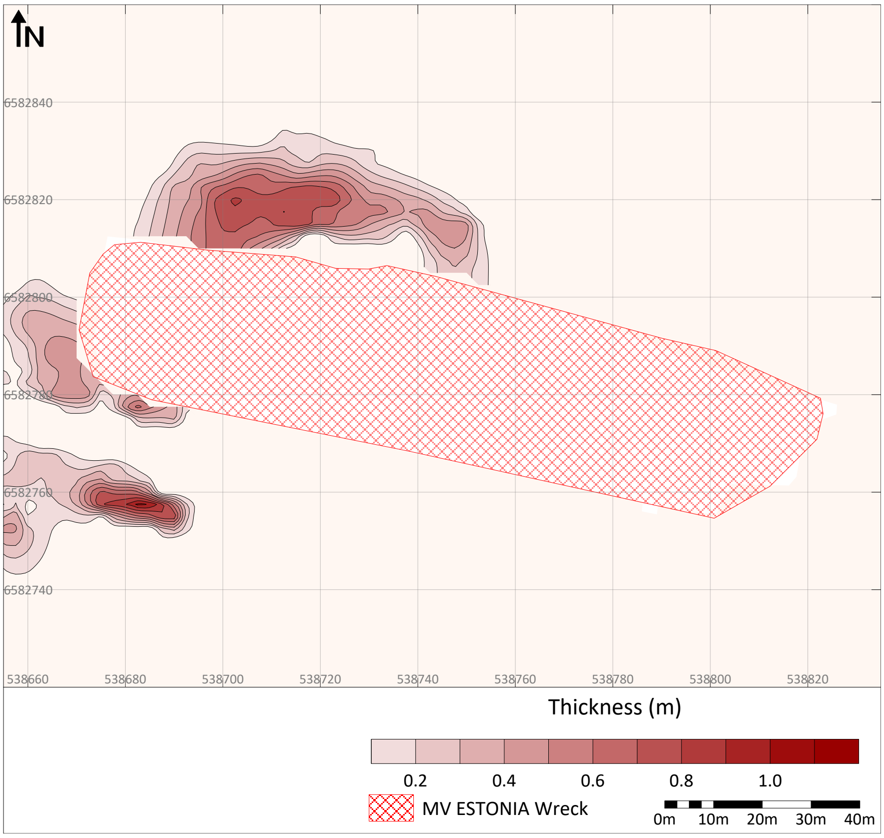

FIG. 3.9: Thickness of the Basal Sub-Unit of Anthropogenically Affected Sediments in the Vicinity of the Wreck

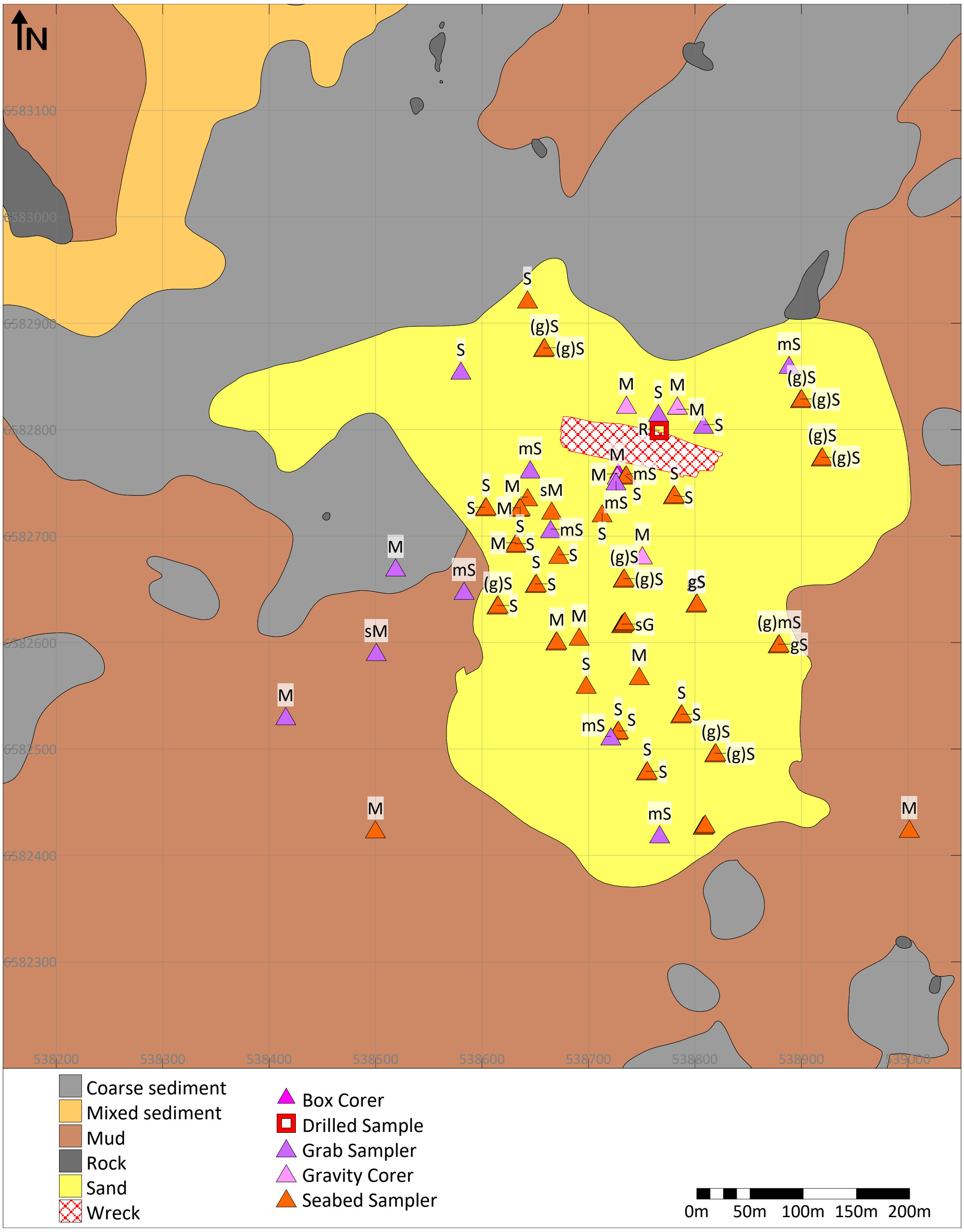

FIG. 3.10: Seabed Sediments with Seabed Sediment Sampling and Drill Locations.
The "Box Corer" and "Gravity Corer" samples date to 1995 [23]; the "Seabed Sampler" to 1996 [32]; the "Grab Sampler" to 2021 [39]; and the "Drilled Sample" to 2023 [13].
Compared to the interpreted seabed sediment areas (based on "Folk 5"), the sample labels follow the more detailed "Folk 16" classifications: slightly gravelly muddy Sand [(g)mS]; slightly gravelly Sand [(g)S]; gravelly Sand [gS]; Mud [M]; muddy Sand [mS]; Rock and Boulders [R]; Sand [S]; sandy Gravel [sG]; and sandy Mud [sM].

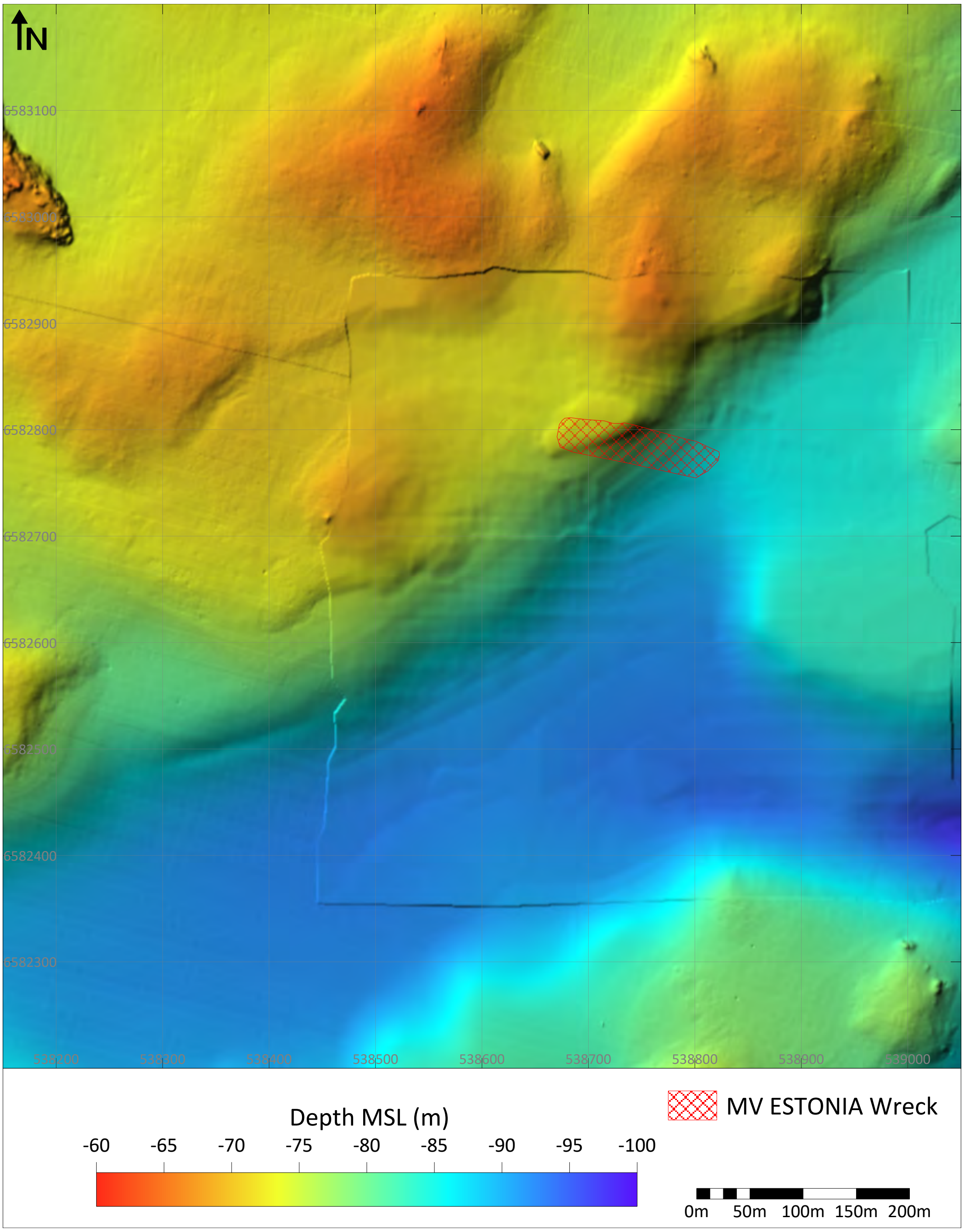

FIG. 3.11: Reconstructed 1994 Bathymetry (Pre-Accident).
The relief visible approx. in the middle of the figure which can be traced in a quadrangular pattern around the wreck represents the crossover from reconstructed data to data acquired during the Preliminary Assessment. While the differences are generally of the order of ±0.5 m, they stand out especially well near any flatter areas.

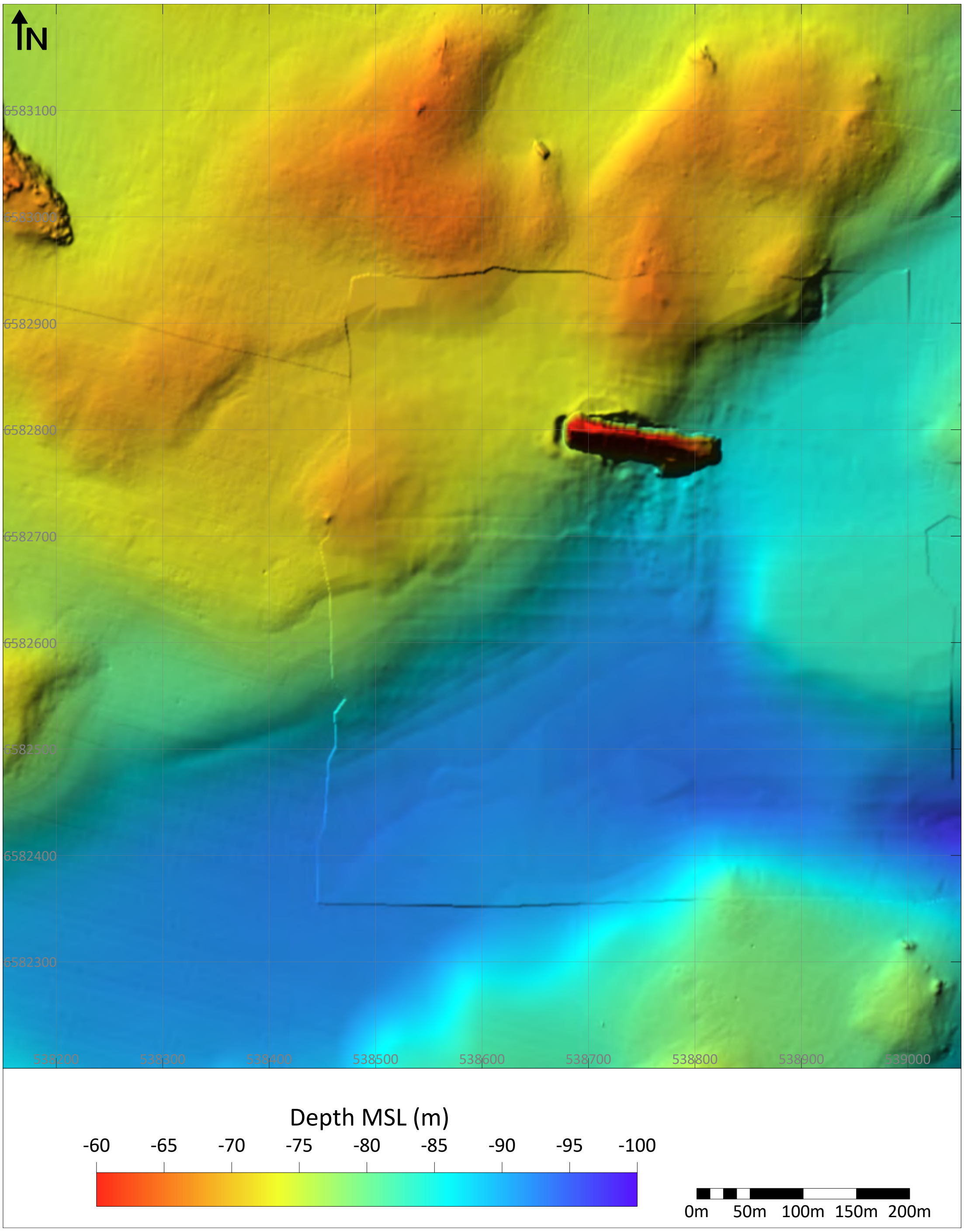

FIG. 3.12: Reconstructed 1996 Bathymetry (Pre-Deposition).
A sediment slump has occurred to the south of the wreck; probably, this occurred during the ship's crash into the seabed at the time of the accident, with the sediment sliding into the deepest part of the near-by valley.

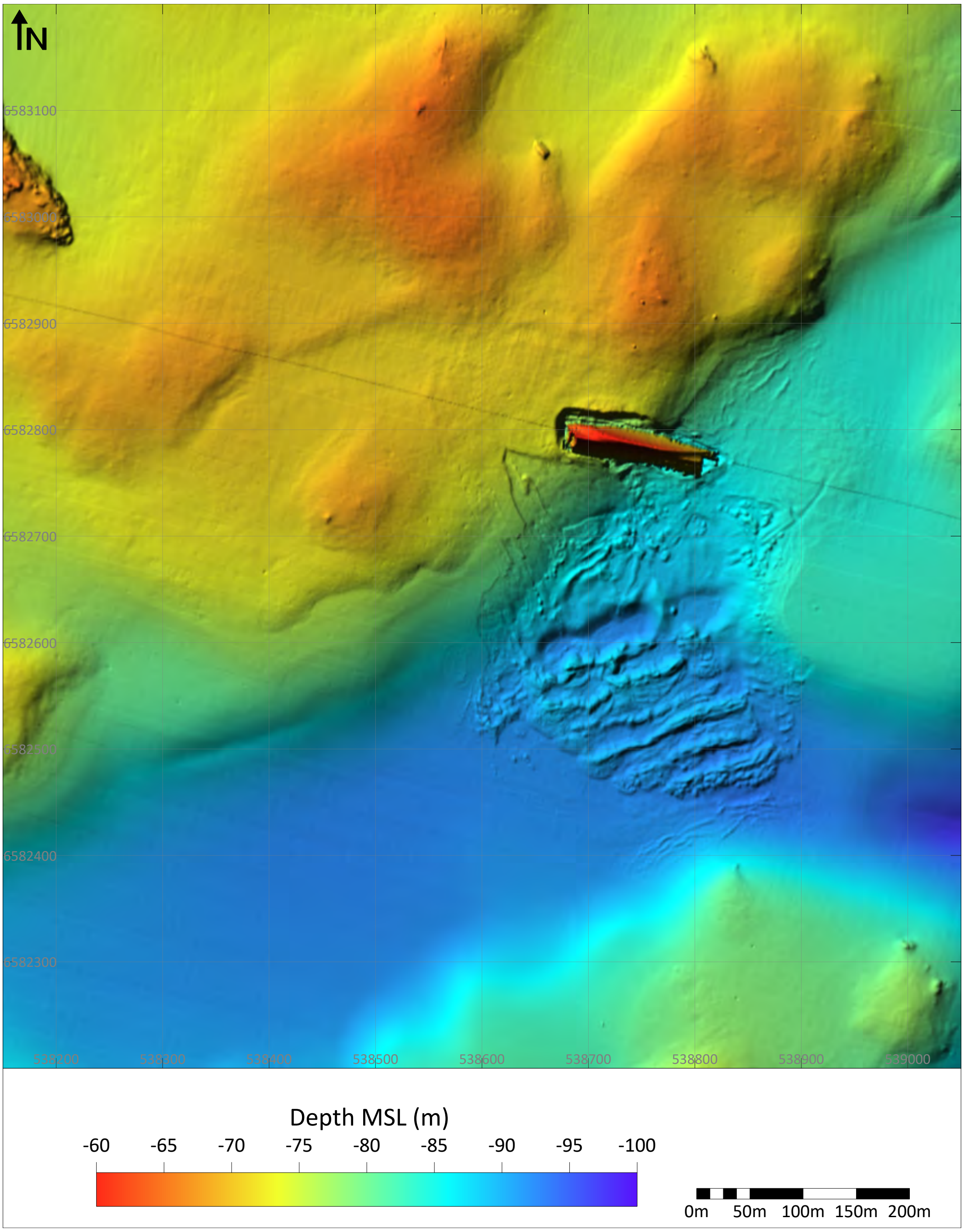

FIG. 3.13: 2021–2023 Bathymetry.
The slumped seabed to the south of the wreck is the result of a number of sediment movements. The slumps have caused the intermixing of natural sediments, dumped sediments, installed forced penetration strings, and installed geotextiles. The area in which the slumps have occurred is well delineated in the bathymetry with nearly linear boundaries on the seabed compared to the unaffected areas. In addition, the increased definition of the data highlights morphological features, interpreted as related to anthropogenic activity around the wreck.

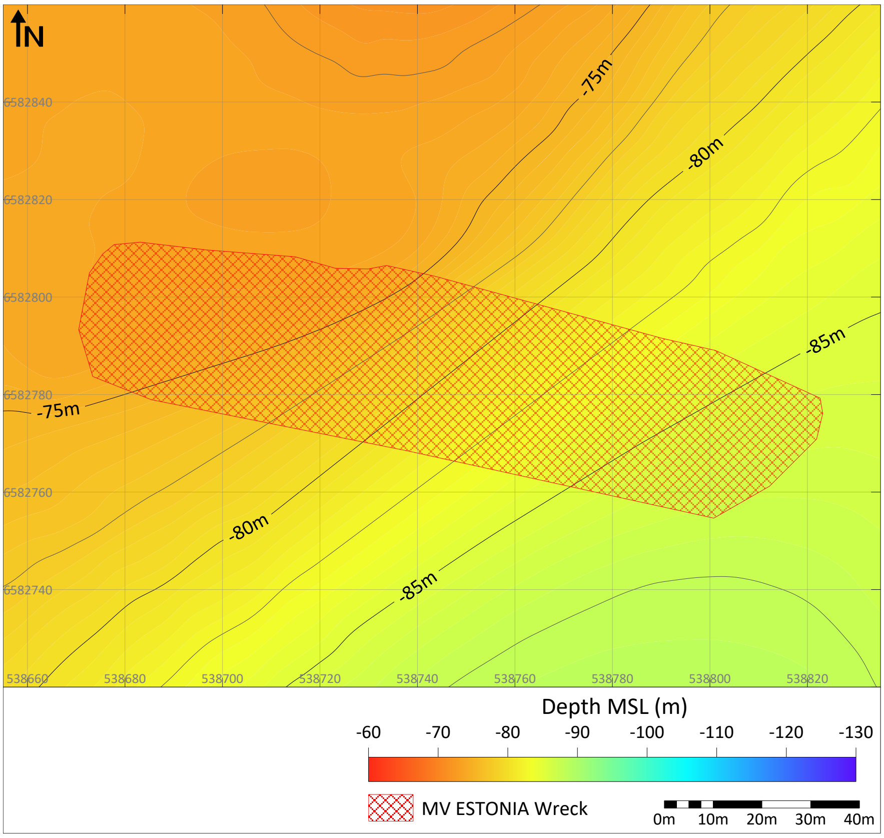

FIG. 3.14: Reconstructed 1994 Bathymetry (Pre-Accident) in the Vicinity of the Wreck

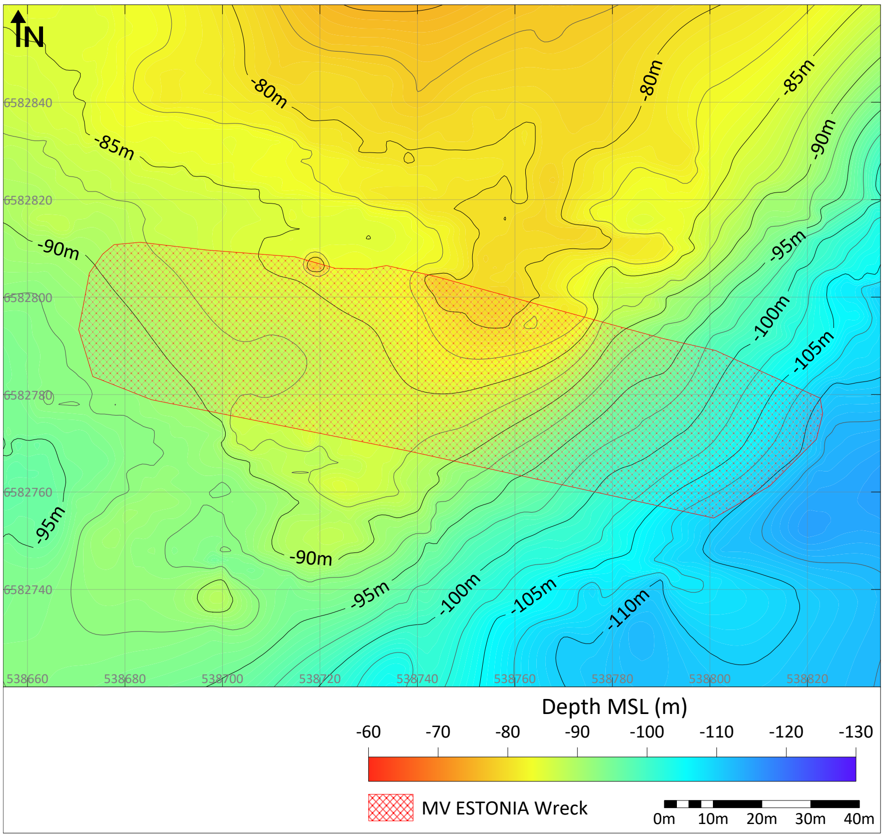

FIG. 3.15: Total Depth from Sea Level to Bedrock in the Vicinity of the Wreck

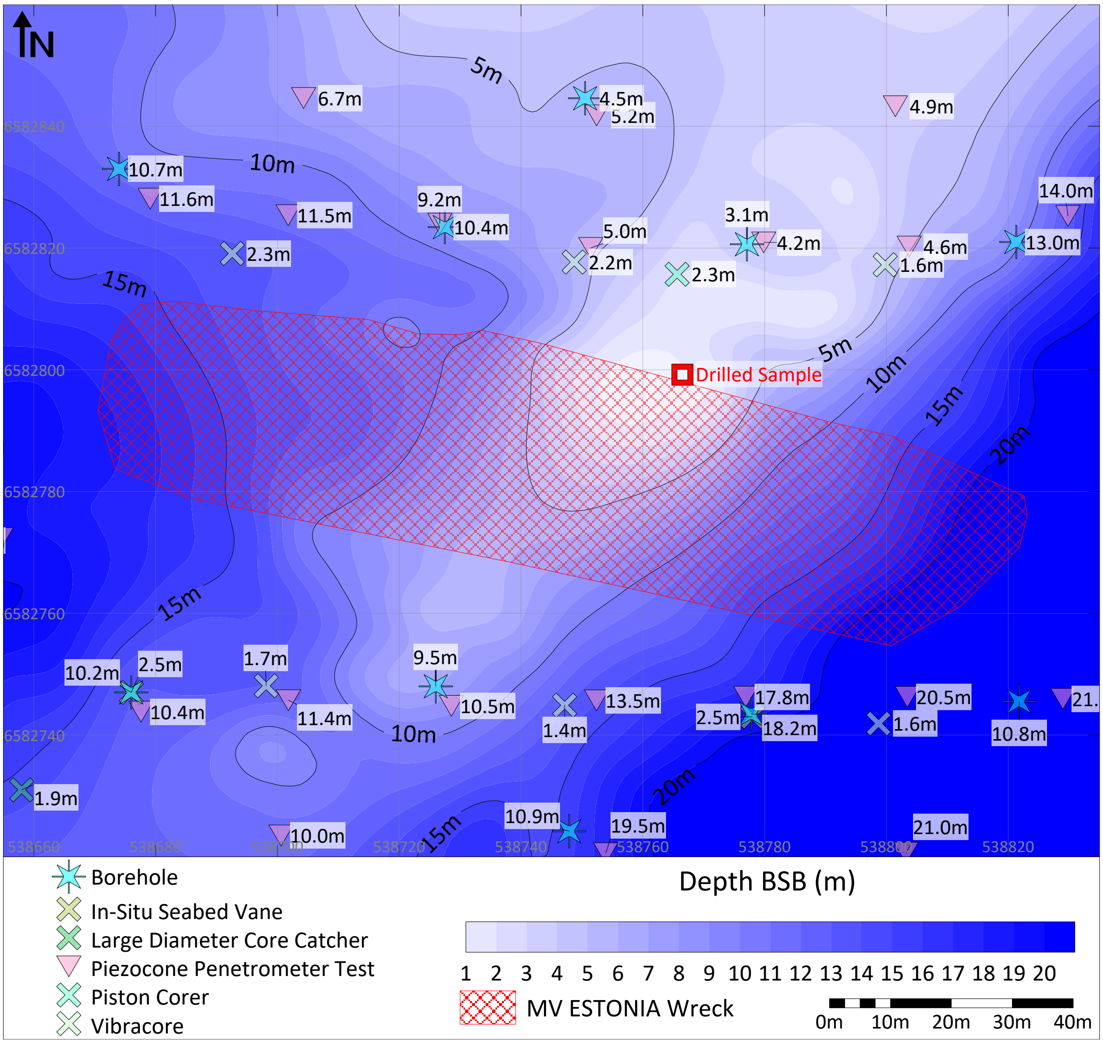

FIG. 3.16: Depth Below Seabed to Bedrock in the Vicinity of the Wreck with Geotechnical Sampling Locations.

The "Vibracore" samples date to 1994 [6]; the "Borehole" and the "Piezocone Penetrometer Test" samples to 1995 [23]; the "In-Situ Seabed Vane" and "Large Diameter Core Catcher" samples to 1996 [32]; the "Piston Corer" samples to 2021 [39]; and the "Drilled Sample" to 2023.[13]

In general, the boreholes and PCPTs had the potential for deepest sampling (respectively, target penetrations of 10 m and 20 m) while the other systems were expected to return a sample of between 2 m and 6 m.

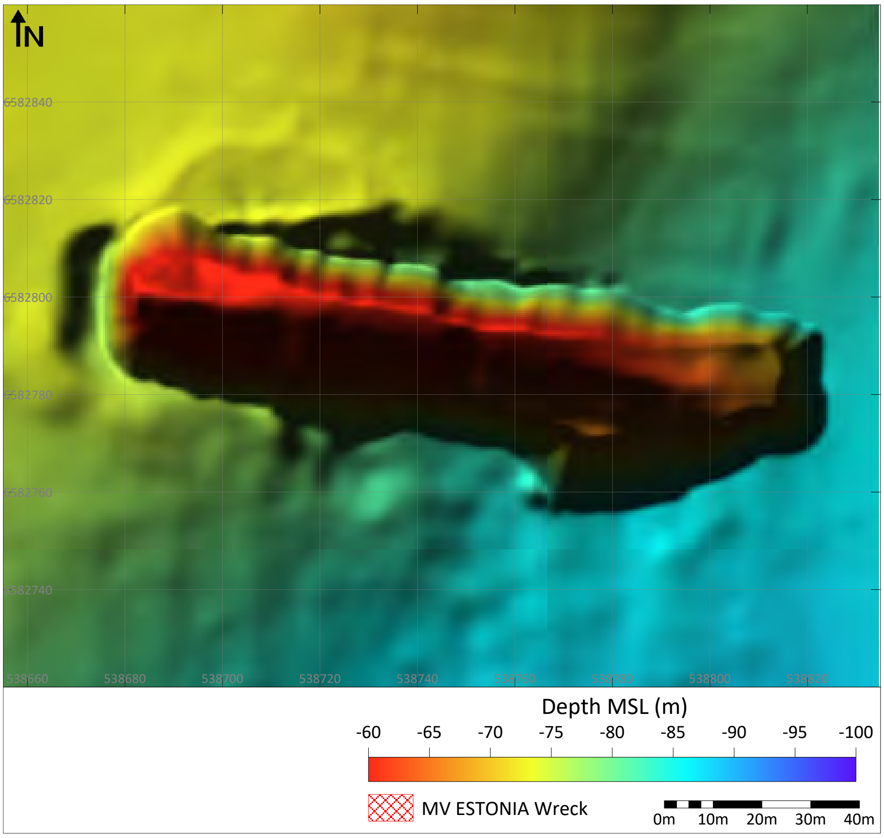

FIG. 3.17: Reconstructed 1996 Bathymetry (Pre-Deposition) in the Vicinity of the Wreck

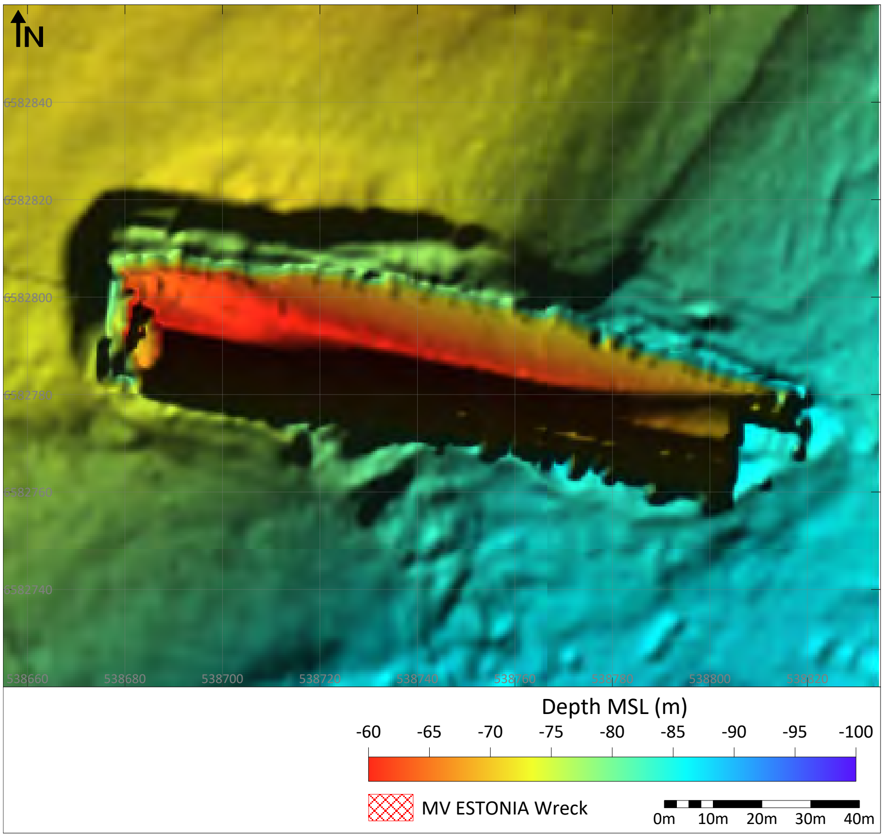

FIG. 3.18: 2021–2023 Bathymetry in the Vicinity of the Wreck

3.3 Wreck Condition

Video footage from 2020 indicates previously unrevealed damage. As described above, seabed conditions have been shown to have changed from 1994 to the present. Therefore, the condition of the wreck on the seabed is described below.

3.3.1 Sub-Conclusions

The following subsidiary conclusions are made on the wreck's condition:

- Numerical assessment of the vessel's contact with the seabed confirms that extensive damage occurred upon impact due to the irregular morphology of the seabed.
- Since the accident, the wreck has remained unstable on the seabed with its position and orientation changing several times. The wreck has gradually shifted downslope and its angle of heel has increased over time. Notably, the bow has moved more than the stern.
- It remains uncertain whether the wreck has reached its final resting position. Future changes in its orientation may occur, potentially exposing additional deformations.
- The wreck's rotational pivot point is located near the starboard-side damage, against documented outcropping bedrock. It is likely that the visible starboard-side damage represents the exposed edge of a more extensive deformation located beneath the wreck, with the shape of the damage closely corresponding with the underlying geological formations. The starboard-side damage was revealed sometime after Aug-2006, i.e., it was not observable during the 1990s.
- The wreck's underwater hull is fully documented and intact, except for one crack (from the starboard side forward deformation) and one penetrating damage (from the starboard side aft-ward deformation) extending over the design waterline.
- There is no available evidence to suggest that the starboard-side damage, or any part of it, was caused by an explosion or a collision on surface.
- The rest of the wreck is in a poor condition with severe structural damage:
  - The severe damage at the stern was caused by the vessel's initial impact with the seabed, as it sank stern-first.
  - The port side damage and compression of the wheelhouse were mainly caused by the increase of the wreck's heel angle over time and its subsequent deformation during contact with the seabed.
  - The wreck is not evenly supported by the seabed, but instead rests on

a local support formation at midships which has caused the structural hogging.
  – The flat-bottom buckling originates from the collapse of internal structures due to hydrostatic pressure when air remained trapped within the sinking ship.

- The wreck's condition may continue to deteriorate over time, making the occurrence of new deformations possible.
- At least 20 % of the heavy fuel in the wreck could not be removed during the oil removal operation in 1996. A minor oil leak exists currently in the wreck, and this could pose an environmental risk in the future.

3.3.2 Wreck Position & Orientation

To analyse the wreck's deformations, it is essential to understand how its location and orientation have changed over time. Survey data, primarily in connection with the planned recovery of the wreck which was later changed to a covering operation, allows a reliable reconstruction of the wreck's past locations and orientations. This section provides an overview of these changes; Table 3.2 summarizes the results.

TABLE 3.2: Documented Wreck Positions

DATE	HEADING (°)	HEEL ANGLE (°)	TRIM ANGLE (°)
Sep-1994	091.00	108	1.50
Dec-1994	096.25	114	1.50
May-1995 to Sep-1997	099.75	119	3.95
Aug-2006	100.50	125	4.25
Jul-2021 to Nov-2023	102.00	134	4.50

Sep-1994

In the data acquired between 2021–2023, a depression, which aligns well with the narrowing bilge part of the ship, is clearly noticeable north of the wreck. When the wreck's theoretical model is positioned to match this depression, the ship has a heading of 091°, a heel angle of approx. 108°, and a trim angle of 1.5° forward. In this orientation, the exposed bedrock observable today would be located near the starboard side of Deck 7. It remains uncertain whether the wreck rested in this position for a period after the impact or if it continued shifting downslope immediately, following the angular descent motion of the sinking vessel (Figure 3.19).

MBES imagery captured by the hydrographic vessel SUUNTA on 30-Sep-1994

FIG. 3.19: Top view of the theoretical wreck position in Sep-1994 aligned with the depression on digitised bathymetry from Jan-1996.

(O 2.1), indicates that the wreck rested on the seabed with a heading of approx. 090°. Due to the absence of information on the coordinate reference system and the limited data available in these images, no further conclusions can be drawn about the wreck's exact orientation based on this.

Oct-1994

Wreck positions shown on large-scale charts from Oct-1994, created by Finnish Naval Research Institute (*Merivoimien tutkimuslaitos / Mariners forskningsanstalt*, MerivTL), are inconsistent, which makes it difficult to assess any changes in the wreck's location.[22] The heading of the wreck on the charts is approx. 095.5°. The heel angle of the wreck on the profile of the bow section is approx. 108°.

However, one recorded wreck position exists in a document dated Oct-1994.[51] This positions is located 7 m northwards from the bulbous bow compared to the first reconstructed position from Dec-1994, as described in the next section.

Dec-1994

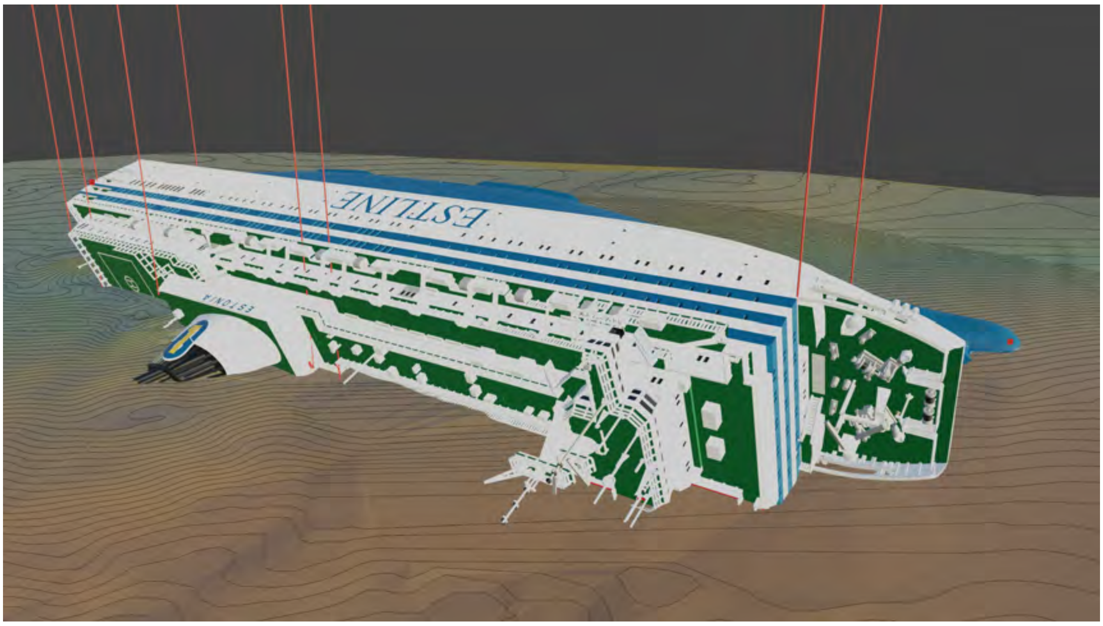

FIG. 3.20: Visualization of the wreck orientation reconstruction method based on ROV depth recordings and positions of bow and stern.

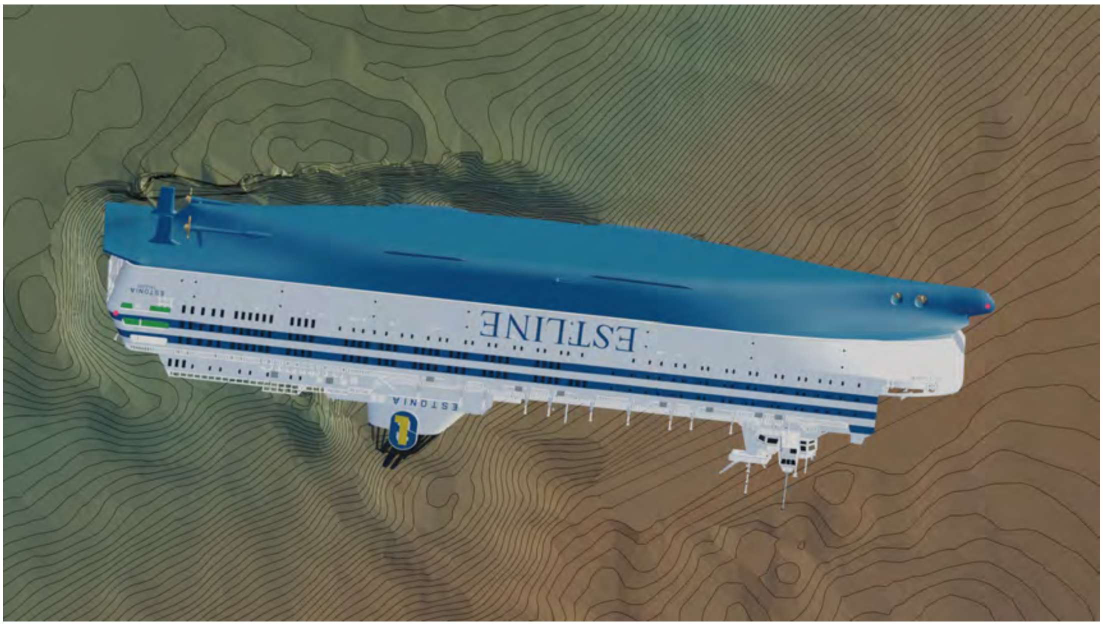

FIG. 3.21: Top view of the reconstructed wreck position in Dec-1994 resting on digitised bathymetry from Jan-1996. Reported positions of the bow and stern are visible on the bulbous bow and on stern corner of Deck 5.

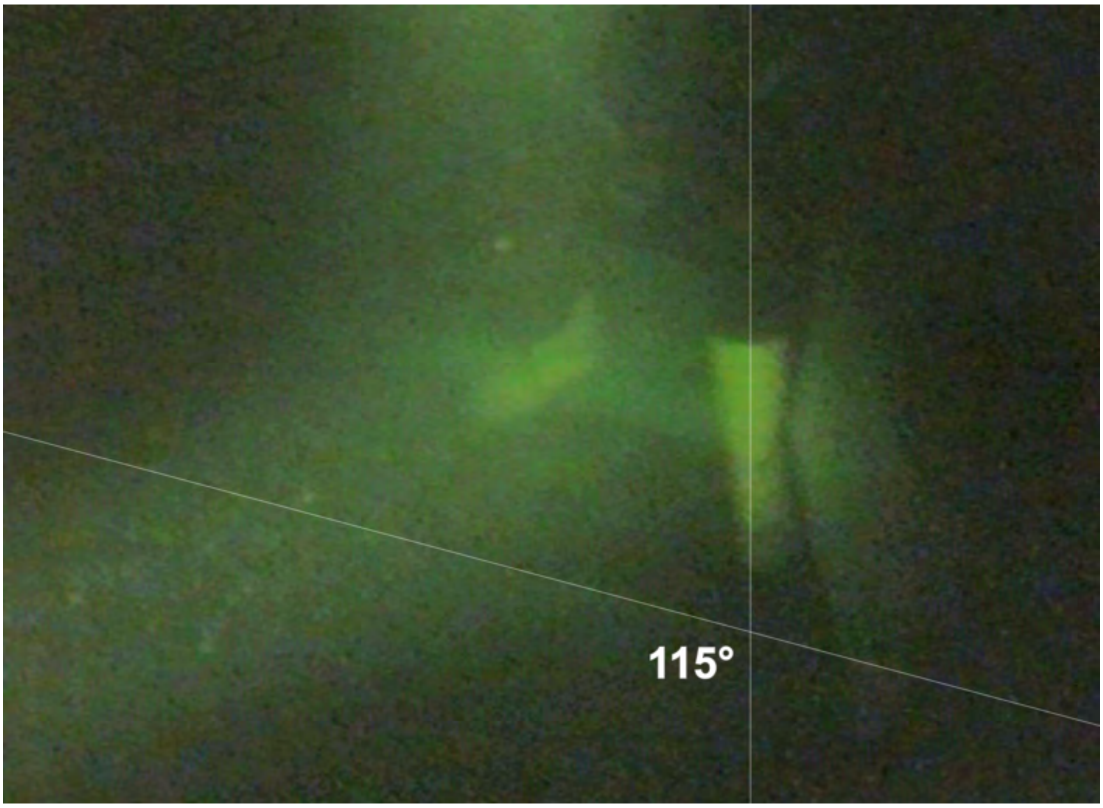

FIG. 3.22: A diver standing on an accommodation deck window on the port side of the wreck in Dec-1994. If the left support leg is considered as the line of gravity, the wreck's heel angle is estimated to be approx. 115° based on the window's orientation. Still from recorded videos.

Although a bathymetric survey was conducted in Dec-1994 (O 2.6), the chart from this survey is too general to assess detailed changes in the wreck's location. Nevertheless, it has been possible to reconstruct the wreck's precise orientation at that time as Shaw provides the wreck's heading and the positions of both the stern and the bow.[6]

At first glance, this data appears contradictory, as the reported latitude for both the bow and stern is identical, implying a heading of 090°.[6], [47] However, the recorded heading was 097°.[6], [47] This discrepancy was resolved by discovering that specific, well-recognisable parts of the wreck were used as reference points for the bow and stern: the bulbous bow and the stern corner of Deck 5. These points align along the same latitude when the wreck's actual heading is approx. 095°–097°.

In addition to its horizontal position, the wreck's orientation was determined using depth recordings and the mudline location from the ROV, in relation to the bathymetry. This method is estimated to provide an accuracy of ±0.5 m for each measured point on the wreck (Figure 3.20). The reconstructed orientation results in a heading of 096°, a heel angle of approx. 114°, and a trim angle of 1.5° forward, which aligns well with the reported data (Figure 3.21).

In Dec-1994, the heel angle was estimated to be 120° based on the ROV mudline survey, while earlier assessments suggested a heel angle of 115°, likely based on ROV imagery of the front bulkhead.[18] Additionally, the ter Haar report stated that there was "little to no" trim angle.[5, Sec. 3.a.] An ROV image showing a diver standing on the port side of the wreck also supports a heel angle of approx. 115° (Figure 3.22).

May-1995

Bathymetric data available from May-1995 (O 2.7) aligns well with data collected between Dec-1995 and Jan-1996 (O 2.8), leading to the conclusion that the wreck's orientation in May-1995 was the same as seven months later. The bathymetric data in May-1995 were collected using a single beam echo sounder. Given that the 1995–1996 bathymetric dataset was acquired using a MBES, it is both denser and more accurate, the wreck's position and orientation are described based on this dataset in the next subsection.

Dec-1995 to Jan-1996 (1995–1996)

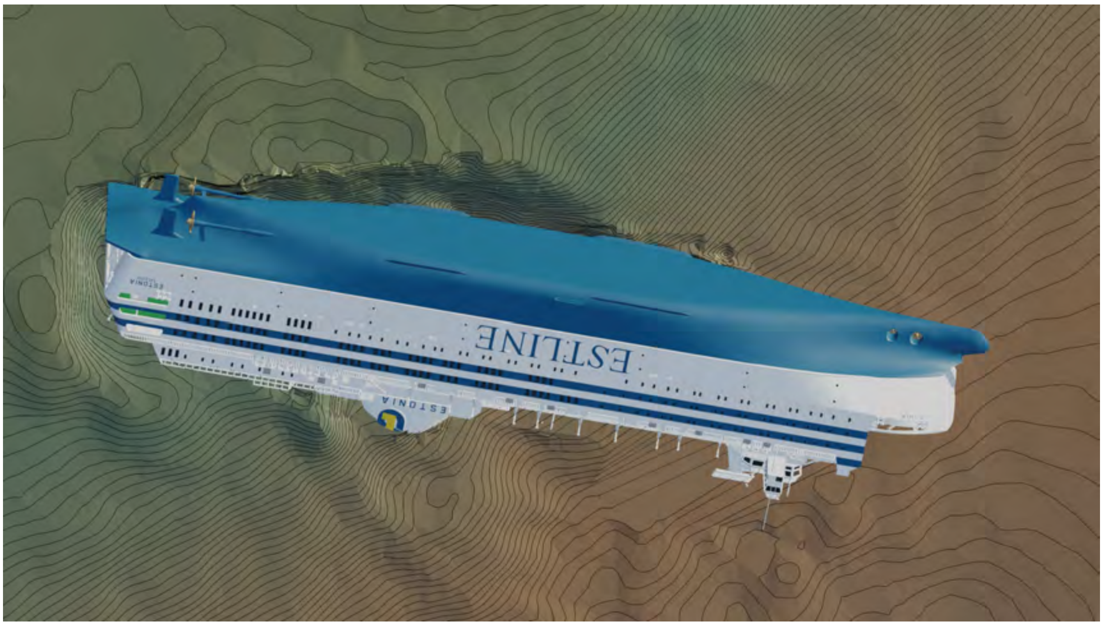

FIG. 3.23: Top view of the reconstructed seabed and wreck position according to the 1995–1996 bathymetric survey. The wreck's stern has reached its maximum extent northwards which forms the trench observable today.

The detailed bathymetric data acquired from Dec-1995 to Jan-1996 (O 2.8) enables to reconstruct the wreck's position and orientation and surrounding bathymetry (before sandfilling operations) with high confidence and an estimated accuracy of ±0.2 m. Compared to the Dec-1994 position, the wreck had rotated both on its horizontal and transverse planes by May-1995. In this position, the wreck's stern reached the most northward. The reconstructed orientation of the wreck has a heading of 100°, a heel angle of 119°, and a trim angle of 4° forward (Figure 3.23).

Jun-1996 to Sep-1997 (1996–1997)

During the wreck covering works between 18-Jun-1996 and 28-Jul-1996 (O 2.10) at regular intervals position surveys were carried out to monitor possible movement of the wreck. This was done by means of five transponders, of which two were placed on the wreck itself and three were placed on the seabed north of the wreck.

The transponders were interrogated again during a seismic survey on 09-Sep-1997 (O 2.11); no change in position of the wreck relative to the surrounding seabed had occurred from 18-Jun-1996 to 09-Sep-1997.[10] As there is no visible change between the Jan-1996 position (Figure 3.23) and positions from surveys made in Jun-1996 and Jul-1996, it can be concluded that the vessel remained stationary from May-1995 to Sep-1997.

Aug-2000

In the results of an unauthorized diving survey carried out in Aug-2000, it is concluded: "The foreship was found to be turned 20°-25° more to starboard than it was initially resting, i.e., the angle was then approx. 140°."[77] This suggests that, by that time, the wreck had shifted from its previous position. This reported increase in heel angle is considered over-interpreted as even the surveys conducted during the Preliminary Assessment have found a heel angle of less than 135°.

Aug-2006

It was possible to reconstruct the wreck's position and orientation with high confidence and an estimated accuracy of ±0.25 m based on a general hydrographic survey (O 2.12). Compared to the previous reconstructed position the wreck had shifted and turned down the slope which resulted in a heading of 101°, a heel angle of 125°, and a trim angle of 4° forward (Figure 3.24).

Jul-2021 to Nov-2023 (2021–2023)

The wreck's recent position has been documented in several surveys (with MBES in O 2.14, with photogrammetry in O 2.20, and with MBES in O 2.22). Compared to the 2006 position, the wreck has continued shifting and turning down the slope. The latest documented position of the wreck in Nov-2023 gives it a heading of 102°, a heel angle of 134°, and a trim angle of 4.5° forward (Figure 3.25).

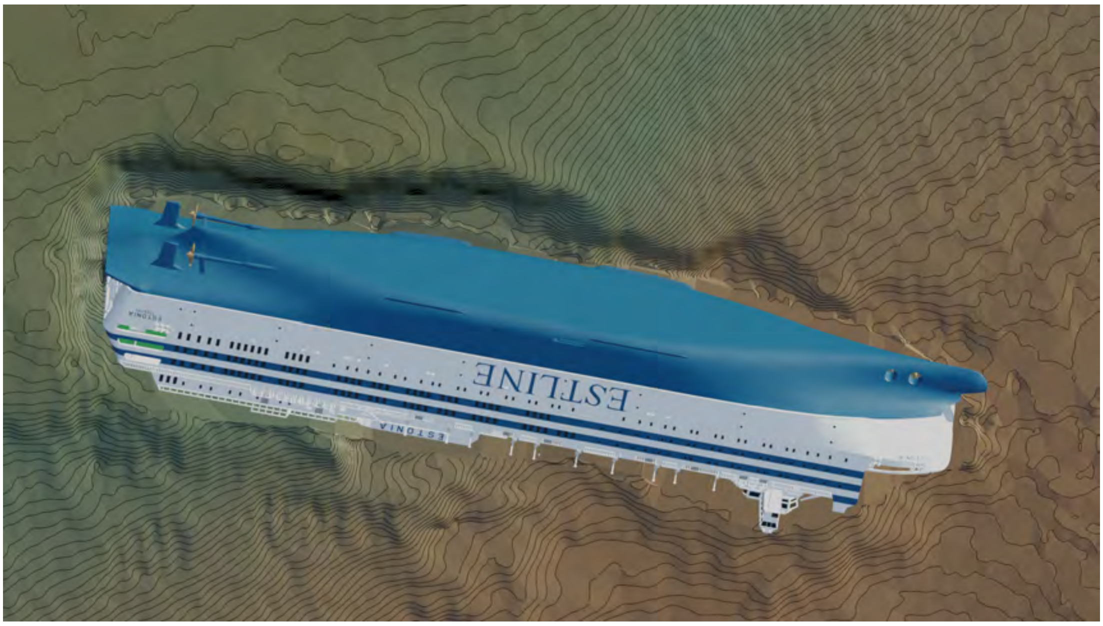

FIG. 3.24: Top view of the seabed and wreck position according to the 2006 bathymetric survey (O 2.12).

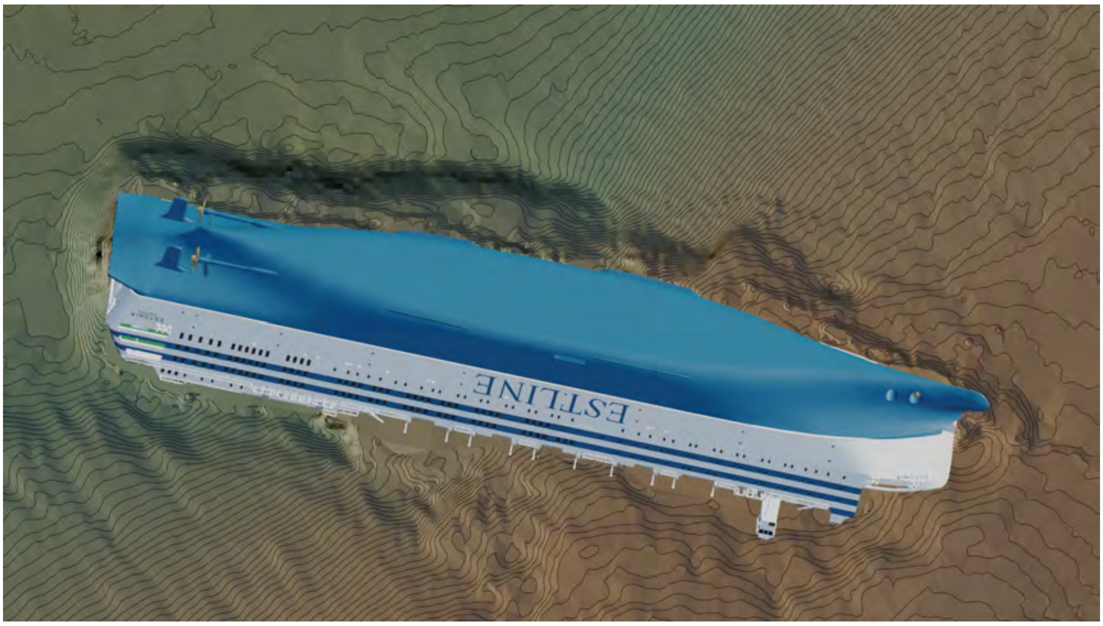

FIG. 3.25: Top view of the seabed and wreck position according to the surveys conducted from 2021 to 2023.

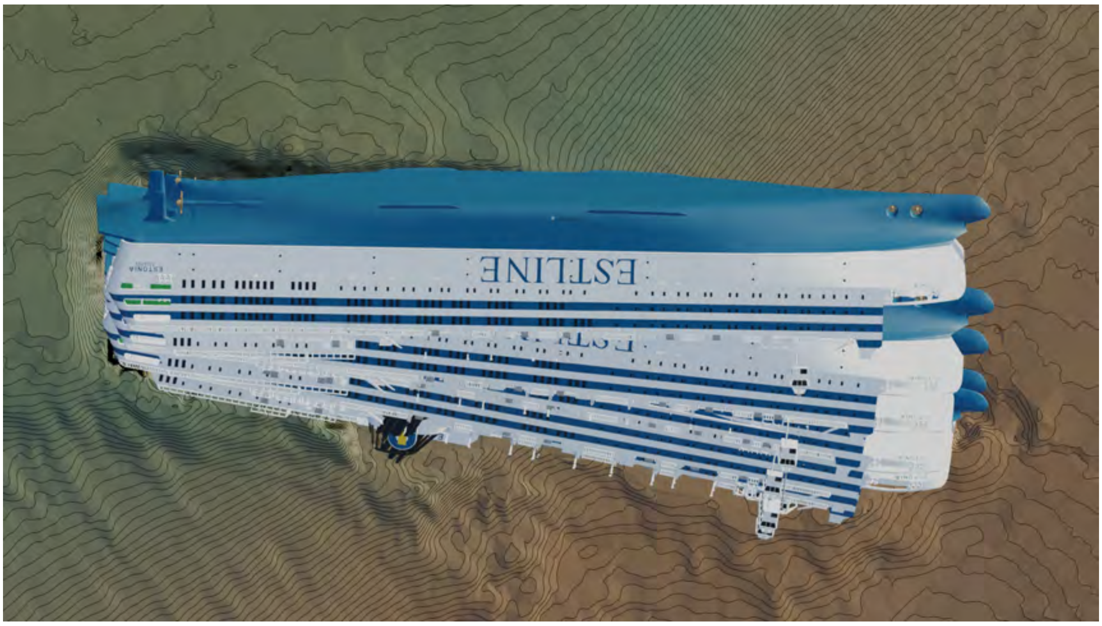

FIG. 3.26: Top view of the five reconstructed positions of the wreck from 1994 to 2023 (Sep-1994, Dec-1994, May-1995 to Sep-1997, Aug-2000, Jul-2021 to Nov-2023)

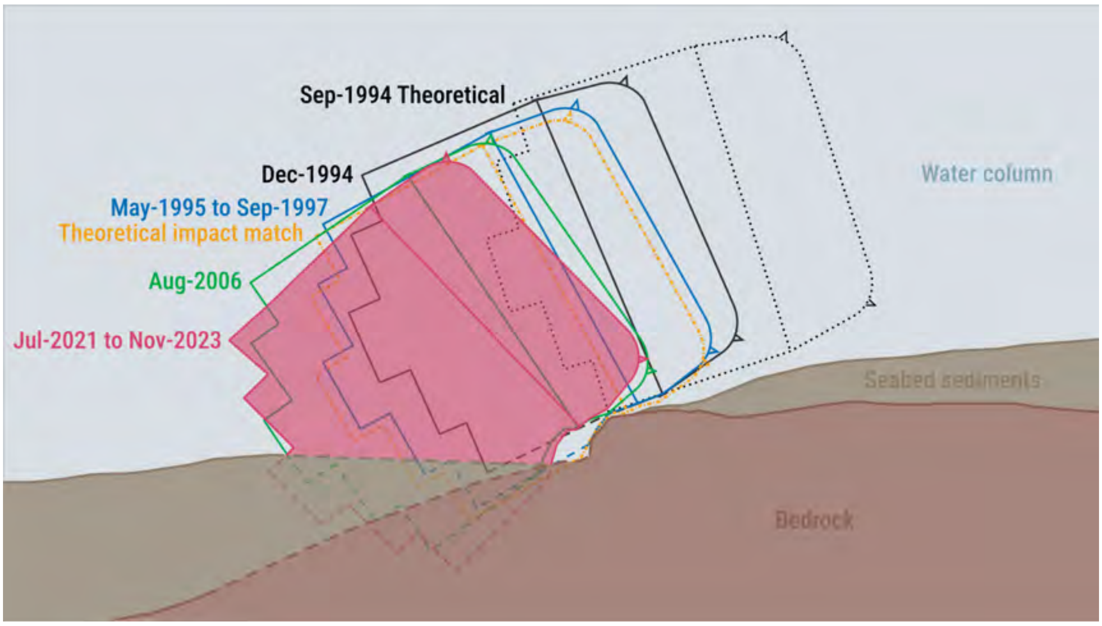

FIG. 3.27: A sectional cut at midships, near the forward penetrating damage, illustrates the wreck's movement over the decades.

3.3.3 Wreck Damage & Condition

New Deformations & Current Condition

In recent years, several previously unknown deformations of the wreck of MV ESTONIA have been discovered. This section describes these deformations and explain their origins. The newly discovered deformations have been identified through visual examination and by comparing the wreck's photogrammetric model with its theoretical model. The mechanics of these deformations have been analysed through numerical assessments using the FEM and by studying the wreck's interpreted movement over time.

Structural Damage & Hogging

The wreck is in a poor condition, exhibiting severe structural damage. The following deformations can be observed:

- The accommodation decks in the stern of the wreck are severely deformed, with a large crack at the rounded stern corner at the level of Deck 6 (Figure 3.28). This deformation continues from the stern to the originally flat port side, where the upper section above Deck 6 is bent outward. The port-side deformation is most pronounced at midships and gradually diminishes towards the bow.
- Below Deck 7, aftwards from the midship, several local protrusive deformations are visible in the port-side shell plating (Figure 3.29). These deformations originate from the ends of the deck beams, which have protruded due to contact with the seabed on the opposite starboard side.
- The wheelhouse has collapsed, with only the port bridge wing remaining visible (Figure 3.30). However, the bridge wing has been displaced approx. 1.5 deck heights lower than its original position. Only the starboard bridge wing was submerged into the seabed in Dec-1994 (Figure 3.20).

A comparison between the photogrammetric model of the wreck and the theoretical model of the vessel reveals structural hogging damage (Figure 3.31)—the wreck is bent toward both the bow and stern. This indicates that the wreck is not evenly supported by the seabed, but instead rests on a ridge of bedrock at midships which has caused the structural hogging.

A numerical assessment of the vessel's bottom contact with the seabed confirms that extensive damage occurs upon impact, even when descending in a nearly statical manner (Figure 3.32). In addition to the rigid seabed, significant deformation also results from the compression of soft soil, when it is compressed several meters.

The severe damage at the stern was caused by the vessel's initial impact with the seabed, as it sank stern-first. During the vessel's descent to the seabed, deformations progressively developed toward the bow. Given the structural weakness of the upper accommodation decks, it is expected that all areas of the wreck in direct contact with the seabed have undergone severe deformation.

The objective of the FEM modelling was not to replicate the damage visible on the wreck today, but to observe how the ship would behave in a theoretical collision with the seabed.

Over the decades, as the wreck has shifted and rotated down the slope, deformations have expanded, particularly on the port side.

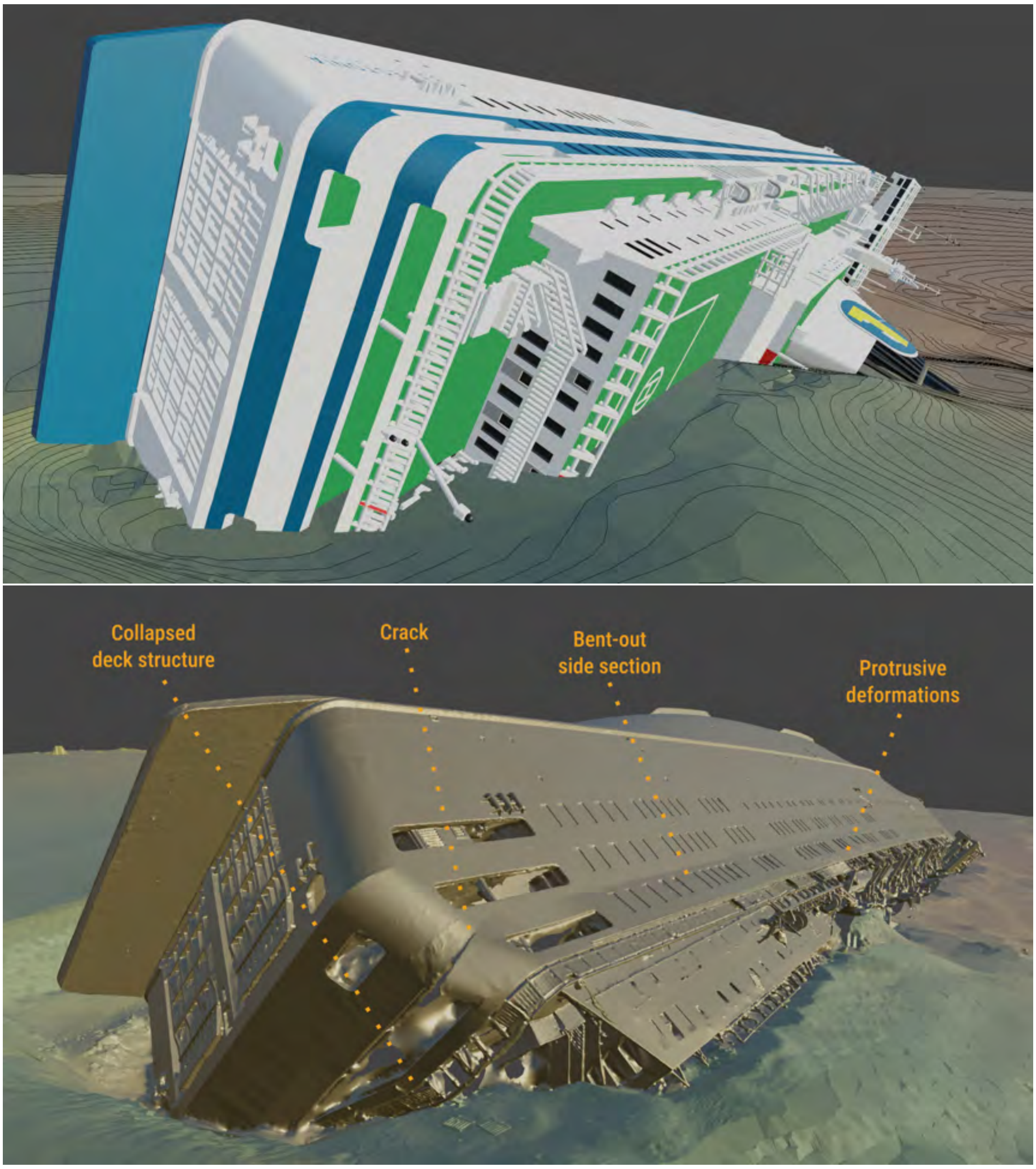

FIG. 3.28: Above: Stern view of the reconstructed wreck position in Dec-1994 resting on digitised bathymetry from Jan-1996. More than half of the helicopter deck was visible then, which now has completely submerged into the seabed because of the wreck movement.
Below: Stern view of the photogrammetric model of the wreck illustrating the observed structural damage.

FIG. 3.29: Protrusive deformation on the port side shell plating below Deck 7.

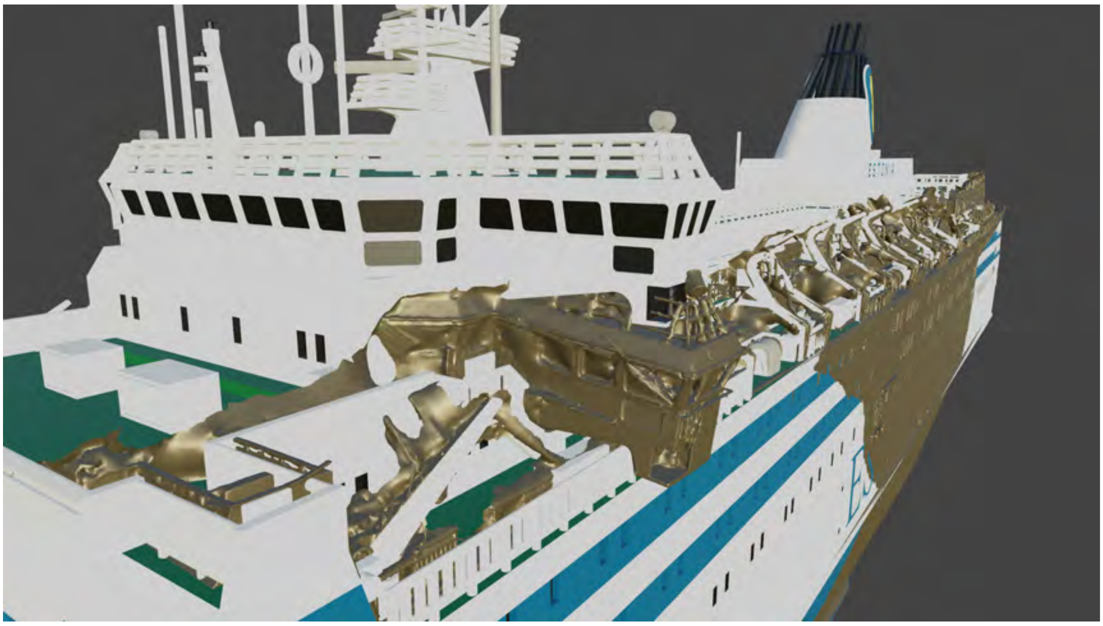

FIG. 3.30: Comparison of the photogrammetric model (metallic) with the theoretical model of the vessel illustrates the collapse of the navigation bridge by 1.5 deck heights because of the wreck movement.

FIG. 3.31: Comparison of the photogrammetric model (metallic) with the theoretical model of the vessel illustrates the hogging of the vessel. Upper decks at midships are pushed out and the stern structure is heavily deformed. Models are aligned by the bilge keels.

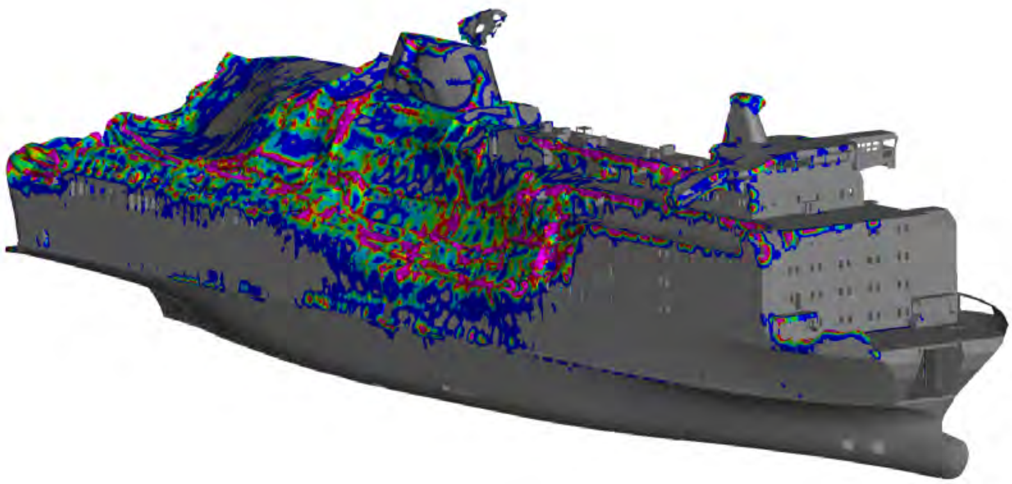

FIG. 3.32: Wreck deformations on theoretical FEM model after the bottom contact illustrating the possible extent of wreck structural damage. Source: Tabri et al. [44].

Starboard Side Damage

The visible part of the starboard-side deformation is located at midships, along the vessel's mudline where the wreck meets the seabed (Figure 3.33). The visible deformed area spans approx. 25 m in width and has penetrating deformations at both ends, with an indentation in the shell plating between them (Figures 3.34 and 3.35).

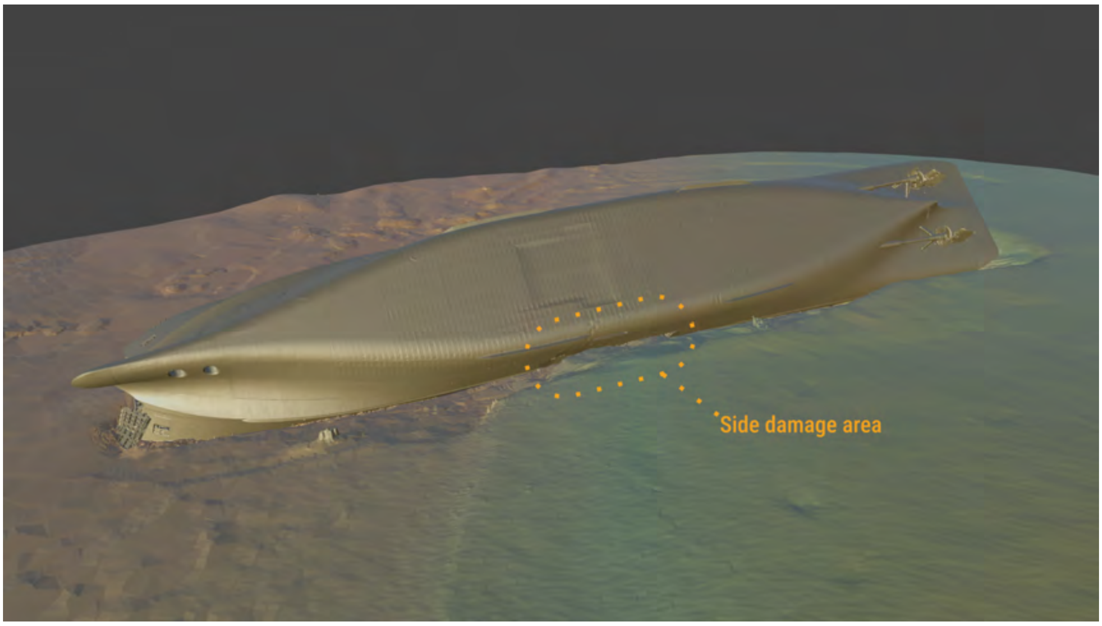

FIG. 3.33: Wreck side damage location on the photogrammetric model of the wreck.

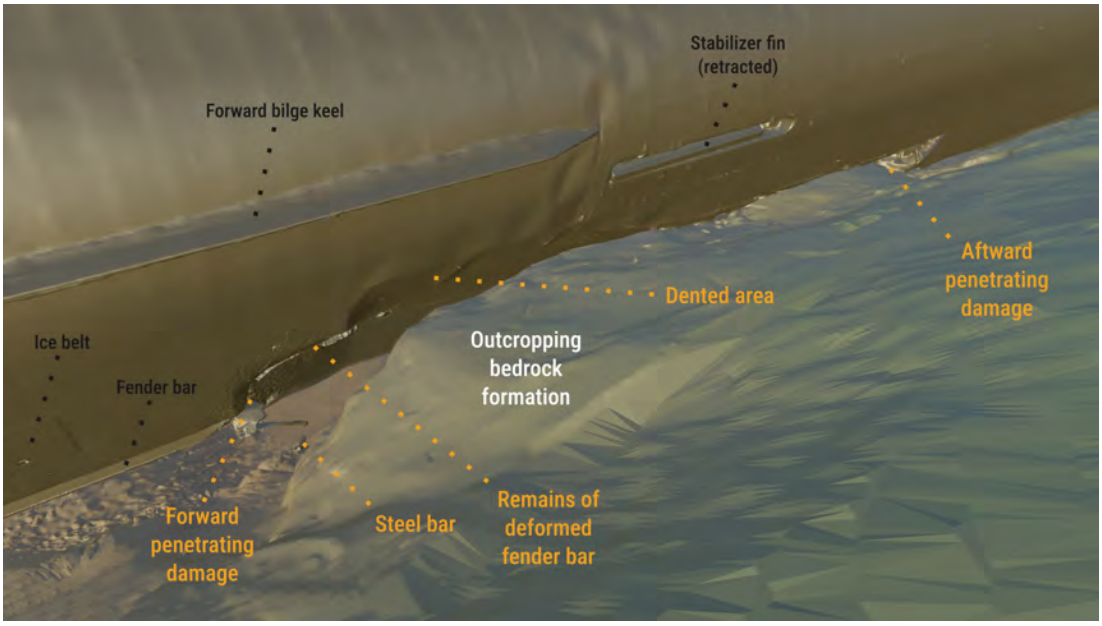

FIG. 3.34: Wreck side damage and the corresponding seabed on the digital model.

Since the wreck's underwater hull is fully documented in the photogrammetric model, it can be concluded that the underwater hull is intact, except for a single crack

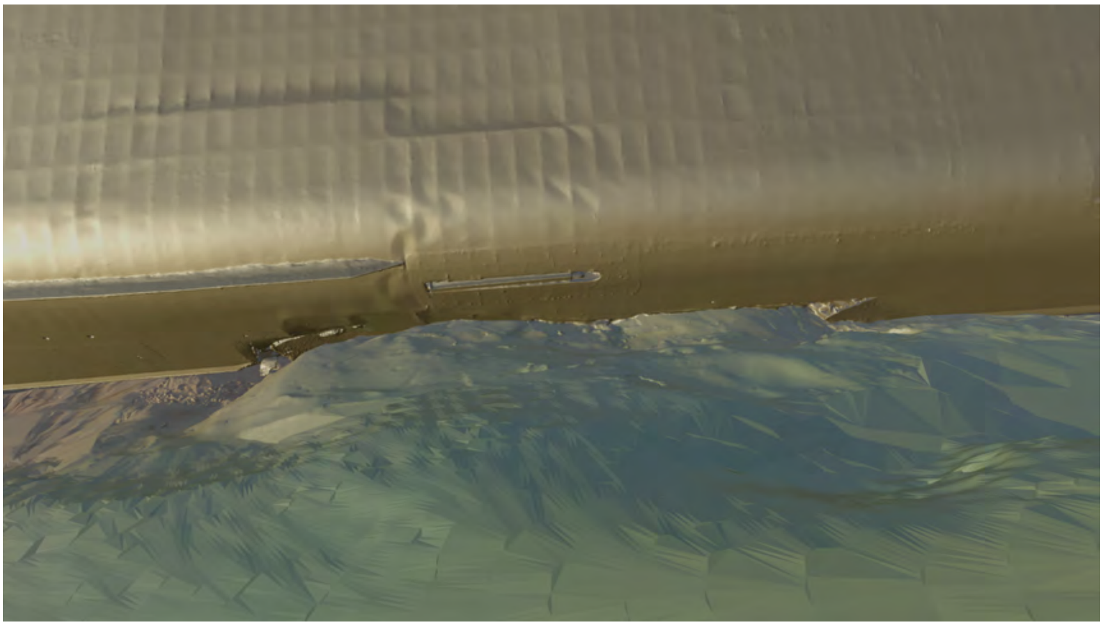

FIG. 3.35: Wreck side damage and the corresponding seabed on the digital model, side view.

extending to the design waterline from the forward penetrating damage and, partly, the aftward penetrating damage located at the design waterline level (Figure 3.38).

The forward penetrating damage is formed next to a web frame, where the shell plating and fender bar have been pushed inward, forming a narrow vertically oriented rhombus-shaped opening when viewed from the stern. This opening narrows and extends as a long crack towards the wreck's bottom. A white rag floated in the shell plating crack (observed in 2021, O 2.13, in 2022, O 2.20, and in 2023, O 2.21). The probable base of a bottle was visible close to the web frame (observed in 2021, O 2.13, and in 2023, O 2.21).

Close to the penetrating deformation, a part of the fender bar is pulled outwards, suggesting that the fender bar got stuck behind the bedrock and was pulled out during the downslope movement of the wreck. A steel bar, resting next to the penetrating damage, probably originates from the fender bar, which supports that the damage to this part of the vessel occurred at or very close to this location.

As the primary concentration of the damage is at the vehicle deck level (Deck 2), the opening extends into the vehicle deck and into passenger cabin No. 1037 on Deck 1, with the crack continuing into the heeling tank. While it is challenging to precisely determine the dimensions and total area of the opening due to its irregular shape, it is estimated to be approx. $1\,m^2$ (Figure 3.36). The fender bar is pushed inwards by approx. 1.5 m in the visible area of the deformation.

The aftward penetrating damage is a horizontal outward deformation (Figure 3.37). The observed character of this damage (similar to the pulled out damage noted on the fender bar above) appears to be related to the wreck's movement on the seabed, across exposed bedrock with which this part is in contact. This damage opens mainly

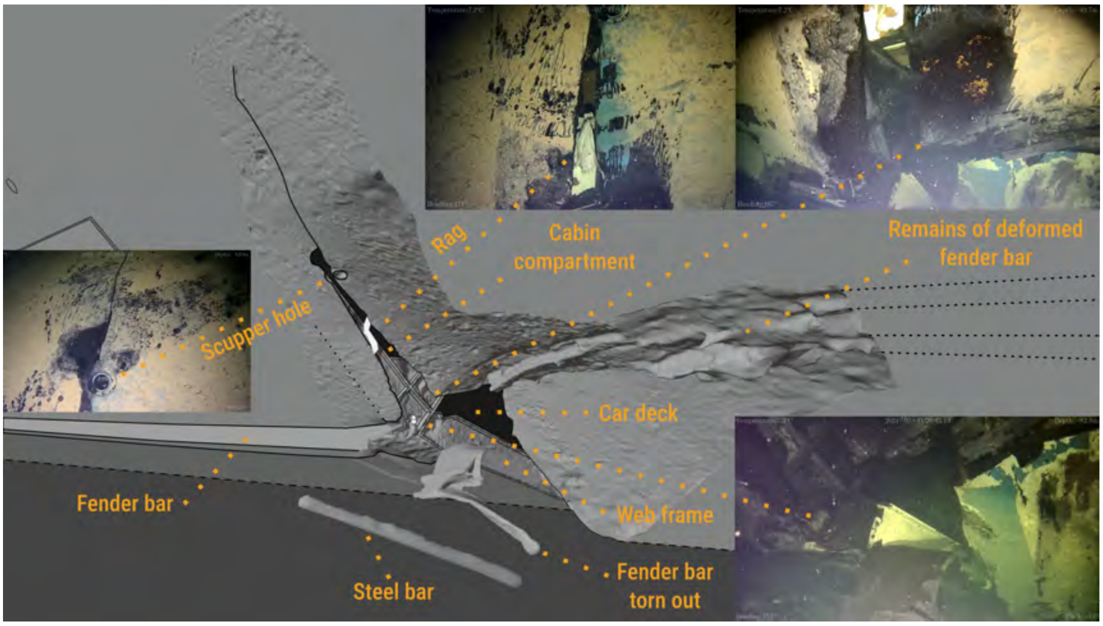

FIG. 3.36: Forward penetrating deformation of the side damage.

to the engine room workshop (Figures 3.38 and 3.39).

The wreck's rotational pivot point is located near the starboard-side deformation, against documented (presently) outcropping bedrock. It is likely that the visible starboard-side damage represents the exposed edge of a more extensive deformation located beneath the wreck.

A 3D digital modelling study analysing changes in the wreck's position and orientation was carried out during the Preliminary Assessment. This confirms that the wreck has shifted over time. During its rotational movement over the bedrock, part of the underside damage became exposed. This starboard-side damage was not observable in the 1990s.

The 3D modelling analysis suggests that it is most likely that the starboard-side damage reached its maximum extent after Sep-1997 and was revealed after Aug-2006 (Figure 3.27). The shape of the starboard-side damage closely corresponds to seabed formations next to the reconstructed wreck positions from May-1995 or later (Figures 3.40 and 3.41). Additionally, numerical assessment of the bottom contact proposes a highly probable scenario of the side damages occurring as a result of the contact between the vessel and the seabed (Figure 3.42).[44]

There is no available evidence to suggest that the deformation, or any part of it, was caused by an explosion or a collision on surface.

Estonian Forensic Science Institute (*Eesti Kohtuekspertiisi Instituut*, EKEI) analysed a steel sample cut from the edge of the forward starboard-side damage, and concluded that there were no traces of contact or collision with a metal object nor any evidence of explosives.[15], [16] Furthermore, no characteristic signs of an explosion were identified in the steel sample nor through visual examination of photos and videos of the starboard-side damage.[17]

The deposits found on the hull and the steel sample associated with the forward starboard-side damage resulted from natural processes.[14] Also, paint damage around the upper end of the crack indicates that that part of the wreck has been in contact with the seabed.

Additionally, the shape and nature of the starboard-side damage does not match the typical characteristics of a collision with another vessel, as there is no corresponding paint damage or other collision-related indicators.

Moreover, there are at least five witnesses claiming they saw the stabilizer fin, folded out in activated position when the vessel was capsizing (Section 5.2.7). Both stabilizer fins are retracted and undamaged currently at the wreck. The starboard side penetrating damage is located close by and forward of the stabilizer fin, which makes it extremely unlikely that a colliding object which could have created the starboard side penetrating damage could have passed by without damaging the stabilizer fin.

FIG. 3.37: Starboard side aftward penetrating damage close-up. Upper image is from 2021 (O 2.13), the lower from 2022 (O 2.20).

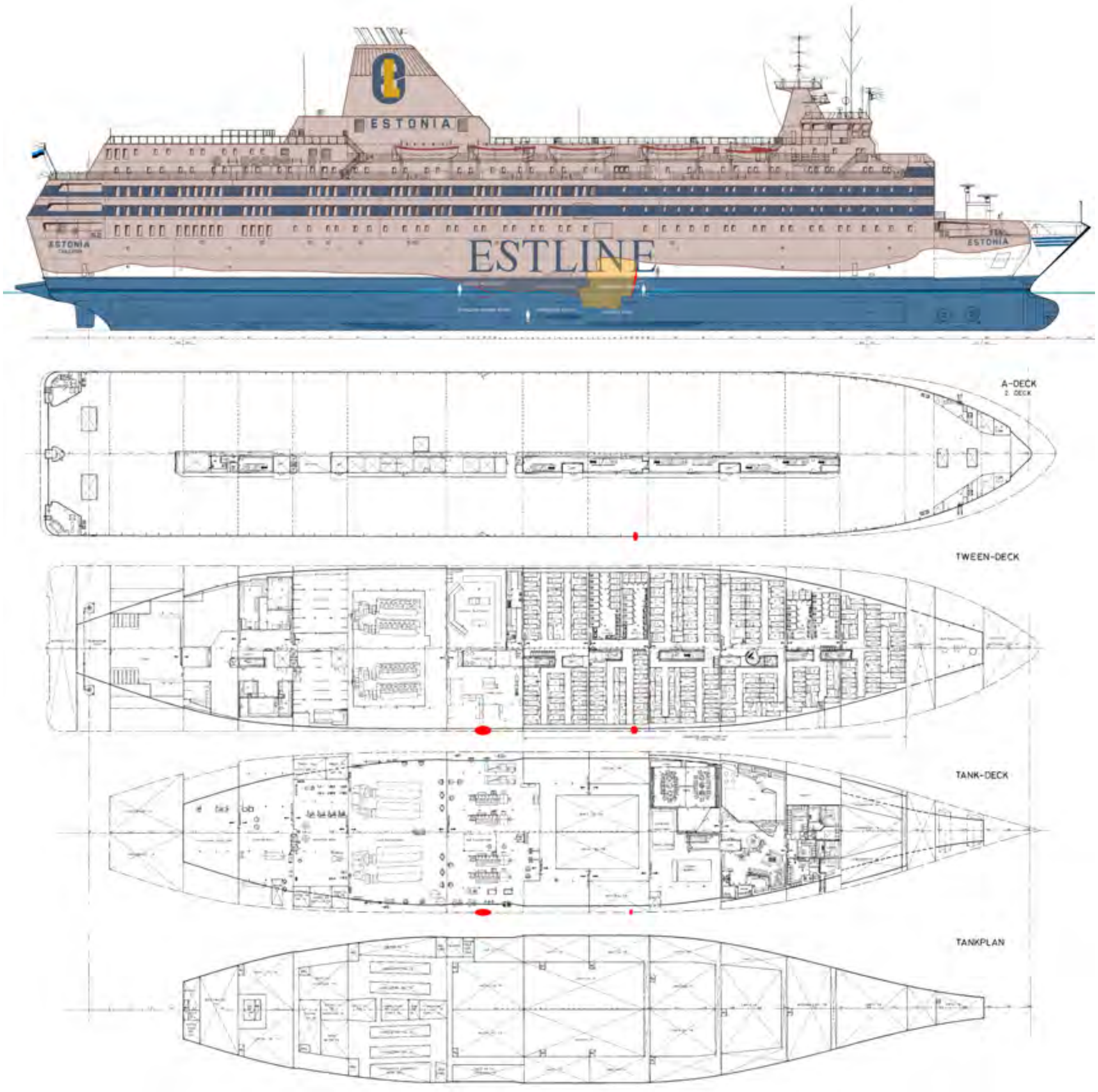

FIG. 3.38: Wreck mudline in the current orientation. Light brown area on the vessel's general arrangement is in contact with seabed. Penetrating damage is marked by red and dents in yellow.

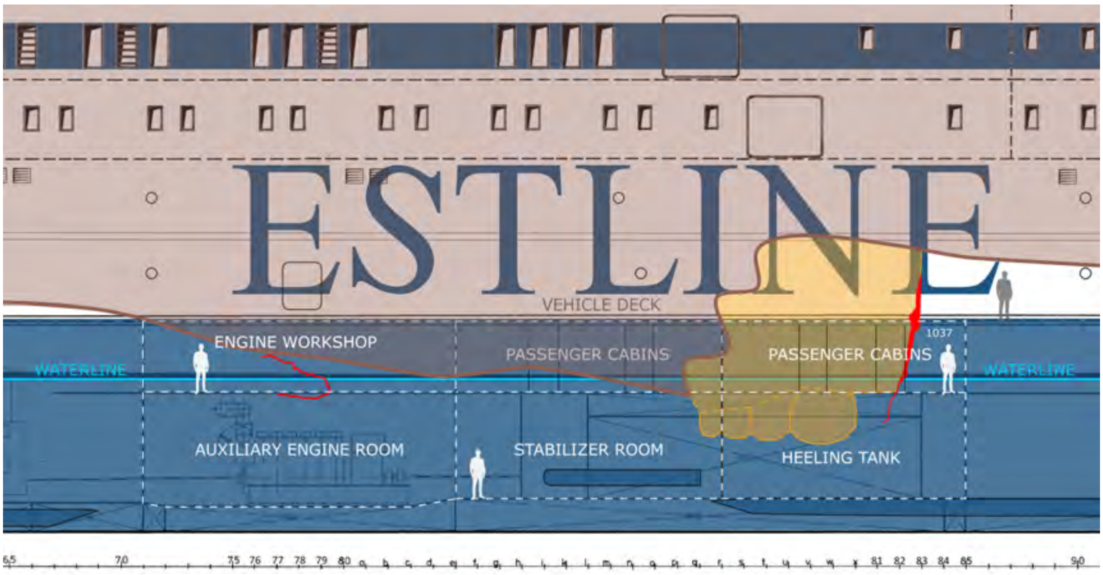

FIG. 3.39: Detailed view of the mudline and side damage. Light brown area on the vessel's general arrangement is in contact with seabed. Penetrating damage is marked by red and dents in yellow.

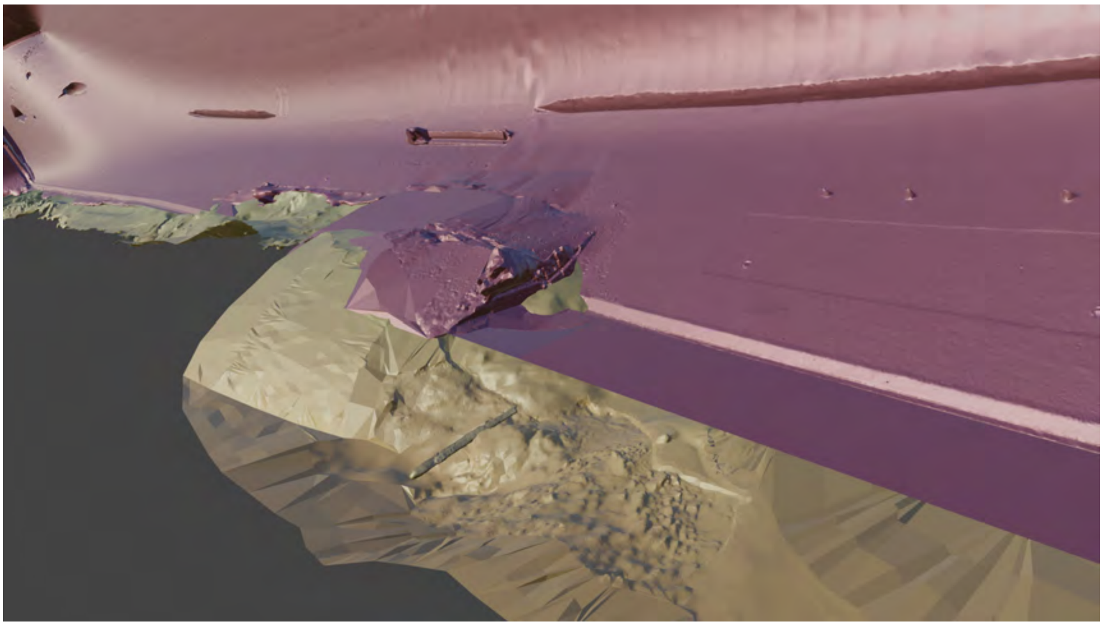

FIG. 3.40: Photogrammetric model of the wreck (purple) shifted and turned upwards to match the contact between the starboard side deformations and the bedrock formation (brownish). This alignment corresponds to the orientation slightly downhill from Sep-1997 orientation. The wreck is shown primarily as measured during the photogrammetry survey (O 2.20); as the photogrammetry did not image below the seabed layer, the parts of the wreck currently extending below the seabed are not shown. Also, the view is from inside the wreck, but it is showing the inverted view of the outer surface of the wreck not the actual inner structure.

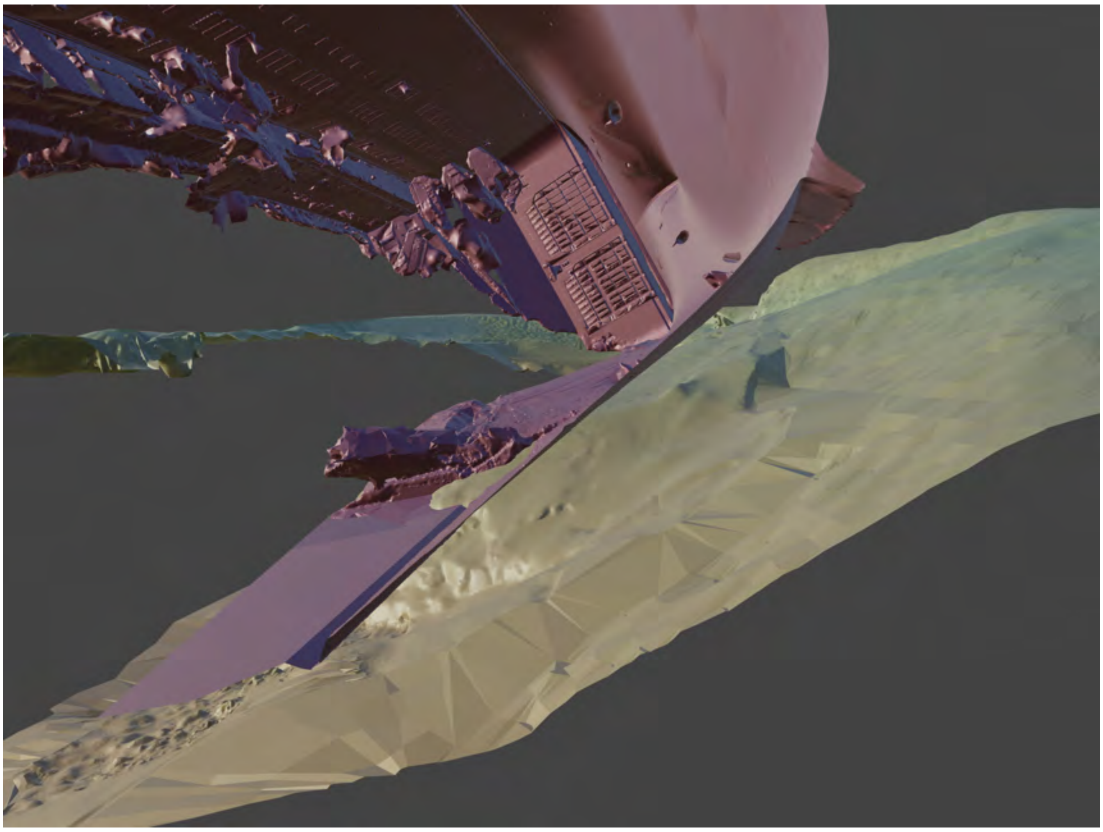

FIG. 3.41: Photogrammetric model of the wreck (purple) shifted and turned upwards to match the contact between the starboard side deformations and the bedrock formation (brownish). This alignment corresponds to the orientation slightly downhill from Sep-1997 orientation. The wreck is shown primarily as measured during the photogrammetry survey (O 2.20); as the photogrammetry did not image below the seabed layer, the parts of the wreck currently extending below the seabed are not shown. Also, the view is from inside the wreck, but it is showing the inverted view of the outer surface of the wreck not the actual inner structure.

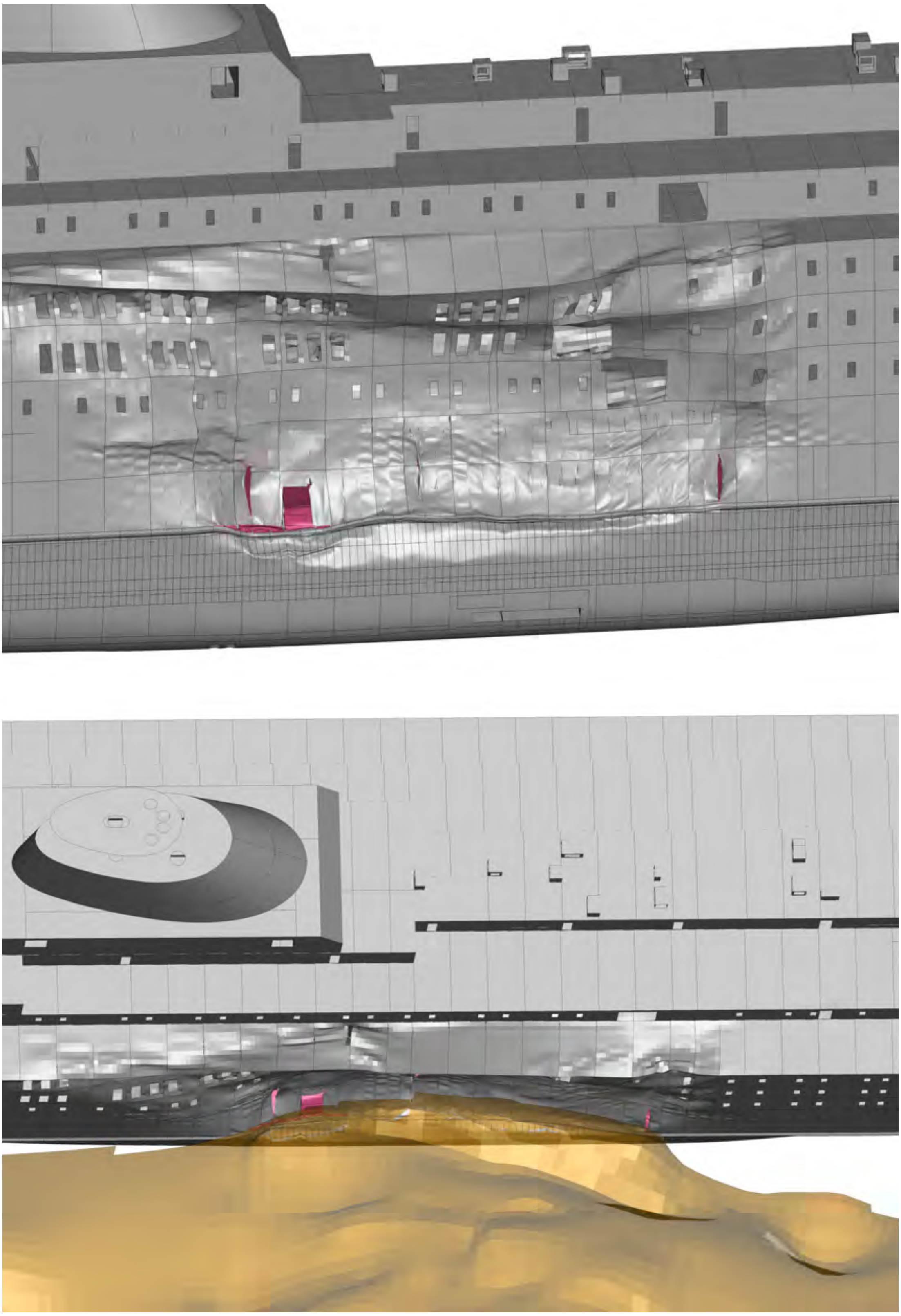

FIG. 3.42: Wreck deformations on theoretical FEM model after bottom contact with the bedrock. Damage stemming from direct impact with the bedrock under wreck's own weight is illustrated. However, the full descent was not simulated and the full extent of deformations were not included. 'Brown' is the bedrock; 'Pink' illustrates penetrating damage. Source: Tabri and Heinvee [49].

Detached Bow Ramp

Although the bow ramp was found to be heavily damaged after the accident, it remained attached to the wreck, as documented during both authorized and unauthorized surveys until the early 2000s. However, during the first underwater surveys of the Preliminary Assessment in Jul-2021 (first observed during O 2.16 and confirmed during O 2.13), it was discovered that the bow ramp was no longer attached to the wreck but instead rested on the seabed, supported by the wreck (Figure 3.43). The exact time of its detachment is unknown and cannot be determined.

The mechanics and causes of the bow ramp's detachment were influenced by its condition following the collapse of the bow structure. Therefore, a detailed analysis of the detachment process is provided in Section 4.1.5.

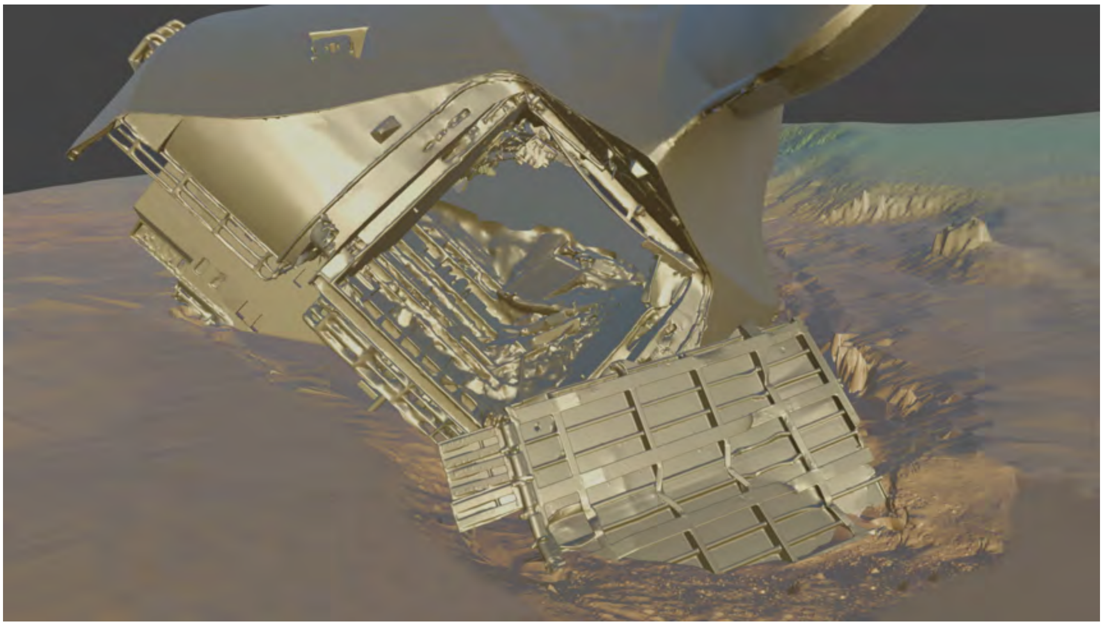

FIG. 3.43: Detached ramp on digital model

Flat-Bottom Buckling

A T-shaped uniform buckling deformation on the flat-bottom was discovered in the photogrammetric model of the wreck following the underwater survey conducted in Jun-2022 (Figure 3.44, O 2.20). Notably, this part of the wreck has never been in contact with the seabed. A numerical assessment conducted in Sep-2023 confirmed that such buckling originated from the collapse of internal structures due to hydrostatic pressure, caused by air remaining trapped within the sinking ship (which created an air pocket).[44]

During the sinking, hydrostatic pressure applied to the flat bottom from outside and to Deck 1 (tween deck) from the inside of the vessel. If air was entrapped between these two structural elements, Deck 1 collapsed under hydrostatic pressure already at an approximate water depth of 35 m. Consequently, the structural elements between Deck 1 and the flat bottom lost their load-carrying capacity, entrapped air could not rapidly escape the compartment and the buckling of the flat bottom followed shortly. The buckling shape of numerical assessment on the flat bottom corresponds very well with the deformation observed on the wreck, exhibiting straight and clear boundaries.

The collapse of the internal structure was also confirmed during the oil removal operation in 1996 (O 2.9), as concluded in the summarizing report: “The tanks above the double bottom had collapsed during the sinking, and some of their contents had drifted into the wreck. A clear indication of the collapse was that when pumped air into the tank, it came out from a hole on the side of the wreck.”[31, p. 7]

FIG. 3.44: Buckling of the flat bottom

Oil Leakage

Indications of an oil leak from the wreck were observed during on-site surveys in Jul-2021. The minor leak was located in the sea chest of the midship hull during on-site surveys conducted in Jun-2022 (Figure 3.45). The Finnish Border Guard (*Rajavartiolaitos / Gränsbevakningsväsendet*, RVL) conducted an aerial survey and subsequently took samples of the oil for analysis. The results of the analysis indicated that the samples mostly contained lubricating oil mixed with some fuel oil. Effective surface response activities cannot be conducted as the leakage is minimal. The RVL continues to monitor the leakage.

At least 20 % of the heavy fuel in the wreck could not be removed during the oil removal operation in 1996.[31]

As the sea chest is located in the oxic layer, which promotes corrosion, and the wreck's condition may deteriorate further over time, oil leakage could pose an environmental risk in the future.

FIG. 3.45: The blue circle shows where a drop of oil is bubbling to the surface. Photo from photogrammetry.

4 Pre-Foundering Analysis & Results

One objective of the Preliminary Assessment was to assess whether new information gives reason to revise the conclusions presented in the JAIC Final Report. Therefore, this chapter covers the period preceding the accident up to the vessel's contact with the seabed. At the same time, the Preliminary Assessment does not constitute a full-scale safety investigation; hence, the purpose of this chapter is not to replace the JAIC Final Report, but to complement existing information and to provide clearer explanations of investigative aspects that have previously been insufficiently addressed.

Although observations regarding the timing of some events have been made during the Preliminary Assessment, its objective has not been to establish a complete timeline of the accident, due to inherent uncertainties.

4.1 Vessel

The vessel condition on departure, departure, voyage, sea state, bow structure collapse, flooding and sinking of the vessel are analysed here. Loading and cargo securing subject is described in Section 5.1.2 and Section 5.1.3, respectively, as these mostly are based on witness interviews.

4.1.1 Sub-Conclusions

The following subsidiary conclusions are made on the question of the vessel's condition and behaviour during the time of the accident:

- Based on the information available to the shipping company and the crew at the time of the vessel's departure, it was justified to consider the vessel seaworthy. However, the post-accident analysis indicated that, due to shortcomings in the design, building, approval, and certification processes, MV ESTONIA was not seaworthy due to anomalies in her certification process, and should not have been operating the Tallinn–Stockholm route.
- It was typical for the vessel to depart with a delay; the actual departure time of MV ESTONIA of 19:15 on the evening of 27 September 1994 was not atypical.

- MV ESTONIA's speed did not deviate in any distinguishable manner from other vessels in her vicinity. MV ESTONIA's speed had been reduced below the average speed necessary to remain on time, i.e., the crew was not strictly following their schedule.
- Seabed debris confirms that the vessel was following the intended route and that she made a U-turn to port after the detachment of the visor.
- The visor locking system of MV ESTONIA failed due to the natural wave loads because the system did not have a structural safety margin for realistic wave conditions. The visor detached in the beginning of the accident and the ramp opened completely after the detachment of the visor.
- There are no signs of explosion or explosives in the bow area.
- The vessel's flooding and sinking behaviour due to the opening of the bow is numerically plausible and consistent with available evidence. Calculations indicate that a side damage occurring while the vessel was still afloat is extremely unlikely.

4.1.2 Condition on Departure

Seaworthiness is a central concept in shipping. Though there is no uniform international definition of seaworthiness, a number of requirements generally need to be fulfilled to entitle a vessel to be called safe. All necessary certificates have to be valid, and the vessel has to be designed, built, equipped, maintained, supplied, manned, loaded, and used in a trade for which she is approved. If any of these conditions is not fulfilled, the vessel is, per se, not seaworthy, and thus not allowed to sail.[67, App. B]

The possibility to continuously inspect and verify each aspect (e.g., design assumptions, building procedures, material quality, etc.) is limited due to practical reasons as there is no reasonable way to control those elements. It is therefore obvious that in some respects the control function at design and building stage is of the utmost importance. Whatever is approved and certified while the vessel was designed and built will in many cases not be subject to later regular control. Therefore, the initial inspection and approval, manifested in initial certificates, may in some aspects follow the vessel through her service history without being questioned.[67, App. B]

This leads to the conclusion that the responsibility of shipowners (including a master as the on-board representative of the owner), builders, authorities, and classification societies for seaworthiness after the vessel is built may be limited to circumstances that they can control, i.e., certification, equipment, maintenance, supplying, manning, loading, and trading area—this is described and analysed below as the 'Operational View'. The whole concept of seaworthiness, including design and building processes, is covered below as the 'Retrospective View'.

Operational View

The operational view is based on the information that is at hand for every single voyage before departure.

Based on the JAIC Final Report, required valid certificates were issued for MV ESTONIA [3, Sec. 3.6.3, p. 45], the maintenance standard of the vessel was good as witnessed in various instances [3, Sec. 5.2, p. 55], the vessel was properly manned [3, Sec. 5.2, p. 55], and had a loading condition that was normal for the route [3, Sec. 5.3, p. 55]. Considering the above, JAIC concluded that there were "no outstanding items" either from authorities or the classification society and the vessel was seaworthy.[3, Sec. 5.2, p. 55]. This is interpreted as an operational assessment of seaworthiness.

Several following aspects from the operational view of the seaworthiness have been reviewed during the Preliminary Assessment. Considering those, there is no solid ground for claiming that MV ESTONIA was unseaworthy from the operational point of view, confirming the JAIC's conclusion from this perspective. These items discussed in detail in separate documents are summarised as follows:

- The pin of the ramp's port side lower locking device was found not fully extended after the accident, but the corresponding mating box on the ramp was twisted.[1] It cannot be ruled out that it partly retracted during the collapse of the bow structure. However, this uncertainty did not have an effect on the course of events.[70, Sec. 3.1]
- Based on 1994 underwater video recordings, the position sensors of the visor bottom lock pin were missing from the mounting bracket. It cannot be ruled out that the sensors were lost during the collapse of the bow structure, e.g., washed away by the waves. However, the bottom lock was confirmed to be closed during the accident and there were no indicator lamps for the bottom lock on the navigation bridge.[70, Sec. 3.7]
- The visor rubber sealing was worn and had some tear marks, but new seals had been ordered (seals were replaced almost yearly through the vessel's service history). Textile material, seen near the ramp hinge from the underwater video recordings in 1994, has been explained naturally.[70, Sec. 3.3]
- It was known that the play in the ramp hinges was approaching the point where corrective action would be needed.[3, Sec. 3.3.6, p. 42] However, this

[1] The JAIC Final Report states that "...the lower port box, however, was not damaged...".[3, p. 192] Actually, this part of the ramp is deformed; this was confirmed in visual observations when the ramp was recovered.

did not have an effect on the course of events.

- After the accident, a temporary maintenance worker reported that some cracks in the fillet welds between the hinge arm side plates and the hinge bushings were observed.[3, Sec. 8.12, p. 133]
- Based on 2023 underwater video recordings (O 2.21), some of the portholes on the car deck were not clamped by deadlights. However, this is not considered to have had any impact on the cause or the outcome of the accident.[70, Sec. 2.1]
- Based on 2023 underwater video recordings (O 2.21), the port side hatch of the bow-thruster room was open. It cannot be ruled out that it opened after the accident.[70, Sec. 2.2]
- On the afternoon of 27 September 1994, before the last departure of MV ESTONIA, the vessel was used for a PSC training session, performed by Swedish and Estonian participants. The reason for the inspectors to be onboard MV ESTONIA was only for training. No reported deficiency gave cause for detention or to stop the departure of the vessel and no such attempt was made. The vessel, while carrying the name "ESTONIA", was exposed to real PSC by the Swedish inspectorate five times in Stockholm, where the Swedish authority had the mandate to perform such controls. Those controls were passed without outstanding findings (on average, no detentions and one deficiency per control). Even though a PSC can be rather thorough, checking drawings, welds, and structural strength is not included in the procedure. It is hence concluded that a PSC cannot be expected to identify the deficiencies which initiated MV ESTONIA's bow visor's collapse. So, from the perspective of the PSC the vessel had been considered seaworthy.[69]

Retrospective View

After the accident, the whole scope of seaworthiness, including design, building, approval, and certification aspects, were thoroughly investigated. JAIC discovered a number of flaws in these processes which were included in the JAIC Final Report. However, JAIC did not make any conclusion about the seaworthiness of the vessel based on those findings.

Although the vessel had valid certificates without restricting trade between Tallinn and Stockholm, she should never be allowed to operate on that route in that constructional configuration. Therefore, the Preliminary Assessment concluded in its intermediate report, based on the information presented in the JAIC Final Report, that the vessel was retrospectively unseaworthy.[67]

The main findings from previous and present analyses about the design, construction, approval, and certification process have been:

- Lacking international regulations and division of responsibility between flag state administration and classification society led to the calculations, design, and implemented result of the locking devices not being entirely inspected for approval[2] either by flag state administration or classification society before issuing the certificates.[67, App. B] That a certificate was issued was in violation of the SOLAS legislation caused MV ESTONIA to not be seaworthy.
- The requirements of the SOLAS Convention for an upper extension of the collision bulkhead were not satisfied onboard MV ESTONIA (Figure 4.1). These requirements meant that either:
  - the bow ramp should have been placed approx. 4.5 m sternwards;
  - additional bulkhead door(s) should have been installed in the same place, i.e., 4.5 m, behind the bow ramp[3]; or
  - the exemption[4] from the SOLAS Convention should have been included in her certificates[5], which would have restricted her trading area to 20 nm from the nearest land, excluding the Tallinn–Stockholm route. That the restriction was not noted in her certification was a violation of the SOLAS legislation, and another reason for MV ESTONIA to not be seaworthy.
- MV ESTONIA never had a fully weathertight front bulkhead with ability to resist water ingress due to the openings arranged for the locking and manoeuvring devices of the bow ramp and visor. This arrangement was not in compliance with the regulations then in force, nor with the vessel's design drawings.[70, Sec. 1.2]

[2] See SOLAS 74, Chapter I, Part B, Regulation 7 (b) (i).
[3] See SOLAS 74, Chapter II-1, Part B, Regulation 9.
[4] See SOLAS 74, Chapter II-1, Part A, Regulation 1 (c).
[5] See SOLAS 74, Chapter I, Part B, Regulation 12 (a) (vi).

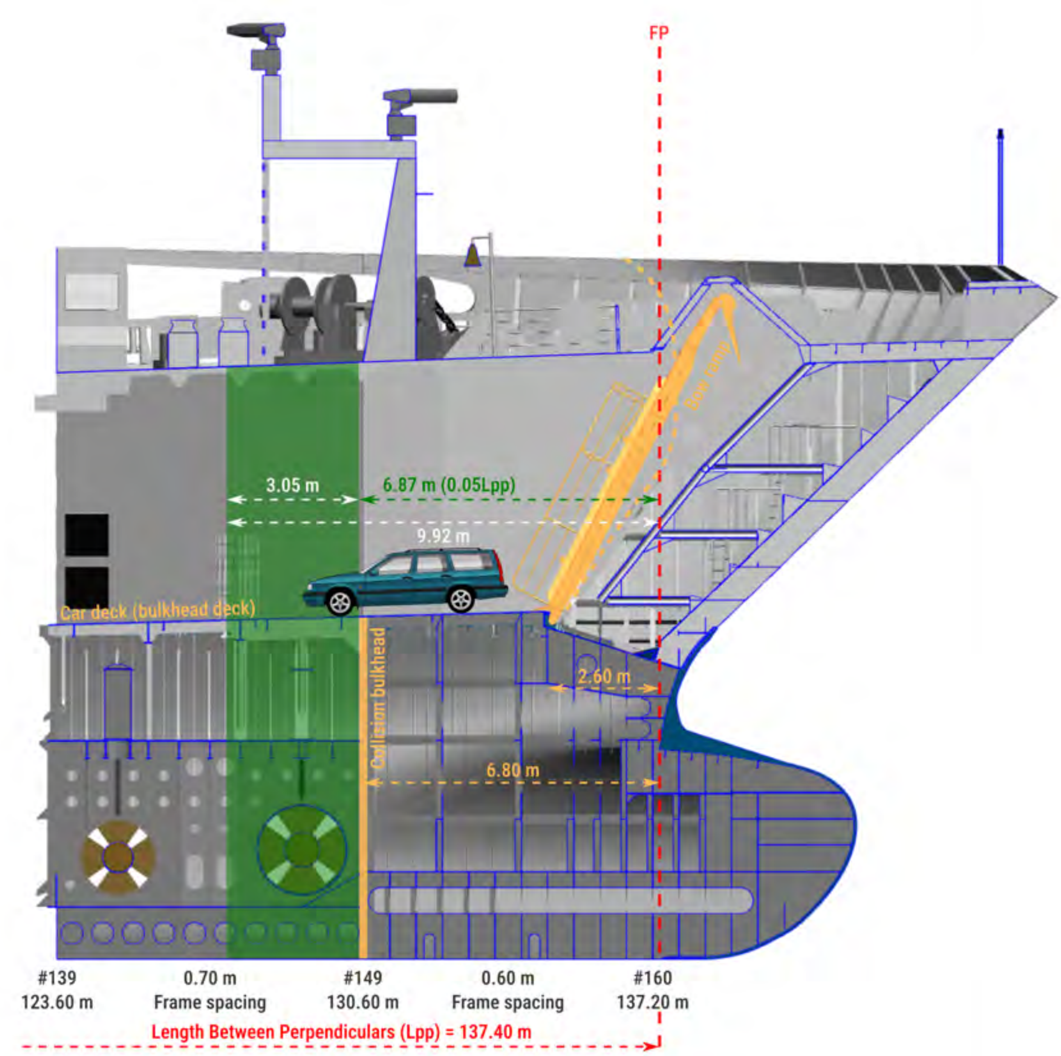

FIG. 4.1: Longitudinal sectional cut of the bow structure of MV ESTONIA. The actual arrangement of the collision bulkhead and its upper extension (bow ramp) above the bulkhead deck (car deck) in 'Yellow'. The required zone for the placement of the forward bulkhead and its extension in compliance with SOLAS 1960 and SOLAS 1974 regulations in 'Green'. This zone depends on the vessel's length between the perpendiculars ('Lpp') and is measured from the forward perpendicular ('FP').

4.1.3 Departure & Voyage

Departure Time

According to the timetable, the departure time of MV ESTONIA from Tallinn was 19:00. The Estonian National Archives preserve the logbooks of Vanasadam, the passenger harbour in Tallinn, recording vessel arrivals and departures.[78] The registered departure times of MV ESTONIA for Sep-1994 are presented as Table 4.1.

The registered data indicate that arrivals and departures were recorded with a five-minute precision. The entries were made alternately by two different individuals. The table shows that every other departure appears to have occurred on time. Therefore, it is likely that one individual registered the scheduled departure time while the other recorded the actual time. Based on the presumed real departure time, all departures occurred with a delay; the departure on 3 September 1994 was delayed by as much as 55 min.

Interviews with crew members and truck drivers allow to conclude that it was relatively typical for the vessel to depart with a short delay to wait for a late-arriving client. This practice has been explained by the development of a customer-centric approach to enhance the reputation of the shipping company after the Soviet period. Thus, the actual departure time of MV ESTONIA on the evening of 27 September 1994 at 19:15 was not out of the usual. There is no evidence to connect the delayed departure with military transport.

TABLE 4.1: Registered departure times of MV ESTONIA in Sep-1994 according to the logbook of Vanasadam, Tallinn.[78]. The entries seem to fall into two categories, one always highlighting the scheduled departure time and the other the real departure time.

Departure Date	Departure Time	
1.09.1994	19:00	
3.09.1994		19:55
5.09.1994	19:00	
7.09.1994		19:15
9.09.1994	19:00	
11.09.1994		19:10
13.09.1994	19:00	
15.09.1994		19:10
17.09.1994	19:00	
19.09.1994		19:20
21.09.1994	19:00	
23.09.1994		19:15
25.09.1994	19:00	
27.09.1994		19:15

Route

MV ESTONIA had two possible routes for the voyage from Tallinn to Stockholm (Figure 4.2): a southern one, entering the Stockholm Archipelago at the Sandhamn pilot station (in total 225 nm), and a northern one, entering at the Söderarm pilot station (228 nm). Normally, the route through Sandhamn passage was used. The Söderarm passage was used when weather conditions were considered unfavourable.

On the night of the accident, the route through Söderarm passage was used due to the prevailing weather conditions and the off-duty captain (from relief crew) was scheduled to take a pilot exemption certificate examination for the Söderarm passage the following morning.

The more southerly route (Figure 4.2) closer to the Estonian mainland and islands provided more shelter with south-westerly winds compared to the routes followed by the vessels departed from Helsinki, Finland–this enabled MV ESTONIA to proceed with higher speed in the first phase of the voyage.

Speed

A common misbelief is that the cause of MV ESTONIA's accident was the vessel's excessive speed, which has been believed to be significantly higher than the speed of other vessels operating in the same area. The wave load on the bow structure depends, among other factors, on the vessel's speed, but the speed of MV ESTONIA did not deviate in any clear way from other vessels in her vicinity (Table 4.2).

The practical maximum operating speed of the vessel in her later years was considered to be 19 kn.[3, Sec. 3.7.2, p. 47] Considering the vessel's delay of 15 min in departing Tallinn, an average speed of 17.5 kn in unrestricted waters was required to reach the Söderarm pilot station on time. From the position where the bow visor was lost, an average speed of 16.6 kn would have been required to reach the Söderarm pilot station on time.

The vessel's actual speed prior to the accident is estimated to have been approx. 14.5 kn, which is lower than any of the above-mentioned speed values.

Vessel navigators were able to use higher speeds than the average needed to remain on time in the first third of the voyage due to the more sheltered waters. When reaching adverse seas, the speed (was) reduced considerably—below the average speed required to remain on time, indicating that the crew was not strictly following their schedule. It is not possible to determine how much of the speed reduction was caused by the natural resistance of the sea state and how much of a action of the bridge crew.

FIG. 4.2: Routes operated by MV ESTONIA throughout her service history

Track

MV ESTONIA was not equipped with a Voyage Data Recorder (VDR), which were made mandatory for such vessels from 1 July 2002. Also, the carrying of an Auto-

TABLE 4.2: Comparison of speeds for vessels which were involved in the search & rescue operation after MV ESTONIA's sinking.[3, Sec. 7.5.3, Sec. 13.2.4, Sec. 13.2.5]

VESSEL	DESTINATION	SPEED	COMMENT
MV ESTONIA	Stockholm	14.5 kn	More sheltered route.
MV MARIELLA	Stockholm	12 kn	More open route. Reduced to 12 kn at 23:00.
MV SILJA EUROPA	Stockholm	14.5 kn	More open route. Kept speed until 00:55.
MV SILJA SYMPHONY	Helsinki	21 kn	From Stockholm.
GTS FINNJET	Germany	16 kn	Headed to site at 15 kn.
MV FINNMER-CHANT	Germany	15 kn	Headed to site at 15 kn.
MV FINNHANSA	Germany	15 kn	Reduced from 18 kn. Headed to site at 10 kn to 12 kn.

matic Identification System (AIS) transponder had not yet been introduced and implemented (mandatory from 1 July 2003 for such vessels). No data was retrieved from the navigation device recovered by divers in Dec-1994 (O 2.6). Thus, no recorded data exist regarding the actual track of MV ESTONIA on the night of the accident. Therefore, the seabed locations of objects interpreted to originate from the vessel have been used to reconstruct the vessel's actual track during the accident.

A sediment depression, associated with the detached bow visor, has remained on seabed since 1994 when the visor was recovered. The cross-track distance of the visor's interpreted location is approx. 0.5 nm to port of the route leg between the waypoint at 59°20′ N, 022°00′ E and the Söderarm pilot station (a course of 288°). This confirms that the vessel was following the intended route.

The foldable part of the ramp's starboard railing was found 485 m west of the visor location. This object is the (currently known) most westward object found on the seabed which undoubtedly originates from MV ESTONIA.

The wreck itself is located approx. 1600 m east of the visor location, meaning that the vessel had to make a U-turn and travel backward after losing the visor and ramp elements. Considering the south-westerly seas and wind conditions and a large debris field south-west of the wreck, it is evident that the U-turn was made to port. The distance that the vessel travelled after the detachment of the visor and its turning radius have been matters of interpretation during the 1990s and 2000s.

The interpretation of the 2023 seabed imaging survey (O 2.22) listed approx. 300 seabed objects as anthropogenic.[46] The follow-up video inspection (O 2.23) identified that several targets previously interpreted as anthropogenic were, in reality, natural, but also that many smaller man-made objects had not been interpreted.[48] Overall, however, the total collection of the targets was used by the

Preliminary Assessment to create a density cloud (Figure 4.3).[6] Such a method of visualisation reduces the possibility of over-interpreting information from any one individual target.

The target density evidenced in the vicinity of the wreck and to its west is not considered natural for the area. Even though some debris may occur on any part of the seabed, the specific density of targets that is evidenced here is associated with the sinking. The periphery of the survey area and the easternmost areas surveyed confirm this as the density of interpreted anthropogenic targets is minimal there. Altogether, the target cloud confirmed prior assumptions about the direction of the U-turn and the distance to which the vessel travelled westwards.

At least 35 elongated cigar-shape objects were recognised from the MAS mosaic; five of these were visually inspected and confirmed to be logs. The distribution of those elongated objects aligns well with the curvature of the vessel's track as proposed by the Hamburgische Schiffbau-Versuchsanstalt GmbH (HSVA) Consortium in 2008.[1] The only visible difference is that the curve of the elongated objects extends roughly 300 m further to the west compared to the track of HSVA.

Even though it is not possible to confidently confirm that these elongated objects originate from MV ESTONIA, it is very unlikely that logs originating from another vessel would end up on the seabed throughout the wreck site of MV ESTONIA in such numbers, with their associated distribution pattern closely matching the extent and curvature of the assumed track of MV ESTONIA (created by independent means). Further, it is known that MV ESTONIA carried cargo which included wood and wooden material.[48] However, the exact mechanism and course of events for the logs to have ended up on the seabed in this pattern is somewhat challenging to reconstruct.

The track reconstructed based on the location of the visor, elongated objects, and the wreck was assessed in numerical sinking simulations completed in 2025 (Figure 4.4).[2] It confirmed that such a track was possible with regards to the timeframe and that it was consistent with expected (modelled) vessel behaviour. Therefore, this is considered the most probable sinking track of MV ESTONIA, based on available information.

[6] For clarity, the targets which were identified as natural, i.e., boulders, by the visual inspection (O 2.23) were excluded from the density cloud, presented as Figure 4.3; additional targets were added based on the results of the visual inspection and a check of the MAS seabed representation.[48]

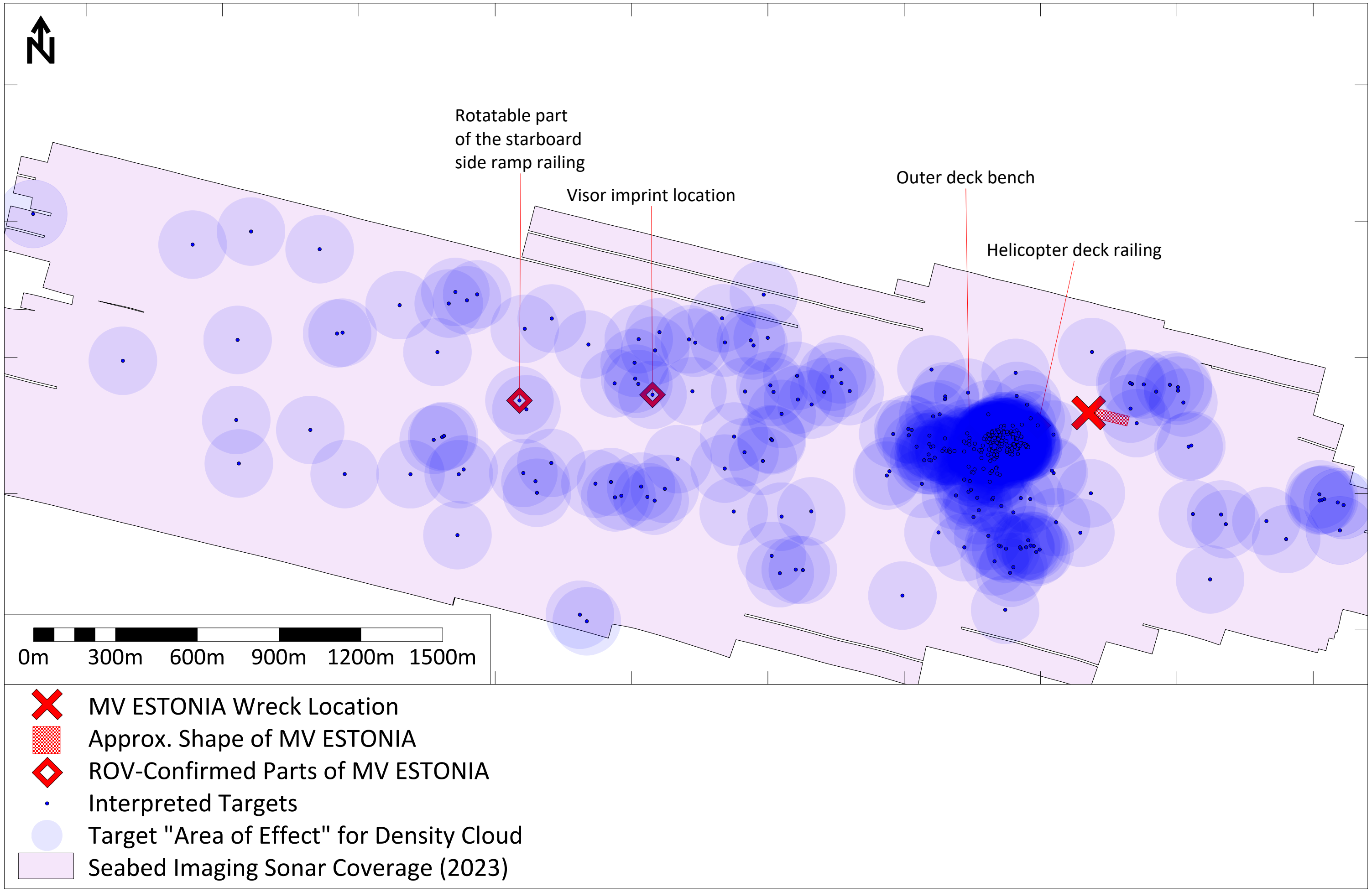

FIG. 4.3: Target density cloud of the debris in the accident area. Almost 300 interpreted anthropogenic objects have formed a basis for reconstructing the vessel's track during the flooding and sinking.

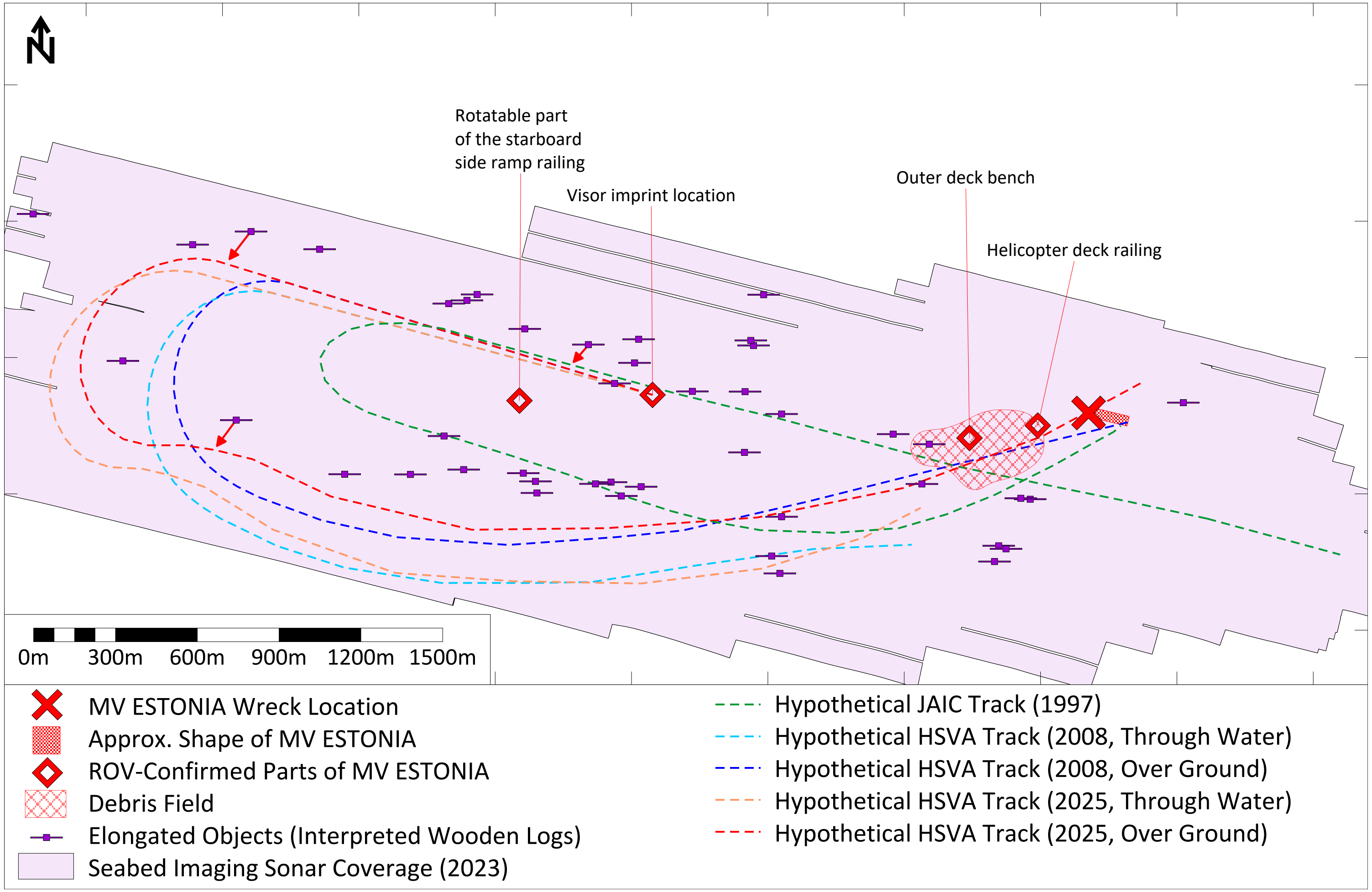

FIG. 4.4: Proposed tracks during the flooding and sinking of MV ESTONIA by JAIC, Valanto, and Kim et al.[1], [2], [3] The main reference points of the vessel's track reconstructions are shown.

4.1.4 Sea State

Both the loads acting on the vessel's bow structure and the water ingress rate through the vessel's openings depend on the sea state. In reality, consecutive waves are never identical—some are lower, others higher. Therefore, the concept of a wave spectrum is used to describe the characteristics of irregular wave patterns. The most widely recognized and commonly used mathematical model is the Joint North Sea Wave Project (JONSWAP) spectrum. The size of sea waves is characterized by the significant wave height (h_s), defined as the mean wave height of the highest one-third of all observed waves. Statistically, the maximum individual wave height can be roughly twice the significant wave height. The higher a single wave is compared to the significant wave height, the lower its probability of occurrence within a given time period.

At the time of the accident, there were no wave measuring buoys near the accident site, and, therefore, there is no recorded data on actual wave heights in the area. The determination of the sea state during the accident has been based on numerical modelling and eyewitness observations. According to these, JAIC concluded that significant wave height in the area immediately before the accident was approx. 4 m.[3, Sec. 13.1, p. 171] Toward the morning, weather conditions deteriorated further.

It is important to note that the weather at the time of the accident was not extreme—a typical autumn gale, but not a "storm of the century" nor anything comparable. JAIC concluded that similar wind and wave conditions had only previously occurred once or twice when MV ESTONIA operated on the Tallinn–Stockholm route.[3, Sec. 13.1, p. 171] Therefore, the failure of the bow structure was not caused by exceptional weather conditions, but by an exceptionally weak bow construction. It is noteworthy that the port bow door of passenger ferry MV SILJA EUROPA was also damaged during the rescue operation of MV ESTONIA.[3, p. 148]

In addition to the uncertainty regarding the specific wave train[7] that the vessel met, it is also not possible to determine how each individual wave hit the vessel. Even if recorded wave heights from the accident location were available, it would not be possible to determine the exact forces that the vessel experienced due to steaming through it. Because of this, it must be acknowledged that the exact waves that the vessel encountered during the final hour after changing its course are unknown. However, there may have been individual waves that were considerably higher than the assessed significant wave height of 4 m.

[7] A sequence or group of waves travelling together.

4.1.5 Bow Structure Collapse

Visor Detachment

Doubts have been raised whether the visor detached and when this took place during the sinking. However, based on both earlier findings and additional evidence collected during the Preliminary Assessment, it is evident that the visor detached at an early stage of the unfolding accident. The main supporting evidence is as follows:

- At least 2 survivors have confirmed that they saw the vessel without the visor during the initial phase of the accident. At least 14 survivors have confirmed the same for the final phase of the accident. Several survivors have reported seeing a straight end of the vessel, interpreted as the stern, but have later acknowledged that this could have been the bow without the visor attached (Section 5.2.7).
- The ruptures in the forecastle deck and forward bulkhead, as well as the bending of the piston rod of the visor's starboard hydraulic actuator, have occurred in a forward direction—indicating that these deformations took place while the vessel was still upright.
- The deformations observed on the front of the visor (including a large dent) indicate that the visor fell straight down due to gravity and collided with the vessel's bulbous bow while the vessel was still upright (Figure 4.5). That was probably the collision which has been described by several survivors as either an impact, a sound, or both (Section 5.2.2). Although, according to Zachrisson, the visor could float under certain conditions, its orientation (also as-found in the seabed) upon collision with the bulbous bow makes it unrealistic after the collision due to lacking air pockets.[55]
- The visor was found approximately 1600 m from the wreck.[51] This means that it could not have detached during the final phase of the accident, when the vessel was drifting slowly. The depression of the visor in the seabed was still extant during the surveys of the Preliminary Assessment [39], [51]; no similar marks have been found elsewhere on the seabed.[51]

Ramp Opening

No survivor has reported seeing the ramp in a fully open position. Crew members who were in the engine control room in the beginning of the accident observed from Closed Circuit TV (CCTV) water flooding the car deck from the sides of the ramp; based on their statements it has been questioned whether the ramp opened completely during the course of the accident.

However, physical evidence confirms that the ramp was fully open at least for some time. Specifically, the underside of the ramp has become deformed as a result of impact with the forepeak deck and the bulbous bow (Figure 4.5). In addition, the ramp's two railings became detached from the ramp and were found on the seabed some distance away from the wreck—damage that could only have occurred if the ramp had been fully open.

There are no signs of anthropogenic marks (e.g., cut marks) on the remaining parts of the ramp. The nearly closed position of the ramp observed by survivors and later confirmed on the wreck was the result of the ramp closing again due to gravity once the vessel's heel angle exceeded 90° (Section 5.2.7). The ramp likely broke off from the wreck after prolonged exposure to corrosion over decades on the seabed.[59]

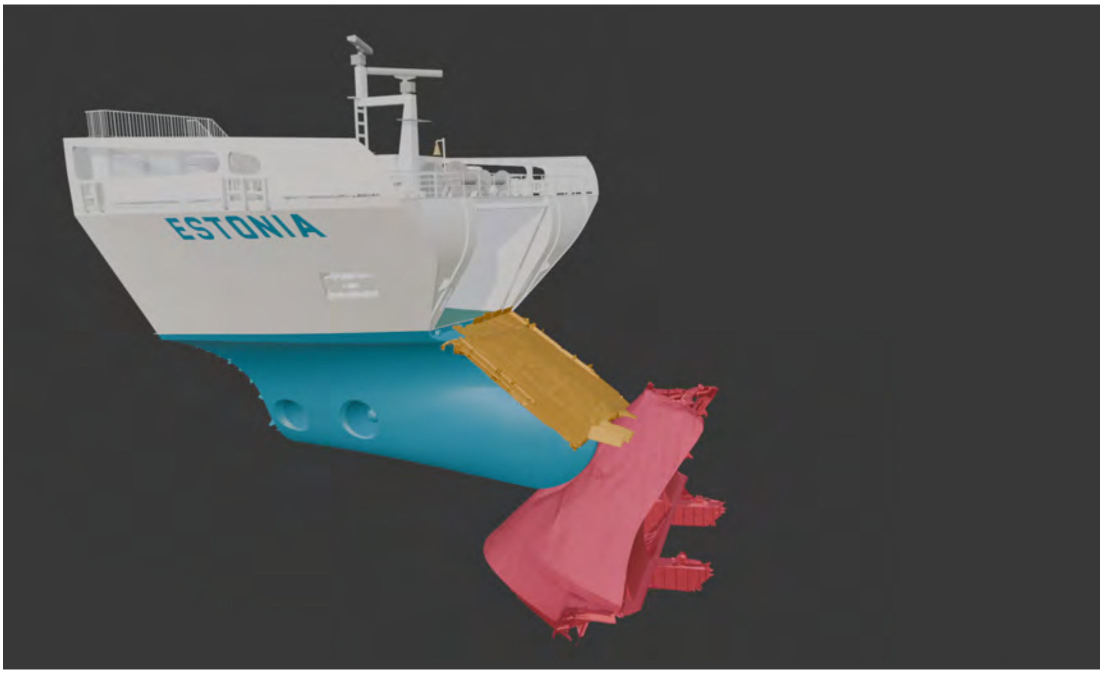

FIG. 4.5: Physical damage of the bow visor and the ramp confirming the full opening of the vessel's bow entrance at the beginning of the accident. The large dent in the front side of the visor (red) is aligned with the bulbous bow and the ramp's (yellow) underside deformations are aligned with the forepeak deck. Visor actuators are not shown.

Structural Strength

The 2025 numerical assessment confirmed that wave loads in a realistic configuration alone could have initiated the collapse of the bow structure of MV ESTONIA.[59] This matches the outcome of the studies conducted by JAIC.[3, p. 194] In addition to theoretical studies, the incident involving the passenger ferry MV DIANA II, which had an identical bow design and which suffered damage in Jan-1993, confirmed the constructional weakness in practice.[3, Sec. 11.3, p. 149]

According to the operating manual, the visor could also be locked by the manual locks "as a reserve"—as substitutes for the hydraulic side locks, if needed. No detailed instructions for the use of these manual locks were given by the manufacturer, the shipyard, or the shipowner. The manual locks were not engaged on the vessel's final voyage and, according to known practice, had not been previously used. The inclusion of manual locks in the numerical assessment was found to increase the wave load required to cause visor lock failure by 19 % to 23 %, depending on the grade of the material.[59] However, even with manual locks engaged, the visor could have failed in realistic wave conditions.

Therefore, the visor locking system did not have a structural safety margin for realistic wave conditions. The JAIC Final Report states that the classification society Germanischer Lloyd had already in 1978 (MV ESTONIA was delivered in 1980) a specific formula for the design load of a bow visor—which would have required approx. three times the load used for MV ESTONIA—and that the requirements of International Association of Classification Societies (IACS) 1982 rules specified equivalent design loads per locking device—approx. twice as high as those used in the design of MV ESTONIA.[3, Sec. 15.1.1, p. 187] In 2007, Carlsson noted that in accordance with IACS rules the bow visor, as it was on MV ESTONIA, would have required 20 locking devices of same strength to the three installed locking devices.[53, p. 4]

As the crew was unaware of the structural vulnerability of the bow structure and, probably also of previous similar incidents on other vessels, they could not have been expected to have lowered the vessel's speed below one which could be considered natural and to have engaged the manual locks as a precautionary measure.

Although some fatigue damage may have developed in the bow structure in her different trade areas during the years, its maintenance quality was not the primary reason of its collapse. As described, the bow structure was too weak even under ideal, design condition—the bow structure could have failed immediately after the vessel's delivery in unfavourable circumstances. The low quality of the welding works during the construction may have further reduced the load carrying capacity of the bow structure.[3, p. 166 & p. 189][57, p. 11]

Origin of the Damage

Previously unexplained deformations can be explained by the natural collapse process using the results of the numerical assessment. No contact with an external object is required to initiate the collapse; there are no obvious signs of such contact.

All samples obtained from the wreck and all analyses performed on these samples have confirmed the absence of any signs of an explosion or of explosive materials in the bow section. These include:

- thin layer chromatography (TLC), liquid chromatography (LC), and spot tests analysis of the visor's paint samples by the Finnish Police in the 1990s [3, Sec. 8.12, p. 133];
- Steel samples from the forward bulkhead near the ruptured opening created by the hydraulic actuator [54];
- Steel samples from the bottom of the visor [56], [57];
- Visual examination of the ramp and associated videos [17].

4.1.6 Flooding & Sinking

Flooding through the Bow Opening

The vessel's sinking has been considered in some accounts as extremely rapid (raising the question of how such a large vessel could sink in such a short time-frame), while others have argued that the vessel should have capsized even faster upon the opening of the bow. However, all numerical analyses have concluded that sinking due to the bow opening is consistent with the available information and is entirely plausible.[1], [2], [60], [62] This scenario also represents the most likely sequence of flooding and eventual sinking.

After the bow visor had detached and the ramp opened, a large volume of water rapidly flooded the car deck due to the heavy seas from the port forward quarter. The car deck is a vast, large space extending from one side to the other and from the bow to the stern. There are no barriers to the longitudinal movement of water, while transverse movement is partially delayed by the centre casing[8].

Initially, water spread on both sides of the centre casing and sloshed back and forth between the centre casing and the vessel's sides as the vessel was rolling (Figure 4.6). Water could also have entered the centre casing through lightweight sliding doors, which were neither watertight nor weathertight. These doors had been designed and constructed solely to meet fire protection requirements, hence their designation as fire doors (Figure 4.7). Already by that stage, some water was penetrating through these doors. At least 5 survivors, who began evacuating from below the car deck (Deck 1), observed water running through the gaps around these doors; several other survivors in various sections of Deck 1 also recalled encountering smaller amounts of water on the deck (Section 5.2.3).

At a certain point, enough water had accumulated on the car deck that it no longer shifted from side to side with the vessel's rolling motion. Instead, it gathered on the starboard side, and the vessel was unable to recover from the resulting heel. This phenomenon is known as the free-surface effect — the greater the mass of the

[8] A narrow longitudinal section in the middle of the car deck which contains the stairways, lifts, and various smaller service rooms.

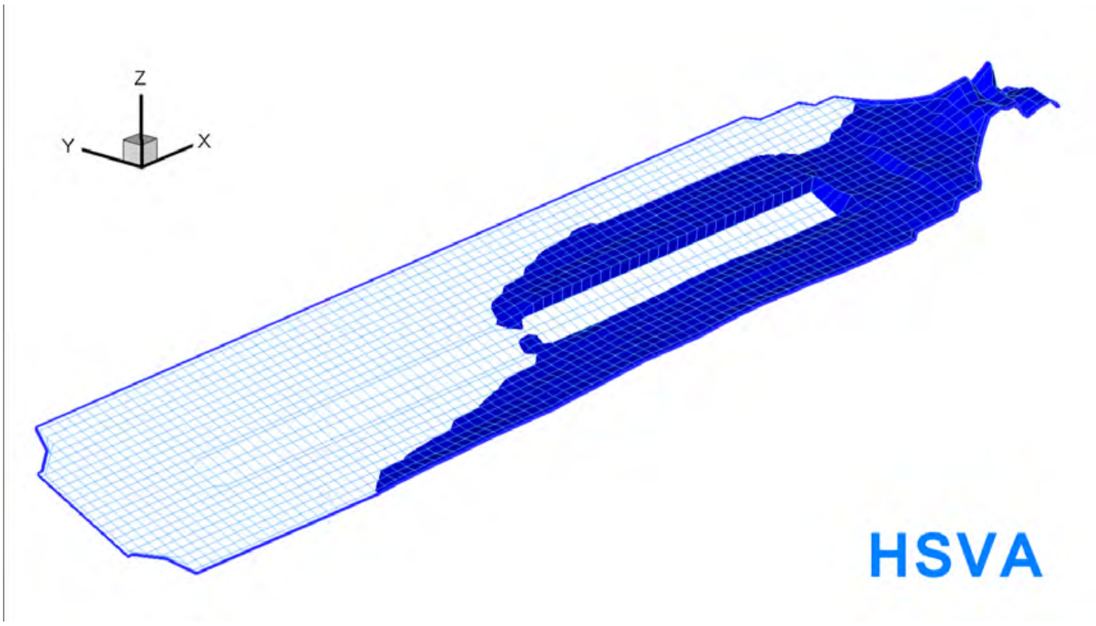

FIG. 4.6: Visualization of the numerical flooding process in the HSVA-Rolls program, illustrating the flooding of the car deck from ahead seas: sloshing water is divided by the centre casing (visible walls not included). Accumulation of water to the port side of the centre casing creates water pressure to non-watertight sliding doors (fire doors). Source: Kim et al. [2].

FIG. 4.7: Sliding fire door on the car deck of MV MARE BALTICUM, the near-sistership of MV ESTONIA. Source: Börje Stenström, 1995-11-07, SHK Archives, F 1 HB. 23A B15.6.

moving water and the farther it can shift transversely from the vessel's centre of gravity, the larger the resulting heel becomes. On a car deck spanning the full width of the vessel, this effect is particularly pronounced. For most survivors, the sudden heeling of the vessel was one of the main triggers for their evacuation. Such an abrupt development of heel is characteristic of the rapid shifting of a large mass, as described above.

It is likely that after the initial heel developed, the navigators turned the vessel to port through the ahead sea. This may have been an instinctive manoeuvre and an attempt to turn the side that was heeling into the wind. The vessel's turn to port, however, partly contributed to the development of a starboard heel. After the turn, the rate of water ingress through the bow decreased, as the bow opening faced downwind which prevented the rapid capsize of the vessel compared to continuing on the same course. This created an interim stage in the development of the vessel's heel, which allowed several hundred people to reach the weather deck from inside the vessel. Once the turn was executed, ventilation openings located under Deck 4 were submerged, allowing water to enter the compartments below the car deck, including the engine compartments, while also allowing air to escape from these compartments to the opposite side (Figure 4.8). It cannot be ruled out that the ventilation shafts were already damaged by the shifting cargo.

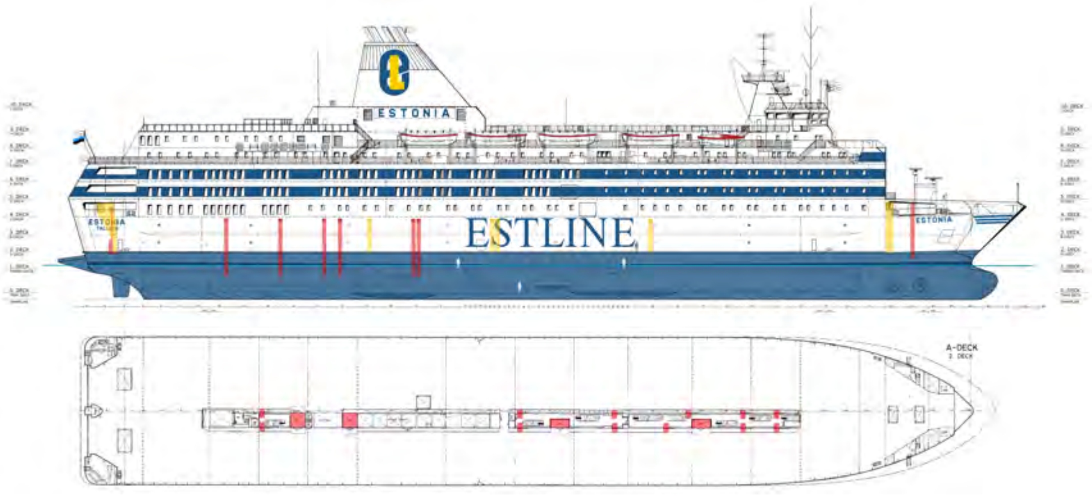

FIG. 4.8: Lowest ventilation openings on the starboard side of the vessel opening to outer shell. 'Red' indicates ventilation channels running below the car deck and 'Yellow' to the car deck. Ventilation channels on other side of the vessel and openings only inside are not shown. Non-weathertight sliding fire doors and elevator doors on the first level of car deck in 'Red'. Other doors and hatches on the car deck are not highlighted.

As the heel increased, windows and doors on the accommodation decks were submerged. These did not fail immediately upon contact with water, but provided the vessel with some residual buoyancy, preventing an abrupt capsize. Around the same time, the sliding doors of the car deck's centre casing were submerged, permitting increasing amounts of water to enter below the car deck. The watertight doors between compartments under the car deck had no significant effect on the course of the sinking, as water entered primarily from above. These compartments restrict horizontal movement of water longitudinally but are not watertight from the above.

At a certain point, the windows of the accommodation decks also imploded, allowing water to enter those compartments, and the vessel's heel exceeded 90°. Since there was still some air in the compartments under the car deck, the vessel eventually turned so that the underwater hull was exposed over the sea surface. Because the heel increased smoothly rather than rapidly, no sufficient air pockets remained in the compartments beneath the car deck to keep the vessel afloat.

Due to the vessel's initial trim to stern and inertia from the movement of the vessel causing water to accumulate stern-wards, flooding from additional openings (e.g., ventilation, windows, and doors) also began from stern-wards. At a certain point, the stern became completely submerged while the bow rose out of the water, after which the vessel sank.

It is not possible to say with confidence how high the bow rose out of the water before starting to sink underwater. It is also not possible to say whether the vessel's contact with the seabed started before or after the bow became completely submerged.

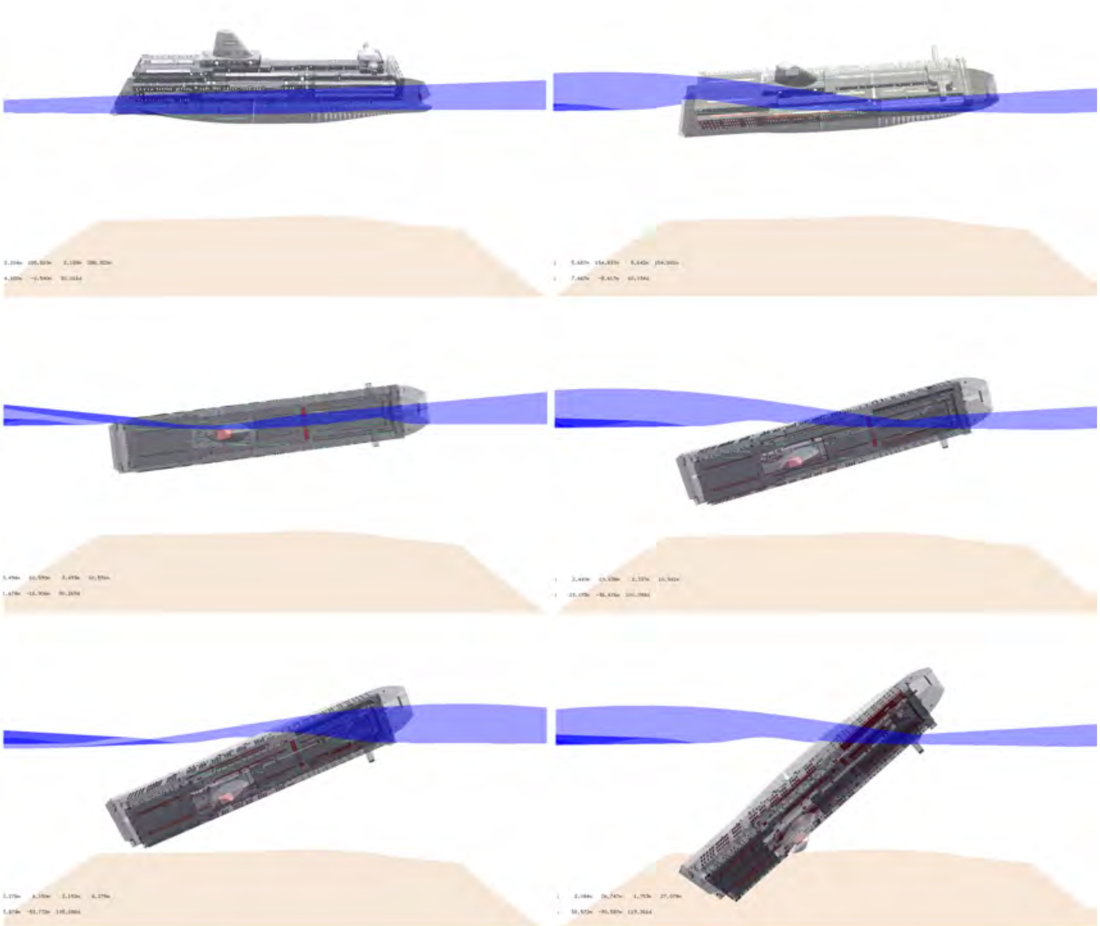

FIG. 4.9: Visualization of the numerical flooding and sinking process in the E4 program and the corresponding heel and trim development until bottom contact. Source: Hamburgische Schiffbau-Versuchsanstalt GmbH.

Alternative Theoretical Behaviour

Water ingress rate, or discharge coefficient, through a hypothetical side damage at the level of the car deck would depend largely on the vessel's heading relative to the waves. On the vessel's last assumed course towards Sweden, the side damage would have faced the leeward side, but after a turn to port, the windward side, significantly increasing water inflow.

If, in addition to the bow opening, the vessel would have had a side opening, its significant effect would have become apparent after the turn to port. Water would have entered the car deck and the spaces below it through an opening located well below the ventilation openings. This would have occurred noticeably during the accident, leading to a much faster sinking than the known timeframe. Therefore, the existence of such an opening while the vessel was still underway cannot be considered possible.

A side opening alone would not have caused a sudden heeling of the vessel. Proceeding on the same course, the volume of water and the water ingress rate would have been too slow to sink the vessel. Even after the turn to port, the vessel's sinking would have taken significantly longer than the known timeframe or would not have happened at all.

4.2 Other Vessels & Objects

It has been speculated that the new damage on the starboard side hull may have resulted from a collision on the sea surface. Therefore, the possible presence of vessels that may have collided with MV ESTONIA in the accident area has been examined.

4.2.1 Sub-Conclusions

The following subsidiary conclusions are made on the question of other vessels near the wreck site during the time of the accident and shortly thereafter:

- No evidence has been found indicating the presence of any previously unknown vessels in the vicinity of the accident site of MV ESTONIA with which the ship could have collided while afloat.
- The vessel hit the visor after it detached.

4.2.2 Other Vessels

One source for questions relating to other vessels the accident area has been Figure 17.1 (“Vessel’s tracks during the accident and rescue operation.”) in the JAIC Final Report, where two ships are labelled as ‘Unknown vessel’ in the vicinity of accident site.[3, p. 206] This figure is based on data plotted by the Utö island radar monitoring station. The investigation has shown that these unidentified ships were most likely GTS FINNJET and MV FINNMERCHANT, which the JAIC Final Report also lists as amongst the first six vessels to arrive to assist in rescue operations.[68] Since the rescue operation was coordinated by Maritime Rescue Co-ordination Centre (MRCC) Turku, the Utö radar station may not have had up-to-date operational information on the positions of all vessels that had arrived at the scene when radar targets were plotted.

In addition, the locations of Swedish submarines on the night of 27-Sep-1994 were queried from the FM to ascertain whether any were near the site of the accident. This was done to answer queries regarding possible interference or potential collisions. Of the twelve submarines, only one was at sea (HMS SJÖORMEN), in the *Gotska sjön*, i.e., between Gotland and mainland Sweden, where it stayed through both 27-Sep-1994 and 28-Sep-1994.[66]

Further, no wrecks have been interpreted in the vicinity of the assumed sinking track of MV ESTONIA based on the high-resolution seabed imaging survey conducted in Nov-2023 (O 2.22).[39], [46]

4.2.3 Other Objects

The vessel hit the bow visor after the visor detached. There is a large dent on the bow visor which matches exactly with the shape of the bulbous bow (Figure 4.5). This event was probably the sound or impact that several people have experienced.

5 Survivors' Interviews

Survivors were interviewed immediately after the accident. In total, there were 137 survivors from the accident. Of these, 134 were interviewed or interrogated by the police in 1994, directly or shortly after the accident. The remaining three were not available for interviews. Based on extant interview protocols, some survivors were further interviewed by JAIC investigators or on behalf of the JAIC. However, interviews encompassing all survivors were not carried out by the JAIC investigation team as the JAIC made the decision that in some cases the information from the police interviews was sufficient.

In an early stage of the Preliminary Assessment, it was decided to offer an interview to willing survivors. In addition to completing info that was never asked for in the nineties, the following reasons were the main reasons:

- most of the survivors were not interviewed by the members of the JAIC or by experts;
- police interrogations were not always considered as conducted on neutral ground;
- the new information about the side damage was not available;
- some topics have emerged after the publication of the JAIC Final Report in 1997;
- the Preliminary Assessment team had additional questions to the ones that were asked 30 years ago.

The interview analysis results are presented here.

All survivors were identified, and except for a few individuals, all were found. Naturally, a number of survivors have passed away since the sinking. Altogether, 118 living survivors—42 in Sweden, 61 in Estonia, and 15 international—were reached and offered an interview. Of those 68 (57.6 %) accepted; one that accepted was never previously interviewed.

The below analysis only relies on the people interviewed from 2021 to 2024, also including their original interviews from the nineties. This means that all interviews from the nineties are not taken into account. This detail complicates compiling easy statistics with respect to the interview results.

All provided statements are confidential with respect to each individual. This is standard procedure and a legal requirement in safety investigations. The interviews were conducted where and when most suitable for the interviewee. The interviewee

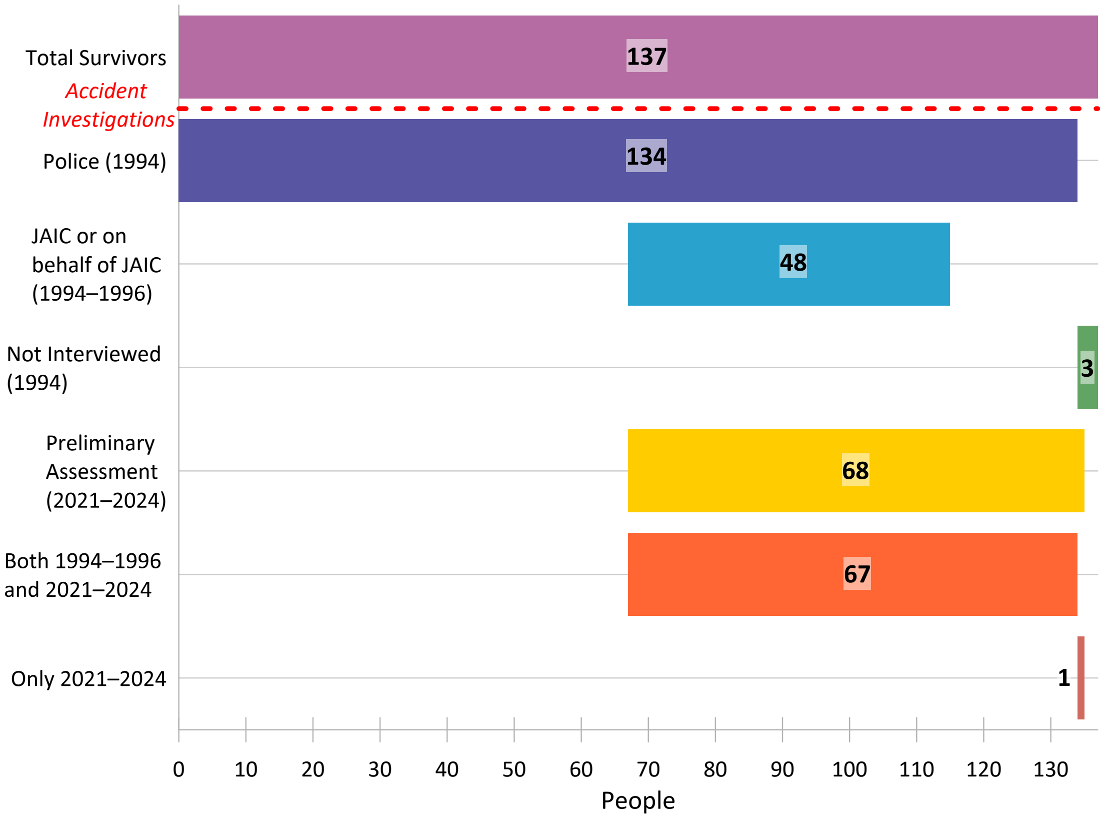

FIG. 5.1: Diagram showing performed interviews. Altogether, 68 survivors were interviewed 2021–2024. The JAIC interviews may include interviews conducted by police in 1995 and 1996.

was asked to tell the whole story as they remembered it in their own words (the principle of free narrative). Thereafter, the interviewers asked questions to add and clarify the interviewee's statements (the principle of direct examination). During most interviews, a physical model of the vessel as well as photographs and drawings of the ship were used to help recall as many details as possible. Further material, such as records from previous interviews, statements, and interrogations, was also available. The interviewers answered any questions from the interviewee about the on-going Preliminary Assessment. The interviews lasted between 45 min and 6 h.

The collected information is documented and systematized according to a common questionnaire and data structure. The same data structure is used for all collation to allow for comparisons. Nevertheless, the information is not always very clear and from time to time the interviewee may be contradictory: what is said in the latter interview may very well be the opposite from what was said during interviews in the nineties. It may also, from time to time, be difficult to interpret what the witness is really trying to say. Hence, the numbers given in this document are not definitive and may vary, depending on the analysis interpretation.

Some witness statements are consistent in the early interviews in 1994, as well as the latter 2021–2024. This may be explained by the witnesses being aware of their earlier statements, e.g., by reading their own witness protocols, or in any other way documenting their story (some have made notes, written books, being active lecturers, etc.). They may, in that way, have kept their once told memories alive. However, some witnesses and their statements are inconsistent, and many times a statement from one witness contradicts a statement from another. For transparency, also statements contradicting with a majority of statements are presented.

It is known that witness statements may not reflect an objective truth, and should therefore be handled with care and not be taken for granted. Thus, the information in this chapter cannot be handled as objective evidence. However, if a number of statements point at the same direction, it should be taken in consideration. Likewise, a testimony, connected to a specific or detailed memory or episode would generally be easier to corroborate with physical evidence, and could therefore as a whole be considered more trustworthy. It has to be mentioned that witnesses, claiming a statement that contradicts to other statements, may not at all be lying. One can have individual memories that diverge from other people's memories. Given the amount of time passed since the accident and the number of theories discussed since the accident, the discrepancies can be accounted for.

5.1 Pre-Sailing

5.1.1 Sub-Conclusions

The following subsidiary conclusions are made based on the experience of the interviewees:

- The information provided to support the existence of any military activities when loading MV ESTONIA is weak. From a total of nine witness statements claiming otherwise, four witness statements are in connection to individual and independent memories. This means that they should be regarded as strong. Altogether, it has to be concluded that it is unlikely that there was any loading of military vehicles.
- Since there is no significant evidence of the lashing status on car deck, it is not possible to make a firm conclusion. In light of the loss of the visor and opening of the forward ramp, lashings could not have prevented the accident from occurring.

5.1.2 Military Transports

From interviews in the nineties, no-one mentions any occurrence of military transports.

Interviews made in 2021–2024 result in two survivors stating that they have seen obstructions and military personnel in the port, restricting the traffic. One of these states that there were military trucks being escorted onboard.

However, nine survivors interviewed claim that there was nothing unusual going on during the loading. One claims, seeing from view deck onboard the vessel, the last truck being loaded. This was described as one ordinary truck, and not military.

Of the other witnesses, two firmly deny existence of any military vehicles during loading. One Swedish driver states that he was driving onboard rather late (the vessel was waiting for him). He had a special piece of equipment for lashing, which he brought to the crew. Although he insisted, the crew did not use it, and an argument arose (Section 5.1.3). Thus, he remembers the situation and should have noted any military vehicles if there were any. The other one[1] states that he wanted to leave with the ferry with his truck, but was refused. He had not booked place for his truck and had originally not planned to bring it to Sweden. He still stayed on the quay until the ferry left, hoping to get a place. Thus, he should have seen any military vehicles being loaded. These two witnesses, one survivor and one left in Tallinn, knew of each-other. One claims that he saw the other one when arranging for the tickets in the terminal in Tallinn. The one that was left in Tallinn went down to the terminal the following morning, after the accident, and met the same woman at the ticket desk as he had met the previous evening.

The non-existence of military vehicles is also confirmed by one Estonian truck driver, arriving after official departure time. The truck was low on fuel, and the driver asked the manager for permission to fill it in Sweden, but was refused. Hence, the driver had to fill the tank in Tallinn, and was delayed. Subsequently, according to the witness, that truck was the last known truck to be loaded.

Another witness, travelling with some fellows in a minivan, was first denied to have the van loaded on the vessel since a permission from the owner to have the van abroad was missing. After some discussion, they were allowed to load the minivan, and had to manually push it sideways into the final position. The witness claims to have been the very last onboard, since the bow ramp was closed right after loading the minivan. The witness denies any military vehicle being loaded amongst the last vehicles.

[1] This Swedish witness stayed in Tallinn and is not a survivor. He has never been interviewed before.

Port Activities

In connection with this information, it should be mentioned that an investigation of harbour activities has been performed by a former state prosecutor in Estonia[2]. The result of this shows no indication of supporting military activity on-going in the port on the day of MV ESTONIA's last departure.

Truck Reversed off MV ESTONIA

During the interviews it has been mentioned by two interviewees that a truck had to reverse off the ferry, after first being loaded. It has been suggested that the reason was to create space for a military transport.

One of these interviewees even gave a nickname of one of the drivers (there were two of them, working together) and the town of the haulier in Sweden. Further investigation of this information was carried out, and one of the drivers of this truck-which-had-to-reverse was traced. However, he denies such a scenario and states that he and his colleague did not start hauling to Estonia until after the loss of MV ESTONIA.

The other driver had arrived late and had understood that a truck, already loaded, had had to reverse off to give the late arriving driver and his truck room onboard. However, the driver that did not get space for his truck onboard claims that he did not get a ticket, never was onboard, and therefore did not reverse off.

This rumour is hence to be dismissed as incorrect.

Discussion & Conclusions

The information provided to support the existence of any military activities when loading MV ESTONIA is weak. Four witness statements of survivors saying otherwise are in connection to individual and independent memories. This means that they should be regarded as strong. Together with the other five survivors' statements, it has to be concluded that it is unlikely that there was any loading of military vehicles.

There is a cargo manifest from the loading available.[3] According to this, no indication of military transports or cargo is shown. There is no evidence to exclude that equipment of military origin or for military use was loaded in any of the trucks. However, if there had been such contraband on board MV ESTONIA during her last voyage, it had nothing to do with her sinking.

[2] 2005-08-31 Report (I) of the commission of experts established to investigate the circumstances of the transport of military-use equipment on board the passenger ferry Estonia in September 1994.

[3] The cargo manifest is available amongst documents from the vessel.

5.1.3 Loading & Cargo Securing

A vessel's cargo plan was prepared based on preliminary information provided from the shore. Interviews with crew members describe that the vessel's cargo plan was prepared based on preliminary information provided from shore; however, sometimes significantly more vehicles arrived on the vessel at the end of loading, making it challenging to revise the original cargo plan. It has also been noted that discrepancies between the declared and actual vehicle weights could have contributed to the uneven distribution of the weight on the car deck.

The JAIC Final Report states that "Due to uneven weight distribution on departure the vessel's port side heeling tank was filled."[3, p. 56] Considering that approx. 180 t of water could be transferred between the heeling tanks, that thousands of tonnes of water entered the car deck through the bow opening, and that approx. 1100 t of deck cargo may have shifted at a certain point, it is unlikely that load distribution between the heeling tanks could have had a significant effect on the course of events.

The car deck was fully laden, and platform decks (hoistable decks, forming Deck 3) were not used. Firstly, the trailers (without trucks) were stowed at the sides of the vessel. Then trucks and other heavy cargo followed. Cars were mostly loaded lastly, stowed mainly in the forward section. Heavy cargo was stowed tight with minimal gaps between vehicles. This was done for two reasons: to stow as efficient as possible, and to prevent much movement in case of heavy listing. Thus, some trucks were placed so close to each-other that lashing them properly would have been difficult, and deemed not necessary,

The loading operation, including lashing the cargo, was conducted under supervision of one of the second officers. The car deck stowing and lashing was done by vessel's crew led by bosun on the one side, and on the other side by a senior Able Seaman (AB). One crew member has stated that they were informed about a gale warning and that the wind speed might reach 25 m/s and therefore extra care was required. According to this statement, heavy vehicles were in general secured with lashing belts and chocks were used for both heavy vehicles and cars (Figures 5.3 and 5.2). Cars were instructed to use the hand brake and to park gear in. This is confirmed by four survived crewmembers. In addition, one driver has stated that he was one of the first vehicles boarding the vessel. Before him trailers without trucks had been stowed. Both his truck and trailer, and the trailers stowed before, were lashed with belts, and both his truck and its trailer were secured with chocks.

However, there are several drivers who did not see their vehicles being lashed. Latter interview statements from passenger witnesses show that three claim that lashing of trucks was not made (these three claimed the same in 1994). Of these,

FIG. 5.2: Footage from the car deck shows a disconnected lashing belt from a shifted cargo unit on the car deck of MV ESTONIA during the visual inspection in 2023 (O 2.21).

one claims that he insisted on having his truck (one of the last ones onboard) lashed and he had a special piece of equipment for this purpose. However, the crew members refused both to lash the truck, and to receive his piece of equipment. Since he still stayed on car deck, the crew asked him to leave the area. Still, it cannot be ruled out that the last vehicles were secured after departure.

Truck drivers have described that after the sinking of MV ESTONIA, considerably more attention was paid to the securing of heavy vehicles. One example is that a welding service was introduced near the harbour, allowing the necessary lashing points to be added in advance if a cargo unit lacked the fittings required for lashing on board.

The Lashing Equipment

Footage from car deck show that there are some lashings still hanging in their storage places, while other storage places are empty (Figure 5.4). Even though it may initially indicate that not all trucks were lashed since not all equipment was used, there is no evidence for such a statement since the total amount of lashings is not known.

Conclusions

Since there are no significant evidence of the lashing status on car deck, it is not possible to make a firm conclusion.

Some trucks were placed so close to each-other that it would have been im-

FIG. 5.3: Footage from the car deck shows a cargo securing chock next to the shifted cargo unit on the car deck of MV ESTONIA during the visual inspection in 2023 (O 2.21).

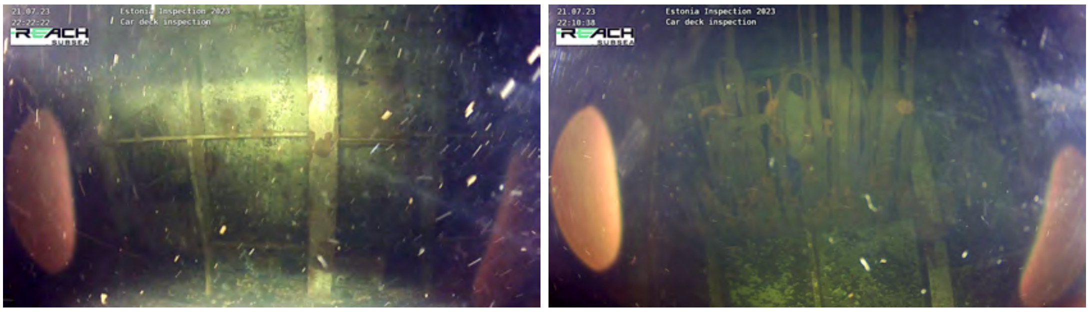

FIG. 5.4: The left image shows an empty space for lashings, while the right shows lashings stored and not being used. Footage from the car deck, made 2023.

possible to lash them properly. However, it would be appropriate to assume that the stand-alone trailers were lashed at least as normal, and that trucks were chocked by blocks at the wheels. It cannot be ruled out that some trucks were lashed after passengers had left the area.

Any movement of the cargo had an impact on the listing and capsizing. However, the movement of unlashed trucks is initially limited by the centre casing and other close-by trucks. In light of the loss of the visor and opening of the forward ramp, lashings could not have prevented the accident to occur.

5.2 Final Voyage & Sinking

5.2.1 Sub-Conclusions

The following subsidiary conclusions are made based on the experience of the interviewees:

- Based on the witness statements, it is not possible to determine a definite time for the initial listing, however the number of witnesses, combined with the fact that one clock was stopped due to batteries falling out, indicate that the initial listing commenced just a few minutes after 01:00.
- The testimonies exclude water ingress from damage in vessel's outward hull in the area of the cabins or the engine workshop. Instead, according to the witness statements, the water ingress to Deck 1 has been from car deck, via openings in the centre casing.
- The witness statements support that the visor was away.
- The result of the ramp status is unclear, but the ramp has been proven to be fully opened with force, but later found fallen back by gravitation to closed position again. This means that it cannot be ruled out that both witnesses claiming the ramp was open and that it was closed may be right.
- The observations of the stabilizer fin confirms that these were out-folded when the vessel capsized. Since it has been proven that they are folded in and undamaged as the vessel is resting on the seabed, it can be concluded that nothing hit or damaged the fins before the listing commenced, neither on port side, nor starboard side.
- The statement from a witness standing on starboard side supports the alternative of no collision.

5.2.2 Initiation of Evacuation

The sudden remarkable list, experienced due to the imbalance and/or dropping items or furniture, and the vessel not recovering from the list, was the main reason for starting evacuation and looking for information. Some survivors fell out of the bed due to the list. In some cases, the heavy list was combined with loud crashes or bangs. Some people claim to have heard a big crash or bang, whereof a few claim there were three bangs. Another few witnesses claim to have heard no bang or crash. Some (of which one is contradictory) claim that the bang had a metallic sound. One witness claims that the sound was not an explosion.

Interviews in the nineties

Some survivors state that there was one sound or bang, while others state there were two bangs. One claim that there were three to four bangs.

The time is noted by five witnesses to be midnight Central European Time (CET) (01:00 EET) or shortly after, while two have stated 01:10 (01:10 EET) and three claimed time to be 00:15 (01:15 EET). Two witnesses noted the time to have been 00:30 (01:30 EET).

Interviews 2021–2024

Of the latter interviews it is evident that many were aware of the danger from loud sounds. Some describe the sound like one bang or crash, while others describe the sound as two bangs. One says that the sound was continuous. Some of the interviewees describe the sound or bang as metallic, while other describe the sound as disturbing, rolling, unusual, cars sliding, flooding water, and rippling. Several claim that no sound was heard.

Several survivors associated the sounds with falling cargo on car deck. For some survivors, the Public Address (PA)-announcement from the ship information desk (Section 5.2.4) was the final call to evacuate. One witness claim that an Estonian person tried to alert people.

No-one states hearing an alarm at this stage (lifeboat alarm with bells and typhoon) or initiating evacuation due to such an alarm.

Survivors have assessed that it took from a few minutes to 15 min to get outside of the vessel, to the weather deck.

Some of the interviewed survivors has noted a certain time for the start of when the evacuation started due to watching the clock, or a clock stopping (batteries fell out). Another had a clock falling in the face when the heavy listing started, thus remembering the time the clock's hands showed.[4] Of these, five claim that it was at midnight CET (01:00 EET) or close thereafter, while one claims that it was 00:15 CET (01:15 EET).

Discussion & Conclusions

There are interviews with no or very little correlation between statements from early interviews and new, but also interviews with good conformity. However, only a few witnesses state the same time in both interviews. Most of the witnesses claim that the initial listing started at 01:00 or shortly thereafter. At least two different

[4] The witness is however in doubt whether the clock showed a correct time. As the witness remembers, it showed 01:10 EET, but the clock may very well be ahead in time.

witnesses (one in the early, and one in the new interview) say that the time was 00:15 CET (01:15 EET).

The sounds heard initially can be explained by the bow failure process—the loose visor affected by the wave impacts, the detached bow visor falling onto the bulbous bow, and the bow ramp to car deck torn open, falling on to the fore peak deck.

Based on the witness statements, it is not possible to determine a definite time for the initial listing, however the number of witnesses, combined with the fact that one clock was stopped due to batteries falling out[5] and another clock fell to the bed from the bed lamp, indicate that the initial listing commenced just a few minutes after 01:00.

5.2.3 Water on Deck 1

Of the witnesses interviewed 2021–2024, twelve were on Deck 1 (tween deck) when the heeling began. Their testimonies are generally consistent, though not all of them have given any information about water on Deck 1 during interviews made in the nineties.

The result show that of the twelve witnesses being on Deck 1 when the heeling started, ten have seen water on floor, in staircase or on wall, while two do not say anything about water on Deck 1 at all (they came from an engine room space). One stepped in water as going up from bed. The amount of water has been described as seeping and not very much, trickling between wall panels, thin layer on the corridor floor, trickling on floor, flowing to staircase from car deck sliding doors, water came to cabin, very strong wave impacts, flowing on the floor. Amounts mentioned are 5 cm to 6 cm, 1 dm, and two buckets.

Five witnesses saw water on car deck or coming from under doors from car deck, while two say that water came from along the wall.

Three of the survivors interviewed 2021–2024 escaped from a cabin in the same watertight compartment and in the very close vicinity of where a damage, consisting of the forward breach in footage shown in 2020 (Figures 3.34 and 3.38). Another three[6] escaped through an engine workshop where the aft damage hole was seen in the footage from 2020. The witnesses have not mentioned anything about any collision, or anything that could have been originating from a collision, or water flooding from a damage in the vessel's hull in the vicinity.

None of the witnesses from Deck 1 mention anything that could be interpreted as an explosion or collision that could cause a hole in the hull.

[5]Theoretically, it cannot be fully ruled out that the clock's hands have been moved, e.g., by the shock of falling, or an unintended touch to the adjusting knob when grabbing the clock.

[6]One has not been interviewed 2021–2024.

Discussion & Conclusions

Sounds heard before or at the first listing of vessel were often heard by survivors from Deck 1 (below car deck) and Deck 4 (above car deck), although some survivors have heard the similar sounds even from the upper decks in stern and other parts. According to a number of witnesses, the water has come from above, either from underneath the doors to the car deck, or seeping along the wall. Three witnesses do not mention water on Deck 1, but on Deck 2 (car deck). Another three did not see any water at all when escaping from Deck 1.

Altogether five witnesses were in or passed through a watertight compartment where in 2020 two holes were shown in a footage. None of these witnesses mentions anything about any explosion, collision or anything else that could suggest that a hole was in the area when they escaped (Figure 3.37).

The escape did not start until the listing was already in progress, and at that time a very large amount of water should have ingressed into the compartments. Considering this impact, it is very unlikely that anyone would survive, escaping from a compartment with a hole or a hull breach. Also, the water is reported evenly from the most forward compartment to the most aftward cabin compartment, suggesting that there was no single source of water ingress to Deck 1, rather one source for every compartment (staircase from the car deck).

Thus, the testimonies from interviews made in 2021–2024 exclude water ingress from damage in vessel's outward hull in the area of the cabins or the engine workshop. Instead, according to the witness statements, the water ingress to Deck 1 has been from car deck, via openings in the centre casing.

In Figure 6.2 ("Plan showing deck I. Red dots mark all known locations of survivors at the onset of the accident.") in the JAIC Final Report, locations of 22 survivors are marked on Deck 1.[3, p. 68] It can during the Preliminary Assessment be concluded based on statements from the nineties and interviews that at least 25 survivors started their evacuation from Deck 1 (Figure 5.5).

It is also concluded that most of the survivors from Deck 1 came from cabins on the starboard side (only three or possibly four came from port side). The reason for this is not possible to determine, however it could be logical to strive upwards in an emergency, which apparently the persons on port side could not—instead, to escape from the cabin area, they should initially need to strive downwards. Another possible factor may be that the existence of water in the aisles and cabins on starboard side made persons to act directly, not loosing time for their escape.

FIG. 5.5: Extract from Deck 1 drawing. The red dots show location of the survivors as highlighted in the JAIC Final Report.[3, p. 68] The yellow dots show location of those not indicated by JAIC (the one outside cannot be connected to a certain cabin). All survivors on the image have not been interviewed 2021–2024, thus may not be mentioned in the text. Altogether, at least 25 survivors evacuated from Deck 1. The starboard side forward and aftward penetrating damage is marked by red rhombs.

5.2.4 Sounds & Lights

Sounds

The statements of sound are corresponding well between earlier and latter interviews, except from a few interviews where the informant is contradictory.

Witness information describe additional sound as imploding, air pressed out, changes in engine sound (like reducing speed) and things moving on car deck from one side to another. There are not many reliable statements about when the main engines stopped. There are slightly more of the witnesses who have said it happened when they were still inside the vessel.

The result shows that the most sound heard by the survivors was a PA-announcement on the vessel, including the Estonian word "*Häire*". This was made by what is supposed to have been a female crew member, most likely from the information desk. When this was heard, the listing angle is commonly estimated to 20° to 45°. A number of witnesses state that they heard another PA-announcement, declaring "Mr Skylight"[7]. This call was made by what is assumed to have been a male voice, probably from the navigation bridge. A few witnesses claim to have heard no call at all.

Many witnesses state that they heard the vessel's whistle, blowing one long signal. There seem to be agreement that this was when the vessel was listing almost 90°, and the funnel reaching the water. A few did not hear the whistle at all, and yet a few heard more than one blow.

[7]The coded call "Mr Skylight" is sometimes used for calling crew members' attention, without disturbing passengers.

No one declares hearing anything that could be described as "abandon vessel" signal (lifeboat alarm with bells and typhoon, or seven short blows on typhoon, followed by one long).

Lights

Although witness statements regarding the vessel's lighting vary, two distinct phases can be identified from the collected statements. The first phase is described, in general terms, as flickering of the lights or a brief blackout. The second phase can be considered the moment when the emergency diesel generator shut down as the vessel lay on its side and the funnel reached the water.

Most of the witnesses have observed the first phase, the flickering or short blackout. Many of these were at that time already outside on weather deck. The listing angle at that time is estimated to have been 40° to 60°, based on the witness' statements.

Also, the second phase of vessel's lightning (electricity shut down) was observed by most of the witnesses. At that time the listing angle is estimated to 70° to 90°, and the funnel close to, or in, the water.[8]

Discussion & Conclusions

The very beginning of the occurrence started with loud sounds, described like crash or bang sounds. These are explained by the bow failure process—loose visor affected by the wave impacts, the detached bow visor falling onto the bulbous bow, and the bow ramp to car deck torn open.

Two PA-announcements were made: one calling all by the word "*Häire*", and another calling "Mr Skylight" internally for the crew.

The vessel's typhoon sounded when the funnel was close to or touched the water surface.

The ordinary electricity system failed as the auxiliary engines, running the generators, stopped. This caused the light to go out or flicker until the emergency generator started. When listing increased and passed a certain angle, also the diesel engine, running the emergency generator, stopped. This is congruent with the function of the electrical system and shows that it worked as intended and designed in such extreme situation.

[8] A vessel's power supply comes from generators, powered by diesel auxiliary engines. When diesel supply fails to these, there is an automatic function that turns on an emergency generator. If list increases over a certain angle, the engine running a generator will stop due to fuel and oil supply failure.

5.2.5 Development of the Vessel's List

Regarding list development, there is not very much difference from statements made in 1994 compared to the ones made 2021–2024.

Most of the survivors have described that initially the vessel heeled rapidly (numerically, 10° to 35°). Majority has said that the vessel did not recover from this single heeling. Some have stated that there were several initial heelings (two to four have been mentioned).

Majority of survivors have described that from that point the heel increased in steps, with smaller rapid drops during longer period. However, several survivors have said that after the first heel its development was quite smooth or with another rapid increase of heel in the very last stage when the vessel was floating on the side. Some have said that the vessel did not roll any more after the first heel, but some had experienced the opposite.

Discussion & Conclusions

It can be concluded that the listing started very quickly, and that an immediate action was necessary for survival. Hereto, it can be concluded that any organised evacuation could not be executed during these circumstances.

5.2.6 Actions by Crew Members

The statements of the interviewees are inconsistent in some cases, meaning there were different statements 1994 compared to 2021–2024. Of the consistent statements, many survivors have in both early and latter statements claimed that they actually saw crew members distributing life jackets, helping passengers evacuating, and trying to launch life rafts. A few consistently claim that they saw no crew in action.

One interviewee mentions that there was no possibility for any rescue action by the crew. The off-duty captain was seen assisting on the weather deck, but any other reports about him in-person do not exist. While near the helicopter deck, one passenger saw on a distance a group of uniformed men (like officers) standing on some sort of platform. One of them was instructing the others and pointing in a certain direction. And then, in the next moment, they were gone.

Discussion & Conclusions

Due to the rapid heel increase, it was extremely difficult for the crew members to reach their designated muster stations and conduct an organized evacuation. The evacuation was instead spontaneous. Since most of the crew members had already gone to rest, they generally did not evacuate in their usual uniforms, which may explain why some passengers did not recognize crew members during the evacuation. Both crew and passengers helped each other to reach the weather deck and distributed life jackets. The launching of lifeboats failed due to the heavy list, while manual deployment of life rafts was more successful. Orders and instructions were not given by the crew after donning the life jackets, again the actions were spontaneous.

Still, it is evident from the witness statements that a number of crew members did whatever they could to assist passengers in evacuating and donning life jackets.

5.2.7 The Vessel's Sinking, Visor, & Ramp Status

The statements by the interviewees when observing the vessel, her sinking, and any sightings of the visor or bow ramp, were consistent with only a few exemptions. Altogether, very many of the survivors have made a statement in this matter.

Vessel Sinking

More than 50 survivors have observed the final stage of the sinking of MV ESTONIA, though not everyone has observed all aspects described below.

In general, the vessel heeled over 90° to starboard, so that the vessel bottom became visible. Most of the witnesses saw the vessel sink stern first. A few state that it sank bow first, and some don't know. Some state that they saw the holes from the bow thruster space.

Some state that the vessel's end rose above the water while the other end sank. One described it as a bottle sinking, while others described it as half-tilted, some 30° to 45° above the water. Yet a few states that the vessel rose 90° straight up.[9]

No one has observed any damage on the hull's port side. Instead, there are at least five witnesses claiming they saw the stabilizer fin, folded out in activated position.[10] Some of these originate from 1994, while others are from 2021–2024 interviews.

One survivor has stated that he was washed to the sea by a wave when the heel was over 90° and his hand watch had stopped at 0135 EET. Another survivor's watch had stopped the same way around 0135 EET. According to the JAIC Final Report, the radio station clock in the chart room showed 23:35 UTC (01:35 EET) during divings in 1994.[3, Sec. 8.8] If the statements from Section 5.2.2, claiming that the

[9] The scenario with a 155 m vessel sinking straight up in waters approx. 80 m deep would mean that half the vessel was above water surface, which is physically impossible. It could be explained by the witnesses seeing the vessel from a certain angle.

[10] The function of the stabilizer fins will cause an automatic in-folding if the speed decreases to only a few knots.

initial listing started a few minutes after midnight Swedish time (01:00 EET), is taken into consideration, the capsizing process from when the listing started (bow ramp was torn open) until the vessel was partly underwater with an angle of 90°, took only 30 min to 35 min. If, on the other hand, the initializing moment suggested in the JAIC Final Report, which is some 10 min to 15 min later (01:15 EET), this process only took 20 min.

The Bow Visor

One Estonian survivor observed from the forward window in the forward staircase already during evacuation that the visor was missing.[11] Several survivors have described a cut or rectangular shape vessel end standing above water, some of them were therefore thinking it was the stern. At least 14 survivors have specifically stated that there was no visor attached to the vessel at this point, while two claim to have seen it in place.

The Bow Ramp

Three survivors claim to have been on the ramp or in the very vicinity, while others have been in a raft, very close to the forward end of the vessel. One of them was sitting on the ramp opening, feeling the air draft from the cargo hold, while the other two climbed down the bow ramp, which was then closed or partially closed. The angle was at this time more than 90°. Yet another two claim that the ramp was in place.

Discussion & Conclusions

The witness statements support that the visor was away.

The result of the ramp status is unclear, but the statement from those who were really close to the ramp (one feeling the air draft) seem to be strong. It should be taken into account that the ramp has been proven to be fully opened with force, but later found fallen back by gravitation to closed position again. It is not determined at which point the ramp fell back to closed position, but a listing angle of more than 90° would have been necessary. This means that it cannot be ruled out that both witnesses claiming the ramp was open and that it was closed may be right.

The observations of the stabilizer fin confirms that these were out-folded when the vessel capsized (the fins are operated simultaneously). At least one statement is consistent with statement from the nineties. Since it has been proven that they are folded in and undamaged as the vessel is resting on the seabed, it can be concluded

[11] Another witness has stated the same in 1994, but has not been interviewed 2021–2024. That witness is thus not included in this report.

that nothing hit or damaged the fins before the listing commenced, neither on port side, nor starboard side. Any such damage would have prevented them to be folded in.

5.2.8 Surroundings

The statements of the survivors rarely provide reliable information about the vessel's orientation (heading) during the sinking. Many recalled that there was a (partially) moonlight, the waves were high, and the wind was strong. The sea was filled with debris, life jackets, and life rafts which had lights. Few survivors mentioned the presence of oil in the water. People were crying and calling for help in the water. Large, illuminated passenger ships could be seen in the distance. Of these, some identified MV MARIELLA. There is no information about other vessels in the immediate vicinity of the accident site, except for one witness, claiming to have seen, together with all the others in the raft, a dark, strange vessel (the witness cannot rule out a submarine). This statement was made in the latter interviews 2021–2024, but is not mentioned in the early interviews. Although in one earlier interview another crew member stated that another crew member had seen a rescue boat departing from the vessel, the damage found on the capsized rescue boat is consistent with that observed on the other lifeboats—it had been torn off from the ship as the vessel submerged.

One witness was outside on starboard side before the listing started, holding the hands on the railing and being fully sober. The witness claim to definitely have seen if any collision had occurred, since the view both forward and aft was good.

At least two witnesses have declared seeing a white object in the water when evacuation was ongoing, one when reaching weather deck, and the other when the vessel was laying on her side.

Discussion & Conclusions

It can be confirmed that MV MARIELLA was one of the very first vessels at site.

The statement from the witness standing on starboard side supports the alternative of no collision.

The observation of a white object in the water is obviously on port side, since evacuation was already on-going. At this stage, i.e., when evacuation is on-going, the bow visor can be ruled out to be the white object due to the fact that some time had passed since the visor fell off, and the vessel had continued with some speed. Thus, the visor was not close to the vessel at this time.

One witness claims that a dark vessel was seen at site. Though the witness claim that everyone in the raft saw the same, there is no other witness mentioning any other vessel at site. The statement is not considered to be credible.

5.2.9 Other Observations

One witness states being robbed during the evacuation, while three others claim to have seen this. These statements are made during the latter interviews 2021–2024, and robbing was not mentioned in 1994 interviews.

One witness states in the 1994 interview having seen a fire or something like a fire, though not very big. Two other witness statements from 1994 claim to have seen smoke from the vessel as she sank, one seeing the smoke from the funnel. In the latter interviews from 2021–2024 the witness saying a fire was seen changed the statement to that it was someone else that saw the fire. One witness repeats the observation of smoke from 1994 (the description is red, hazy smoke), the other not. However, a new witness, not mentioning fire in 1994, claim that it definitely was a fire on board, seen from the raft.

5.3 Post-Sinking

5.3.1 Sub-Conclusions

The following subsidiary conclusions are made based on the experience of the interviewees:

- By comparing stories from 2021–2024 versus the previous written protocols, it can be concluded that even some 30 years later a lot of more information could be collected. However, it should be taken into consideration that some subjects that were of interest during the interviews 2021–2024 may not at all—neither for the investigation nor the public—have been of interest from 1994 to 1997 when the JAIC Final Report was written. It should also be taken into consideration the long time that has passed since the accident may have influenced the witness statements as well as the different theories that have been brought up since then.

5.3.2 Name Registration

There was no uniform method for recording the names in different locations. Some survivors only said their name and others had to wrote it down by their own hand. Sometimes name was asked several times in different locations (onboard rescuing vessels, onshore, etc.). Several survivors were not capable of writing their name after rescuing due to their physical condition. Different and incorrect name versions in the survivor list(s) also suggest that not all of them were written by the survivors themselves.

Several survivors said their names on board rescuing vessels, but these did not appear to the list for a daytime or longer. Several next-of-kin heard about the status when survivors got the chance to call home. One survivor added that next-of-kin forwarded information to an acquaintance working within commercial media, and after that the list was updated. Some survivors were also asked who else they knew/saw on the vessel, which could have increased the confusion with the lists.

5.3.3 Previous Interviews

The survivors don't always remember all the interviews that they have attended. Some survivors have said that the first interviews were made with like a conveyor method—the interviewers were not interested in details and the witnesses' whole experience, and sometimes lacked knowledge of shipping, resulting in some witnesses judging the interviews as bad (even though some actually has a good experience from their interviews).[12] Some survivors have emphasized that the interviews done few years after the accident by the police were not pleasant to attend.

In general survivors agreed with their written statements, though some anomalies were at hand. Usually reading previous interviews helped to recall some other details or confirm the sequence of events, names etc. However, not always everything written in statements was recalled. Some survivors were confident that some errors exist in their written statements. However, these errors are not considered significant to change the general course of events. Some witnesses, only interviewed by the police, believe that they should also have been interviewed by JAIC.

Discussion & Conclusions

By comparing stories from 2021–2024 versus the previous written protocols, it can be concluded that even some 30 years later a lot of more information could be collected. However, it should be taken into consideration that some subjects that have an interest during the interviews 2021–2024 may not at all have had an interest in 1994–1997 when the JAIC Final Report was made, neither for the investigation, nor the public.

[12] It should be noted that the Swedish police had organised a questionnaire, used from the very beginning of their interviews. This questionnaire was shared with at least the Finnish police.

5.3.4 JAIC Final Report

Surprisingly few of the survivors have actually read the 1994 JAIC Final Report. There are many survivors that have accepted the JAIC Final Report's conclusions and the bow structure failure as an initiating event of the accident, but they have usually avoided media attention. On the other hand, there are as many survivors that do not accept the JAIC Final Report conclusions, although almost all of them have not seen and/or read the report itself.

Amongst the substantial arguments against JAIC's conclusions, the relatively short sinking time of the vessel has been mentioned. Description of JAIC's witness summaries were generally accepted but descriptions by survival crafts do not always correspond to survivors' memories (regarding the total number, genders and position of survivors, their activities, etc.). It seems (due to anonymous descriptions) that some survivors have been mixed up while grouping the survivors by survival crafts in the 1994 JAIC Final Report, which is somewhat understandable because of the limited information in police interview protocols. The JAIC investigators interviewing all the survivors shortly after the accident could have resulted in better data quality in this matter.

5.3.5 Political Decisions Outside the Safety Investigation

The main criticism towards the JAIC investigation and the JAIC Final Report is based on the decisions not to recover bodies from casualties and the wreck itself. The decision to cover the wreck and restrict the access to the wreck site has also been heavily criticized.

However, those decisions were not made by JAIC and had nothing to do the safety investigation conducted on the accident. Still, the decisions are directly attributed to the JAIC investigation, which thus has been wrongly connected.

5.3.6 Other Observations

Three witnesses have claimed that they were warned not to talk about the accident, amongst one was advised not to return to Estonia due to the accident. Any further details have not been told. These statements were made in the latter interviews 2021–2024, and were not mentioned in 1994.

6 Assessment of JAIC's Conclusions

One objective of the Preliminary Assessment was to assess whether new information gives reason to revise the conclusions presented in the JAIC Final Report. Considering the sub-conclusions of the previous sections, the Preliminary Assessment concludes that, in general, the JAIC Final Report remains valid and its conclusions stand. However, during the Preliminary Assessment, certain observations and differing opinions have been made on the following aspects, though these do not have a significant impact on the JAIC Final Report or its conclusions.

Table 6.1 presents observations and assessments regarding Chapters 20 ("Findings") and 21 ("Conclusions") of the JAIC Final Report, where applicable.[3, Chap. 20–21]

TABLE 6.1: Summary Assessment of JAIC's Conclusions

ORIGINAL JAIC FINAL REPORT TEXT	OBSERVATIONS & ASSESSMENTS
"The vessel was seaworthy and properly manned." [3, Ch. 20]	Due to shortcomings in the design, building, approval, and certification processes, MV ESTONIA was not seaworthy due to anomalies in her certification process, making her unseaworthy, and should not have been operating on the Tallinn–Stockholm route with such a constructional configuration (Section 4.1.2).
"The ramp rested for a while within the visor before the visor at about 0115 hrs fell into the sea, pulling the ramp fully open." [3, Ch. 20]	The objective of the Preliminary Assessment has not been to establish an exact timeline of the accident; however, based on numerical sinking simulations and survivor testimonies in collection, it is likely that the accident began with the separation of the bow visor shortly after 01:00.

An observation of the Preliminary Assessment is that all the survivors of the accident should have been interviewed by the JAIC.

7 Causes of the Accident

The actual causes of the sinking of MV ESTONIA have been sidelined many times or put in the background during discussions about alternative causes. Thus, both media and the public may have had the impression that some aspects, e.g., ship's speed or maintenance standard, have influenced the accident more than they really did. There is often a tendency to look for a single root cause of a disaster and to even oppose different causes and contributing factors against each other. The purpose of this chapter is to better emphasize and explain why the ship sank—that it did not sink because of one root cause, but rather as a result of systemic failures within the shipping industry. These systemic failures incorporated socio-cultural, regulatory, design, construction, inspection, and certification aspects that together paved the way for the accident. The formed latent unsafe conditions were extremely difficult to identify at the operational level, in the beginning of the accident.

This section is largely based on the facts included in the JAIC Final Report and does not introduce new information, but instead presents previously fragmented information in a compact and systematized form. A common factor of less than adequate risk management can be observed across all categories. The bow structure was not considered a critical element from the point of view of the ship's safety. No apparent considerations were given as to whether such a vessel might sink. This was also reflected in the initial reactions of the maritime stakeholders and the public, which in turn fuelled the spread of alternative theories.

A simplified and visualised overview of this chapter is made in Appendix A.

7.1 Factors Contributing to the Accident

7.1.1 Socio-Cultural Factors

The socio-cultural factors emerged primarily from two sources: the rapid growth in Baltic ferry traffic (demand and competition) and the tradition-based hierarchical structure of the shipping industry. The following socio-cultural factors have contributed to the accident:

- Due to the demand, ship construction practices were advancing faster than the supporting scientific knowledge. As vessels continued to grow in size, understanding of hydrodynamic loads on large hull structures remained limited, and design procedures for bow doors were still not well established.[3, Sec. 10.2, p. 144] [3, Chap. 21, p. 225]

- The ferries were very attractive on the second-hand market, and existing flaws (e.g. weak bow construction) were frequently not disclosed to new owners, not to make them less appealing for buyers. For example, the owner of MV ESTONIA was not aware of such quotation (strengthening of the locks) of the previous owner.[3, Sec. 3.3.6, p. 42] [3, Sec. 10.2, p. 144] [65, p. 256]
- Information on bow visor incidents was not systematically collected, analysed and spread within the shipping industry—it is most likely that the crew of MV ESTONIA were unaware of visor incidents involving other vessels.[3, Chap. 21, p. 225–226]
- A long series of bow visor incidents on other ships had not led to general action to reinforce the attachments of bow doors on existing ro-ro passenger ferries, including MV ESTONIA.[3, Chap. 20, p. 224] This has been explained by the heavy seas' damage considered common and routine, reinforcements were an extra cost and the out of operation period needed to be minimized due to the competition.[65, p. 266, p. 277]
- Applying new rules and regulations retroactively to existing ships has generally been avoided and sometimes considered unacceptable within the shipping industry (so-called grandfather principle)[3, Sec. 15.3, p. 197] due to the cost.[65, p. 72, p. 313] For example, the requirements of IACS 1982 rules specified equivalent design loads per locking device—approx. twice as high as those used in the design of MV ESTONIA but were not applied to MV ESTONIA delivered two years before.[3, Sec. 15.1.1, p. 187]

7.1.2 Regulatory Factors

The following regulatory factors, primarily missing regulatory framework, have contributed to the accident:

- There were no detailed design requirements for bow visors in the rules of the ship's classification society (Bureau Veritas) at the time of the building of MV ESTONIA.[1] [3, Chap. 20, p. 224] There was no regulation handling risks of interaction between hull structures, i.e., any risk assessment of having the upper end of the bow ramp into the hull of the visor was never done.
- Interaction between flag state administration and classification society failed due to the improper share of responsibilities.

[1] However, another classification society (Germanischer Lloyd) had already in 1978 a specific formula for the design load of a bow visor—which would have required approx. three times the load used for MV ESTONIA.[3, Sec. 15.1.1, p. 187]

  - The ship's flag state administration (Finnish) was, according to a national decree, exempt from doing hull surveys of vessels holding valid class certificates issued by authorised classification societies.[3, Chap. 20, p. 224]
  - The vessel's classification society (Bureau Veritas) had no authorisation by the flag state administration (Finnish) to survey the vessel for compliance with the SOLAS Convention.[3, Sec. 3.6.3, p. 46]

- The shipyard was lacking sufficiently detailed manufacturing and installation instructions for certain parts of the bow structure devices, which might have affected the welding quality.[3, Chap. 20, p. 225]

7.1.3 Design Factors

The following factors in the planning stage have contributed to the accident:

- The vessel had extensive flare in the bow area, which increased wave impacts steaming in heavy seas.[3, Sec. 3.7.4, p. 48] Such flares were increasingly applied at the time to provide full width of the car deck and accommodation area as far forward as possible.[3, Sec. 3.2.2, p. 31]
- The visor attachments were not designed according to realistic design assumptions:
  - Design load used for calculations was unrealistic and underestimated—estimated actual sea loads at the time of the accident was equalling to the design load used in calculations.[3, Sec. 15.2, p. 188]
  - Equal distribution of forces between two hinges and three locks in the calculations had no basis in physics, because load rarely distributes equally.[3, Sec. 15.11, p. 196]
  - The calculations did not take into account the reduced strength in the shear mode to which many of the attachment elements would be subjected.[3, Sec. 15.1.2, p. 188]
  - No safety margin was incorporated in the total load-carrying capacity of the visor attachment system.[3, Chap. 20, p. 224]

- The visor could not be seen from the conning position on the navigation bridge, which significantly reduced the crew's ability to understand what had happened.[3, Chap. 21, p. 225]
- The design arrangement of bow ramp engaging with visor through the box-like housing had crucial consequences for the development of the accident.[3, Chap. 21, p. 225]

- The visor indicator lamps on the bridge did not show when the visor was detached due to the designed positions of the sensors, which was thus misleading for the crew.[3, Chap. 20, p. 223] [3, Chap. 21, p. 226]
- The SOLAS Convention requirements for an upper extension of the collision bulkhead were not satisfied.[3, Chap. 20, p. 224] This was done due to the practical acceptance by the flag state administration, but which was never documented as an exemption from SOLAS requirements.

7.1.4 Construction Factors

The following factors in the executing stage of the design have contributed to the accident:

- The visor locking devices installed were not manufactured in accordance with the design intentions:
  - The calculated effective design cross section was not incorporated in the bottom lock, meaning that the installed lugs were smaller than calculated.[3, Sec. 15.1.2, p. 188]
  - Designed high-tensile strength steel was not used in any of the attachment lugs available for examination.[3, Sec. 15.1.2, p. 188]
  - The deck part of the installed visor hinge arrangement differed considerably from the manufacturing drawing.[3, Sec. 8.12, p. 133]
- Welds of the bottom lock elements have showed signs of poor fusion and lack of penetration (poor quality).[3, Sec. 12.7.3, p. 166]

7.1.5 Inspection & Certification Factors

The following factors in the initial inspection and certification stage have contributed to the accident:

- The calculations and the design of the visor attachment points for the locking devices were not examined for approval either by the classification society or by the flag state administration.[3, Sec. 15.1.2, p. 188]
- The carried-out construction of the visor locking devices was not examined for approval either by the classification society or by the flag state administration.[3, Chap. 20, p. 224] Although, a certificate for the vessel was still issued.
- No required and documented exemption was issued for the factual decision to deviate from the requirements of SOLAS convention regarding the upper extension of the collision bulkhead. Such an exemption could be given on

condition that the vessel trading area would have been limited to 20 nm from the nearest land.[3, Sec. 3.6.3, p. 46]

7.1.6 Operational Factors

The following factors in the operational stage have contributed to the accident:

- The bridge officers did not reduce speed after receiving two reports of metallic sounds and ordering an investigation of the bow area, although attempts were made to find the reason for the sounds.[3, Chap. 20, p. 223] [3, Chap. 21, p. 225] However, as pointed out above, the bridge officers were missing the background information to suspect the visor detaching.
- The bridge CCTV monitor covering also the ramp was mounted at the entrance to the chartroom, facing starboard. It could not be kept under observation from the conning station.[3, Sec. 13.4, p. 180]
- The initial action by the officers on the bridge indicates that they did not realise that the bow was fully open when the list started to develop. Not all available means to restore the situational awareness were used (instantly).[3, Chap. 21, p. 225–226]

7.2 Factors Contributing to the Low Survival Rate

Only 137 (14%) people survived out of the 989 in the sinking of MV ESTONIA. 95 victims were recovered from the sea. The factors which contributed to the low survival rate are described below (Figure 7.1).

FIG. 7.1: Pyramid illustrating the magnitude of the negative impact that the main stages of the accident's aftermath had to the final number of survivors.

7.2.1 Evacuation

Altogether, only a few hundred people were able to get out of the vessel:

- Sudden heavy listing hampered the mobility of the people and made the organised evacuation impossible.[3, Chap. 20, p. 224]
- Interior design of the vessel was not favouring the evacuation:
  - Cabin doors were opening to inside, thus the shifting luggage and one's own bodyweight restricted opening doors in the cabin's heeling side. Open cabin doors created traps on evacuation routes.[3, Sec. 6.3.4, p. 73]
  - Narrow corridors and transverse staircases created crowding and dead ends.[3, Chap. 20, p. 224]
  - Loose furniture, other falling objects and detaching handrails blocked the way and injured people.[3, Sec. 6.3.8, p. 79] [3, Chap. 20, p. 224]

- Delayed and unclear public announcements due to the lack of understanding what had happened postponed the evacuation of those whose instincts had not yet alarmed them.[3, Chap. 21, p. 226]

7.2.2 Abandoning

Additional casualties occurred during the abandoning of the ship and the boarding of the survival crafts:

- Lifeboats and davit-launched life rafts were impossible to lower due to the large heel.[3, Chap. 20, p. 224] No other means of dry evacuation were available (like evacuation slide or chute); thus, the survivors had to start tackling with a hypothermia from the very moment.
- Additional casualties and injuries occurred when people jumped, or they were washed into the sea. This rarely happened in a controlled way, therefore the probability to get hit by a vessel's structure or equipment was remarkable.
- Many people had difficulties donning the life jackets correctly, therefore often they lost it when entering the water. Life jackets did not have self-igniting lights; thus it was challenging to locate persons in the water calling for help.[3, Sec. 17.7, p. 214]
- There was no effective way to collect people from the water after abandoning: rescue boats or other self-propelled lifeboats were not available, and their usage would still have been challenging in such a sea state.
- Many life rafts capsized and were waterlogged. It was challenging to embark the life rafts and to close the openings.[3, Sec. 17.7, p. 214]

7.2.3 Rescuing

Additional casualties occurred during the search and rescue operation:

- For those who managed to embark the survival craft, a hypothermia was the main time-critical danger.
- The first response of the rescue centre to the large-scale accident was delayed due to limited manning of the MRCCs and the radio stations, with only one person on duty.[3, Sec. 17.2, p. 204] However, despite initial difficulties the work improved after the first hour and functioned well.[3, Sec. 17.3.2, p. 208]
- There was no effective solution to recover survivors by the ships in heavy sea state. There were attempts to recover survivors from the water which failed. Probably some lives were lost during such attempts.[3, Sec. 17.6.1, p. 211]
- Technical failures with the winches of the rescue helicopters reduced the general rescuing capability.[3, Sec. 17.6.2, p. 213]

- It was not possible to use the full potential of the rescue helicopters which carried only one rescue swimmer. The rescue work was very exhausting both physically and mentally, several rescue swimmers were injured during the operation.[3, Sec. 17.6.2, p. 213]
- Life rafts had no individual identification, therefore the rescuers were initially unable to keep track which rafts had already been searched. Probably many rafts were searched several times, thereby delaying the search of others.[3, Sec. 17.7, p. 214] This issue was solved when the rescue swimmers started cutting open the tents of the life rafts to mark the completed action.

8 Final Conclusions

Taking into account all sub-conclusions, particularly the following:

- The visor locking system of MV ESTONIA failed due to the natural wave loads because the system did not have a structural safety margin for realistic wave conditions. The visor detached in the beginning of the accident and the ramp opened completely after the detachment of the visor.
- The vessel's flooding and sinking behaviour due to the opening of the bow is numerically plausible and consistent with available evidence. Calculations indicate that a side damage occurring while the vessel was still afloat is extremely unlikely.
- Since the accident, the wreck has remained unstable on the seabed with its position and orientation changing several times.
- The wreck's rotational pivot point is located near the starboard-side deformation, against documented outcropping bedrock. The shape of the starboard-side damage closely corresponds with the underlying geological formations.
- A numerical assessment of the vessel's bottom contact with the seabed confirms that extensive damage occurs upon impact.
- There is no available evidence to suggest that the new deformation, or any part of it, was caused by an explosion or a collision on surface.

It can be concluded with confidence that MV ESTONIA sank due to the failure of the bow structure, and that the new damage on the starboard side resulted from contact with the seabed. Therefore, there is no need to reopen the safety investigation of the accident of MV ESTONIA.

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Appendices

A Simplified Visualisation of the Causes of the Accident

The simplified Swiss cheese model shown as Figure A.1 highlights the main causes of the accident. A more detailed description is provided in Chapter 7.

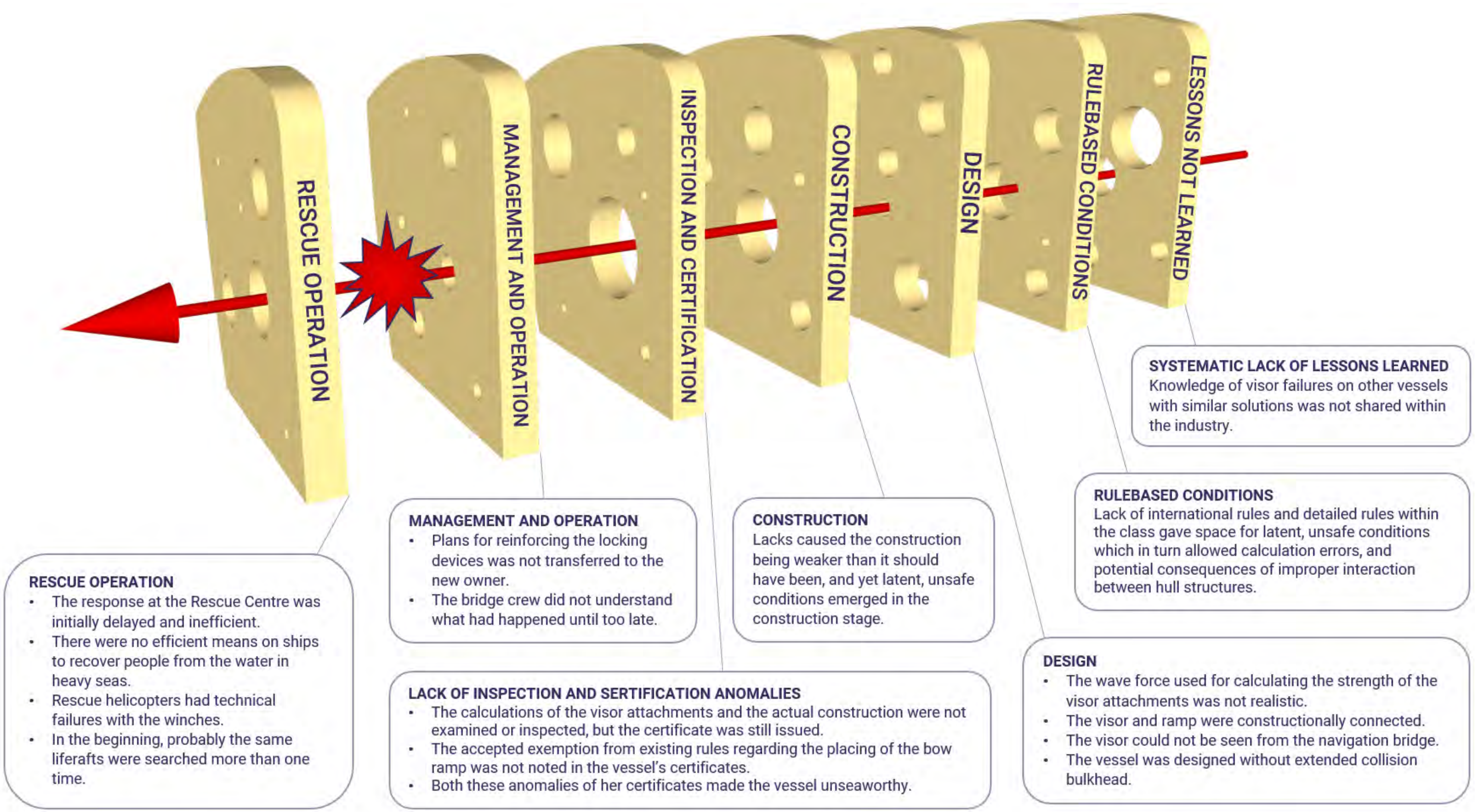

FIG. A.1: Simplified Swiss cheese model of the main accident causes.

REPUBLIC OF ESTONIA
SAFETY INVESTIGATION BUREAU

SAFETY INVESTIGATION AUTHORITY

Statens
haverikommission

Estonian Safety Investigation Bureau | Safety Investigation Authority, Finland | Swedish Accident Investigation Authority