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final report

ON THE CAPSIZING ON 28 SEPTEMBER 1994
IN THE BALTIC SEA
OF THE RO-RO PASSENGER VESSEL

MV ESTONIA

The Joint Accident Investigation Commission
of Estonia, Finland and Sweden



final report



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*The Joint Accident Investigation Commission
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In case of discrepancies between the Estonian, Finnish and English texts, the English text is to be considered the authoritative version.

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The Joint Accident Investigation Commission

ESTONIA: Ministry of Transport and Communications, Viru 9, Tallinn EE-0100.

Telephone +372 6 397 613, Fax +372 6 397 606

FINLAND: Accident Investigation Board, P.O. Box 1, FIN-00131 Helsinki.

Telephone +358 9 1825 7635, Fax +358 9 1825 7811

SWEDEN: Board of Accident Investigation, P.O. Box 12538, SE-102 29 Stockholm.

Telephone +46 8 441 38 27, Fax +46 8 441 38 21

The Government of the Republic of Estonia

**Final report on the MV ESTONIA disaster of
28 September 1994**

Pursuant to an agreement concluded between Estonia, Finland and Sweden a "Joint Accident Investigation Commission" for the investigation of the capsizing of the passenger vessel MV ESTONIA on 28 September 1994 was set up on 29 September 1994, in accordance with a decision taken by the prime ministers of the three countries. The Commission consists of three members from each state and is chaired by one of the members from Estonia, the flag state of MV ESTONIA. Each state has appointed experts to assist the Commission.

In April 1995 the Commission published a part-report that covered its first technical findings and conclusions. The Commission has now concluded its task and hereby presents the final report on the accident. On the whole the conclusions in the part-report are still valid. As well as technical matters, this final report covers all other factors and circumstances found to have contributed to the inception and development of the accident. Should there be any discrepancies between translations and this English text, the English text is to be considered the authoritative version. The final report is unanimous on all points.

for Estonia	for Finland	for Sweden
Uno Laur Chairman	Kari Lehtola	Ann-Louise Eksborg
Heino Jaakula	Heimo Iivonen	Hans Rosengren
Jaan Metsaveer	Tuomo Karppinen	Olle Noord

Identical letters to:

The Council of State of the Republic of Finland
The Government of the Kingdom of Sweden

PREFACE

The Joint Accident Investigation Commission has concluded its investigation of the foundering of the MV ESTONIA, a disaster that has taken the greatest toll of human life in the Baltic Sea in times of peace.

The Commission has thoroughly considered all available information directly related to the accident and the rescue operation. The information includes documents and statements regarding the ship and its operation, witness statements, analysis of the prevailing weather and sea conditions, results from diving investigations and analysis of the recovered bow visor. In addition, to reach a full understanding of the sequence of events, the Commission has initiated theoretical and experimental studies to analyse in more detail the vessel's wave-induced motion and loads, structural strength, manoeuvring characteristics and stability when flooded. The Commission has furthermore found it necessary to investigate the design procedures and operating history of the vessel as well as to collect information on other bow visor failure incidents and to consider legal and administrative issues.

This final report covers all factors and circumstances considered to have contributed to the development and outcome of the accident. In the report the Commission presents the facts found, the analysis and evaluation, conclusions drawn on the basis of the work and the recommendations made to help prevent the occurrence of similar accidents in the future. The fundamental purpose of investigating the accident was to determine its circumstances and causes, with the aim of improving the safety of life at sea and avoiding further accidents. It is not the Commission's task to apportion liability, nor, except so far as is necessary to achieve the fundamental purpose, to apportion blame.

Many people and organisations have helped significantly with support, advice and assistance to the Commission. Their contributions are gratefully acknowledged.

During the investigation, circumstances brought about changes in the membership of the Commission and its experts. It is with great regret that we remember Börje Stenström and Simo Aarnio, who did not live to see the final report. Their expertise and contribution to the report were of the greatest value.

Lastly, the Commission wishes to express to the relatives and friends of those who perished in the accident, its deepest sympathy.

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THE JOINT ACCIDENT INVESTIGATION COMMISSION

Appointment

The joint Estonian/Finnish/Swedish Accident Investigation Commission was set up on 29 September 1994, in accordance with a decision taken on 28 September 1994 at Turku, Finland, by the prime ministers of the three countries.

Chairmen

Andi Meister, Minister of Transport and Communications of the Republic of Estonia (until 1996-07-30)

After his resignation from the minister's post on 17 April 1995 Andi Meister's powers as a member of the Commission were extended by order the Estonian Government 12 May 1995.

Uno Laur, Master Mariner, Chairman, Consulting of Merchant Marine Ltd, Nominee of the President of the Republic of Estonia (from 1996-09-24)

Estonian members

Uno Laur (until 1996-09-23)

Enn Neidre, Master Mariner, Head, Navigational Department, Estonian Shipping Company (until 1996-04-16)

Priit Männik, Master of Laws, Deputy Director-General, Estonian Police (from 1996-04-16 until 1997-10-27)

Heino Jaakula, Naval Architect, Head of Department, Estonian National Maritime Board (from 1996-07-30)

Jaan Metsaveer, D.Sc., Professor, Tallinn Technical University (from 1997-10-28)

Finnish members

Kari Lehtola, Master of Laws, Director, Accident Investigation Board

Heimo Iivonen, Rear-admiral, Director, Finnish Life-Boat Society

Tuomo Karppinen, D.Tech., Senior Research Scientist, Technical Research Centre of Finland, Manufacturing Technology

Swedish members

Olof Forssberg, Master of Laws, Director-General, Board of Accident Investigation (until 1997-05-27)

Ann-Louise Eksborg, Master of Laws, Director-General, Board of Accident Investigation (from 1997-06-16)

Hans Rosengren, Master Mariner, Chief Nautical Investigator, Board of Accident Investigation

Börje Stenström, Naval Architect, Chief Maritime Technical Investigator, Board of Accident Investigation † 25.2.1997

Olle Noord, Master Mariner, United Tankers AB (from 1997-06-16)

Estonian experts

August Ingerma, Ph.D. (Structural Integrity)

Heino Jaakula (until 1996-07-29)

Jaan Metsaveer (until 1997-10-27)

Priit Männik (until 1996-04-15)

Enn Neidre (from 1996-04-17)

Estonian observer

Kalle Pedak, Master Mariner, Director-General, Estonian National Maritime Board

Estonian administrators

Tiit Kaurla, M.Sc. (Tech.), Ministry of Transport and Communications

Aet Varik, B.A., Ministry of Transport and Communications

Finnish experts

Simo Aarnio, Master Mariner (Navigation) † 22.1.1996

Kari Larjo, Master Mariner (Navigation) (from 1996-02-27)

Harri Rahikka, Detective Chief Superintendent (Liaison, Finnish Police)

Klaus Rahka, D.Tech. (Structural Integrity)

Seppo Rajamäki, M.Sc. (Maritime Radio)

Finnish observer

Jukka Häkämies, Head, Division of Maritime Inspections, Finnish Maritime Administration

Finnish administrator

Pirjo Valkama-Joutsen,
M.Sc., Accident Investigation Board

Swedish experts

Mikael Huss, Ph.D. (Naval Architecture)

Olle Noord (until 1997-06-15)

Bengt Schager, M.Sc. (Organizational Human Behaviour) (until 1997-09-08)

Swedish observer

Sten Anderson, Master Mariner, Swedish Maritime Administration

Swedish administrator

Gunnel Göransson, Board of Accident Investigation

Status

The Joint Commission was set up to find the cause of the accident, to examine the reasons why the loss of lives attained such magnitude and to present proposals for measures that would help to prevent

the future occurrence of a similar accident.

At the first meeting of the Commission, on 29 September 1994, it was deemed essential that the Commission act as a single unit in drawing conclusions and issuing official reports, but in carrying out the investigation the parties of the three countries were to have an independent status, without any duty to report back to, or to act on the instructions of, the states that proposed their appointment.

Work schedule

At the first meeting, the areas of the investigation were divided between the Estonian, Finnish and Swedish parties of the Commission.

The Commission has had 20 internal meetings, lasting a total of 51 days. In addition to the meetings of the entire Commission, meetings have been held by experts and other working groups.

Tracing the wreck of the ESTONIA

The locating of the wreck of the ESTONIA began on the day after the accident, 29 September 1994. The wreck was found on 30 September 1994.

Underwater operations by ROV

The wreck was filmed with a submarine ROV camera on 2 October 1994 and again for further details on 9–10 October 1994 and 19 June 1996.

Tracing and recovering of the bow visor

The bow visor of the ESTONIA was found on 18 October 1994. It was raised to the surface on 18 November 1994 and taken ashore in Hanko, Finland.

Diving operations

Diving investigations of the wreck, including a survey of the bow area and the navigation bridge, were carried out on 2–5 December 1994.

SUMMARY

This is the final report by the Joint Accident Investigation Commission on the background and sequence of events leading to the foundering of the ro-ro passenger ferry *ESTONIA* shortly before 0200 hrs¹ on 28 September 1994, and on the subsequent rescue operation. The vessel was on a scheduled voyage from Tallinn to Stockholm with 989 people on board.

The report consists of four parts. The first part gives factual information on the accident, the rescue operation, and on the *ESTONIA* and her operation. It includes a summary of testimonies by the survivors. The second part presents background information, or associated facts related to the accident such as a short development history of the passenger ferry traffic in the Baltic and a review of bow door failures. The third part presents the results of the analysis and evaluation by the Commission of the accident and the rescue operation. This part incorporates short accounts of the separate investigations carried out on behalf of the Commission. The detailed research reports and copies of the most important documents are collected in a separate Supplement. The fourth part presents the conclusions based on the work carried out by and for the Commission.

PART I FACTUAL INFORMATION

Chapter 1 gives facts on the most important events during the accident voyage, on the accident and very briefly on the rescue operation. *Chapter 2* describes the operating history of the vessel under the Finnish and Estonian flags with emphasis on the organisation of the operations and on the experience of the partners in the Tallinn – Stockholm traffic. *Chapter 2* includes also general statistics on wave conditions in which the vessel had been sailing during her life.

Chapter 3 is a general technical description of the *ESTONIA* focusing on the bow visor and ramp installations with

detailed data on the design and construction of their locking systems, including the monitoring and control. The history of the vessel and in particular of the bow visor and the ramp installations with regard to maintenance, modifications, damage and repairs is reviewed. Emergency and life-saving equipment and arrangements on board are outlined in 3.4. The vessel was built to comply with several international conventions which are listed, and the compliance was documented by certificates. The collision bulkhead compliance is dealt with in some detail. Certificates valid at the time of the accident are reviewed and the changes in wording of the most important certificate, the Passenger Ship Safety Certificate, which has to be renewed every year, are explained in detail.

Chapter 4 describes the arrangement of operations on board and working routines, and gives summaries of qualifications of each deck officer and engineer on duty on the accident voyage. The safety organisation is outlined comprehensively.

Chapter 5 is the second chapter directly dealing with the accident. The environmental conditions: wind, sea state, visibility and current during the accident voyage are defined on the basis of information obtained from meteorological institutes. The chapter concludes with an estimate of the *ESTONIA*'s speed during the voyage. The speed profile has been constructed from the DGPS recording of the passenger ferry *SILJA EUROPA*'s speed and is compared with observations of the actual speed.

Chapter 6 is a summary of all statements made by the survivors and covers their experience from the time just prior to the accident until their rescue. The chapter is divided into two parts. The first part reports on statements made by the individual surviving crew members who were on duty during the accident, the second part summarises statements from both passengers and crew members off duty. *Chapter 6* summarises as closely as

¹ If not otherwise stated all times in the report are given in Estonian time = UTC + 2 hrs.

possible the statements made by survivors, but specific details are not necessarily regarded as facts and may differ from the Commission's statements in other chapters.

Chapter 7 begins with a general description of the rescue operation. This description first deals with international agreements on the safety of life at sea and then with the maritime search and rescue organisations of Estonia, Finland and Sweden as well as the co-operation between these countries.

The section on the *ESTONIA*'s distress message and distress traffic describes the radio systems in use at the time of the accident and the coast radio stations which were keeping watch on distress and safety channels. The *ESTONIA*'s entire distress traffic from 0122 hrs to 0130 hrs on 28 September 1994 has been transcribed on the basis of the tape recordings made.

The section on the search and rescue operations begins with a chronological list of the most important rescue actions during the first hours. After this, the operations undertaken by the vessels, helicopters and aircraft are described. The section concludes with data on victims and survivors.

Part 1 ends with *Chapter 8* which presents a detailed review of damage to the wreck, the ramp and the visor with their attachments, as observed visually during inspections with a submarine Remotely Operated Vehicle (ROV), the diving operation and after the visor had been recovered and taken ashore. The damage is illustrated with several photographs. The extent of the diving operation is described and the divers' observations on the bridge and elsewhere in the wreck concerning e.g. victims are summarised. The state of the *ESTONIA*'s life-saving equipment and emergency beacons (EPIRBs) when found after the accident is specified in 8.10 and 8.11, respectively.

PART 2 ASSOCIATED FACTS

Chapter 9 includes a general review of

international co-operation and conventions within the framework of the International Maritime Organisation (IMO) and shortly describes the organisation of the Estonian, Finnish and Swedish Maritime Administrations. The role of the classification societies and their relationship with the ship owners, shipyards and the national administrations is described. The problems recognised in safety of ro-ro vessels before the *ESTONIA* disaster are pointed out with particular emphasis on the *HERALD OF FREE ENTERPRISE* accident in 1987.

Chapter 10 is a brief commercial and technical history of the ro-ro ferry traffic in the Baltic. The chapter includes a list of passenger ferries put in traffic between south-west Finland and the Stockholm region in Sweden by the Silja Line and the Viking Line between 1959 and 1993, with the type of original bow enclosure defined.

Some of the incidents involving failure or part-failure of bow visor attachments of Finnish and Swedish ro-ro passenger ferries in the Baltic and the North Sea are summarised in *Chapter 11*. The type and extent of damage is indicated in each case as well as the action taken after the accident. The incident of *DIANA II* in January 1993 in the southern Baltic has been investigated in more depth since she had a similar visor and attachment system design to the *ESTONIA*'s.

PART 3 ANALYSIS AND EVALUATION

Chapter 12 opens the analysis part of the report. It presents an overview of the separate investigations carried out for the Commission. These include analysis of wave loads on the visor based on model tests and numerical simulations, calculations of wave-induced motions and analysis of hydrostatic and hydrodynamic characteristics during flooding and sinking of the vessel. The chapter also summarises the various strength and metallurgical investigations carried out on parts

recovered from the visor and ramp installations and calculations of the strength of the visor attachments.

Chapter 13 is a main chapter in the report presenting the Commission's views on the course of events starting from the preparations for the accident passage and ending with the sinking of the *ESTONIA*. The chapter is based on an analysis of witness statements (*Chapter 6*) and all technical observations and data of which the main part is summarised in *Chapters 3, 5, 8, 12 and 15*.

The possible deficiencies existing in the visor and ramp closure before the accident voyage and their effect on the operation of the vessel are analysed in 13.2.3. Separation of the visor and development of the list and sinking are handled shortly in 13.2.5 and 13.2.6, respectively, while a more thorough treatment is given in 13.5 and 13.6.

Actions on the bridge in the light of information available to the bridge are analysed in 13.3, including an analysis of the effect of the *ESTONIA*'s speed on passenger comfort and the accident. The time span considered is from the first signs of something being wrong at about the time of changing watch at 0100 hrs until the end of the distress traffic at 0130 hrs.

There were indicator lamps on the bridge showing locked or unlocked visor and ramp, respectively. Their indications and other advance alarms when the visor was becoming detached are analysed in 13.4.

Chapter 14 describes the ownership and operating arrangements of the *ESTONIA* and analyses whether these may have been a contributing factor in the accident.

Chapter 15 analyses the structural design of the visor and ramp attachments. The basis and procedures for design, manufacturing and approval are discussed. The estimated combined strength of the attachment system is compared to the estimated wave-induced loads and a probable load level and sequence of failure is presented.

Chapter 16 is an analysis of the evac-

uation of the ship from the first early signs of the accident until the ship was abandoned by all who could. The basis for this chapter is witnesses' statements and findings by divers after the accident. The chapter deals with the alarms, activities and efforts by parts of the crew, activities by passengers, various obstacles to the evacuation and the role of rational and irrational human behaviour displayed.

Chapter 17 is an analysis of the rescue operation on the basis of information and data summarised in Chapter 7. Chapter 17 considers first the distress traffic between the vessels and the coast stations. The action initiated by the distress calls on board the vessels in the vicinity of the ESTONIA and at the land-based res-

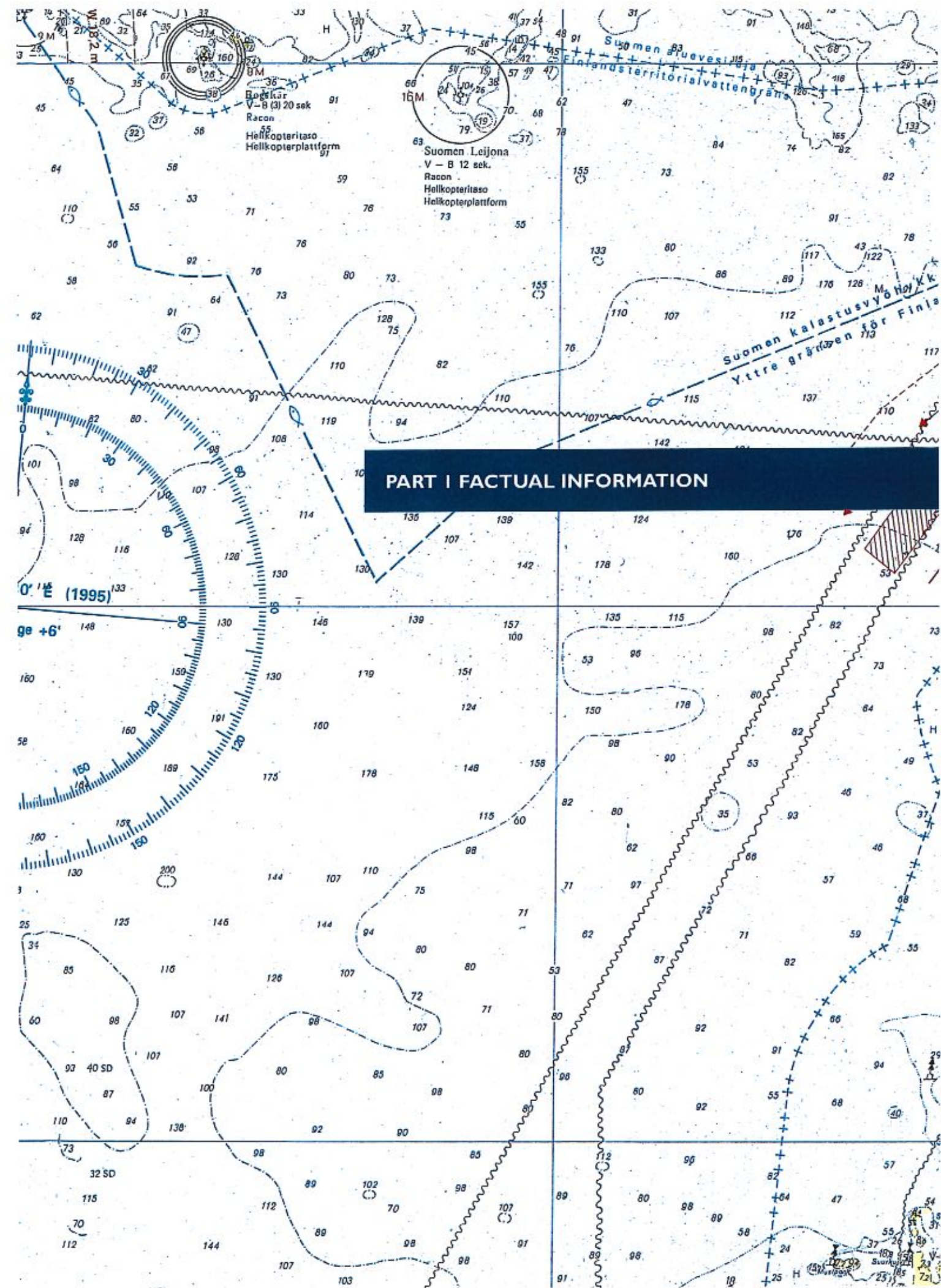
cue centres, in particular MRCC Turku, are evaluated in 17.3. The concluding part of the chapter deals with the action of vessels and helicopters during the rescue operation.

Chapter 18 begins with a consideration how the practice common amongst the Finnish and Swedish Maritime Administrations of accepting in passenger ferries a forward-located bow ramp as an upper extension of the collision bulkhead, contrary to the SOLAS regulations, may have developed. This chapter also evaluates the bow ramp arrangement of the ESTONIA in comparison with some other contemporary passenger ferries, and draws conclusions on the effect on the accident of non-compliance with the regulations.

The ESTONIA accident prompted an extensive investigation within the International Maritime Organisation (IMO) on all aspects of ro-ro passenger ships' safety. The work has led to improvement of existing safety regulations and development of detailed new ones of which a significant part has already come into force. The new safety regulations for passenger ferries developed by IMO after the accident are reviewed in *Chapter 19*.

PART 4 CONCLUSIONS

Part 4 presents findings, conclusions and recommendations, in *Chapters 20, 21 and 22*, respectively.



CHAPTER 1

THE ACCIDENT

The Estonian-flagged ro-ro passenger ferry ESTONIA (Figure 1.1) departed from Tallinn, the capital of Estonia, on 27 September 1994 at 1915 hrs for a sched-

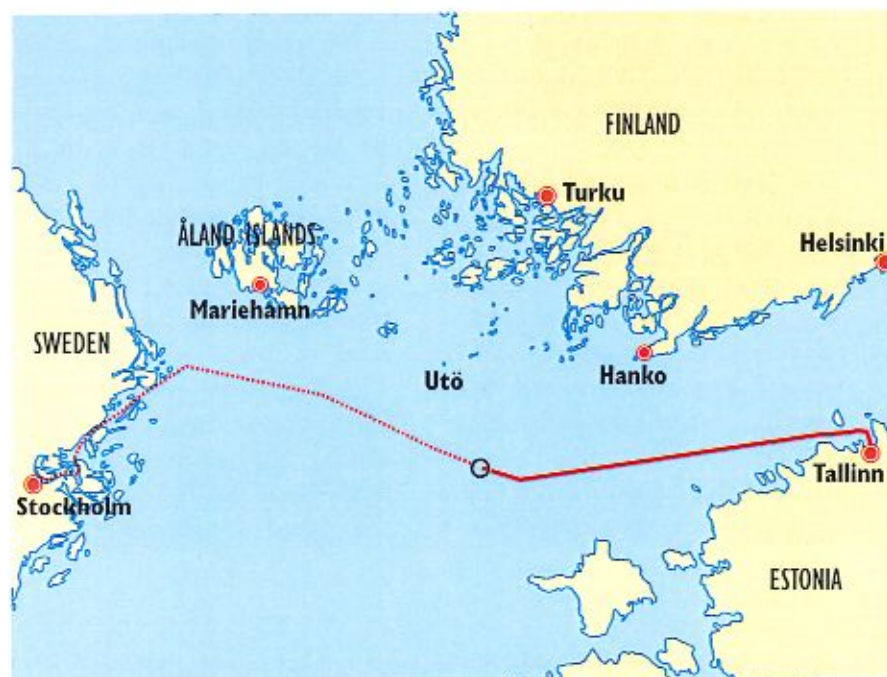
uled voyage to Stockholm, the capital of Sweden (Figure 1.2). She carried 989 people, 803 of whom were passengers.

The ship left harbour with all four

Figure 1.1 The ro-ro passenger ferry ESTONIA.



Figure 1.2 The ESTONIA's route and the site of the accident.



main engines running. When she was clear of the harbour area full service speed was set. The engine setting was maintained up to the accident. The wind was southerly, 8–10 m/s. Visibility was good, with rain showers.

At 2000 hrs the watch on the bridge was taken by the second¹ officer B and the third officer.

The voyage proceeded normally. Sea conditions along the Estonian coast were moderate, but became more rough when the ship left the sheltered waters. The ship had a slight starboard list due to a combination of athwartships weight disposition, cargo disposition and wind pressure on the port side.

As the voyage continued the wind velocity increased gradually and the wind veered to south-west. Visibility was generally more than 10 nautical miles. At midnight the wind was south-westerly 15–20 m/s with a significant wave height of 3–4 m. The rolling and pitching of the vessel increased gradually, and some passengers became seasick.

At about 0025 hrs the ESTONIA reached a waypoint at position 59°20' N, 22°00' E and from there headed true course 287°. The speed was about 14 knots and the vessel encountered the seas on her port bow. Due to increasing rolling, the fin stabilisers were extended.

During his scheduled round on the car deck the seaman of the watch heard shortly before 0100 hrs a metallic bang from the bow area as the vessel hit a heavy wave.

The seaman of the watch informed the second officer B about what he had heard and was ordered to try to find out what had caused the bang. The seaman did so by waiting at the ramp, listening and checking the indicator lamps for the visor and ramp locking devices. He reported that everything seemed to be normal.

At 0100 hrs the watch on the bridge was taken over by the second officer A

and the fourth officer. After being relieved the second officer B and third officer left the bridge.

Further observations of unusual noise, starting at about 0105 hrs, were made during the following 10 minutes by many passengers and some crew members who were off duty in their cabins.

When the seaman of the watch returned from his round, soon after the change of watches, he caught up the master and entered the bridge just behind him. Shortly afterwards he was sent down to the car deck to find out the cause of the sounds reported by telephone to the bridge. He did not, however, manage to reach the car deck.

At about 0115 hrs the visor separated from the bow and tilted over the stem. The ramp was pulled fully open, allowing large amounts of water to enter the car deck. Very rapidly the ship took on a heavy starboard list. She was turned to port and slowed down.

Passengers started to rush up the staircases and panic developed at many places. Many passengers were trapped in their cabins and had no chance of getting out in time. Lifejackets were distributed to those passengers who managed to reach the boat deck. They jumped or were washed into the sea. Some managed to climb into liferafts which had been released from the vessel. No lifeboats could be launched due to the heavy list.

At about 0120 hrs a weak female voice called "Häire, häire, laeval on häire" the Estonian words for "Alarm, alarm, there is alarm on the ship", over the public address system. Just a moment later an internal alarm for the crew was transmitted over the public address system. Soon after this the general lifeboat alarm was given.

A first Mayday call from the ESTONIA was received at 0122 hrs. A second Mayday call was transmitted shortly afterwards and by 0124 hrs 14 ship- and shore-based radio stations, including the

Maritime Rescue Co-ordination Centre (MRCC) in Turku, had received the Mayday calls.

At about this time all four main engines had stopped. The main generators stopped somewhat later and the emergency generator started automatically, supplying power to essential equipment and to limited lights in public areas and on deck. The ship was now drifting, lying across the seas.

The list to starboard increased and water had started to enter the accommodation decks. Flooding of the accommodation continued with considerable speed and the starboard side of the ship was submerged at about 0130 hrs. During the final stage of flooding the list was more than 90 degrees. The ship sank rapidly, stern first, and disappeared from the radar screens of ships in the area at about 0150 hrs.

Rescue efforts were initiated by MRCC Turku. About one hour after the ESTONIA had sunk, four passenger ferries in the vicinity arrived on the scene of the accident. Rescue helicopters were summoned and the first one arrived at 0305 hrs.

During the night and early morning, helicopters and assisting ships rescued 138 people, of whom one later died in hospital. During the day and on the two following days 92 bodies were recovered. Most of the missing persons accompanied the vessel to the seabed.

The wreck was found in international waters within Finland's Search and Rescue Region, resting on the seabed at a water depth of about 80 m with a heading of 95° and a starboard list of about 120°. The visor was missing and the ramp partly open.

The position of the wreck is 59°22,9' N, 21°41,0' E. The visor, which has been recovered, was located at 59°23,0' N, 21°39,2' E, about one nautical mile west of the wreck.

¹ The ESTONIA had two second officers, here designated second officer A and second officer B.

CHAPTER 2

OWNERSHIP AND OPERATING HISTORY

2.1

Operating history under Finnish flag

The vessel was delivered to Rederiaktiebolaget Sally on 29 June 1980 under the name VIKING SALLY and placed in daily operation between Turku and Mariehamn in Finland, and Stockholm.

Rederiaktiebolaget Sally, based in Mariehamn, was at that time one of the major Finnish shipping companies with engagement in tankers and passenger vessels. The company was one of three which together formed the marketing consortium "Viking Line" for ferry operations between Finland and Sweden (see 10.2).

In 1986, ownership of the vessel was taken over by the Finnish/Swedish group Effjohn, owners of the competing Silja Line. The vessel continued, however, to operate in the Viking fleet under the original name. The technical operation was subcontracted with the remaining part of the Sally company.

In April 1990 the Effjohn group took over full operation of the vessel and transferred her to the Silja Line under the name SILJA STAR for continued operation between Turku and Stockholm.

In January 1991 the vessel was transferred to the Wasa Line, another subsidiary of the Effjohn group, and was placed in the Wasa Line operation in the Gulf of Bothnia between Vaasa in Finland and Umeå and Sundsvall in Sweden. The ship was then renamed WASA KING. She was operated on this route until she was sold to the Estline Marine Company

Limited, which is registered in Cyprus.

The ship was under Finnish supervision and flew the Finnish flag from delivery until 14 January 1993.

2.2

Under Estonian flag

The vessel was delivered on 15 January 1993 to the Estline Marine Company Limited. She was registered in Cyprus to satisfy the requirements of the European Bank of Reconstruction and Development for financing the vessel on a mortgage basis. Permission had been obtained for parallel registration in Estonia and the vessel was entered in the Estonian Ship Register on 28 January 1993.

After delivery drydocking in Turku she entered service for passenger and cargo traffic between Tallinn and Stockholm under the new name, ESTONIA. The first voyage took place on 1 February 1993 and the traffic continued thereafter with departures every second day from Tallinn and Stockholm respectively. Figure 2.1 shows a summary of the vessel's operating history.

The Estline Marine Company Limited was owned equally by the Estonian Shipping Company Limited (ESCO) and Nordthulin Luxembourg S.A., the latter a company fully owned by the Swedish shipping company Nordström & Thulin AB.

The vessel was bareboat chartered to the Estonian company E-line Limited, also owned equally by ESCO and Nordthulin Luxembourg S.A.

Figure 2.1 Ownership and service.



Table 2.1 Ownership of companies for operating the ESTONIA.

Company	Nationality	Owner
Estline Marine Co. Ltd	Cyprus	50 % Estonian Shipping Co. Ltd 50 % Nordthulin Luxembourg S.A.
E-Line Ltd	Estonia	50 % Estonian Shipping Co. Ltd 50 % Nordthulin Luxembourg S.A.
Estline AB	Sweden	50 % Estonian Shipping Co. Ltd 50 % Nordstöm & Thulin AB
Estonian Ferry Services Ltd	Estonia	100 % Estline AB
Estonian Shipping Co. Ltd	Estonia	100 % Estonian State
Nordstöm & Thulin AB	Sweden	Public Swedish joint-stock company
Nordthulin Luxembourg S.A.	Luxembourg	100 % Nordstöm & Thulin AB

E-line had signed a Ship Management Agreement with ESCO because ESCO had more extensive resources and experience than E-line for managing operations.

ESCO in turn signed a Technical Management Agreement with Nordström & Thulin AB, the reason being that the latter company had more experience of this type of ferry and easier access to spare parts and service. For the same reason Nordström & Thulin was contracted to handle insurance matters regarding the ESTONIA.



Figure 2.2 Organisation of Estline Marine Company Limited.



The commercial side of the operations, including catering, was handled by the Swedish company Estline AB under an agency agreement with E-line. Estline AB was owned equally by ESCO and Nordström & Thulin. Estline AB had a subsidiary company in Estonia to provide the commercial and catering services in Tallinn. Table 2.1 summarises the ownership of the companies involved in the ESTONIA's operation. Figure 2.2 shows the organisation of the Estline Marine Company Limited.

Nordström & Thulin AB is a Stockholm-based public company, established in 1850, with experience of extensive world-wide operation of large modern tankers and bulk carriers, and passenger ferry operations between the Swedish mainland and the island of Gotland in the Baltic Sea. Shipbroking is another important company activity.

The day-to-day technical management functions regarding the ESTONIA were handled by one full-time superintendent and one purchasing manager, both based in Stockholm.

ESCO is a Tallinn-based, state-owned stock company. Its history dates back to 1879, when the first shipping company, "Linda", was established in Estonia. ESCO operates world-wide a variety of cargo vessels of up to 50,000 dwt. ESCO also operates passenger ferries in the Baltic Sea and the Gulf of Finland. In the autumn of 1994 the company owned and operated 55 vessels.

Operation of the ESTONIA was under the supervision of the Navigational Department of ESCO. The crew was provided by the Personnel Department of ESCO. Two full crews were employed, manning the ship in two-week shifts each. The qualifications and training of the crew are described in Chapter 4.

The master taking over a shift was required to visit the ESCO Navigational, Technical and Personnel departments for briefing. The master being relieved likewise had to report personally to the navigational department of ESCO on the situation on board.

A captains' meeting was held at the

Table 2.2 Routes operated by the ESTONIA.

Route	Open sea [NM]	Crossings per day	Time per day [h]	Years on route	Total time on open sea [h]
1 Turku—Stockholm	20	2	3	10.5	11 000
2 Vaasa—Umeå/Sundsvall	20/75	4/2	6/6	2.0	4 000
3 Tallinn—Stockholm	150	1	9	1.7	5 500

Table 2.3 Probability of significant wave height exceeding certain levels.

Significant height greater than [m]	Route 1 Sea of Åland Lägsjär Prob. [%]	Route 2 Gulf of Bothnia Vaasa-Sundsvall Prob. [%]	Route 3 Northern Baltic Bogskär ¹ Prob. [%]	Route 3 Northern Baltic South of Utö Prob. [%]
2	5.7	12.6	20.4	24.6
3	0.4	3.9	6.5	11.1
4	0.04	1.2	1.3	4.2

¹ Measured

Table 2.4 Upper estimates of times the ESTONIA had spent in seas with significant wave height exceeding 3 or 4 m.

Significant height greater than [m]	Route 1 Turku—Stockholm Time spent in hours	Route 3 Tallinn—Stockholm Time spent in hours
3	40	500
4	4	150

ESCO office once a week attended by all masters in Tallinn on that day, including those on vacation. Regular meetings were also held on board the ESTONIA, attended by the masters, chief officers and chief engineers of both shifts and by representatives from ESCO and from Nordström & Thulin AB.

2.3 Operating history with regard to wave conditions

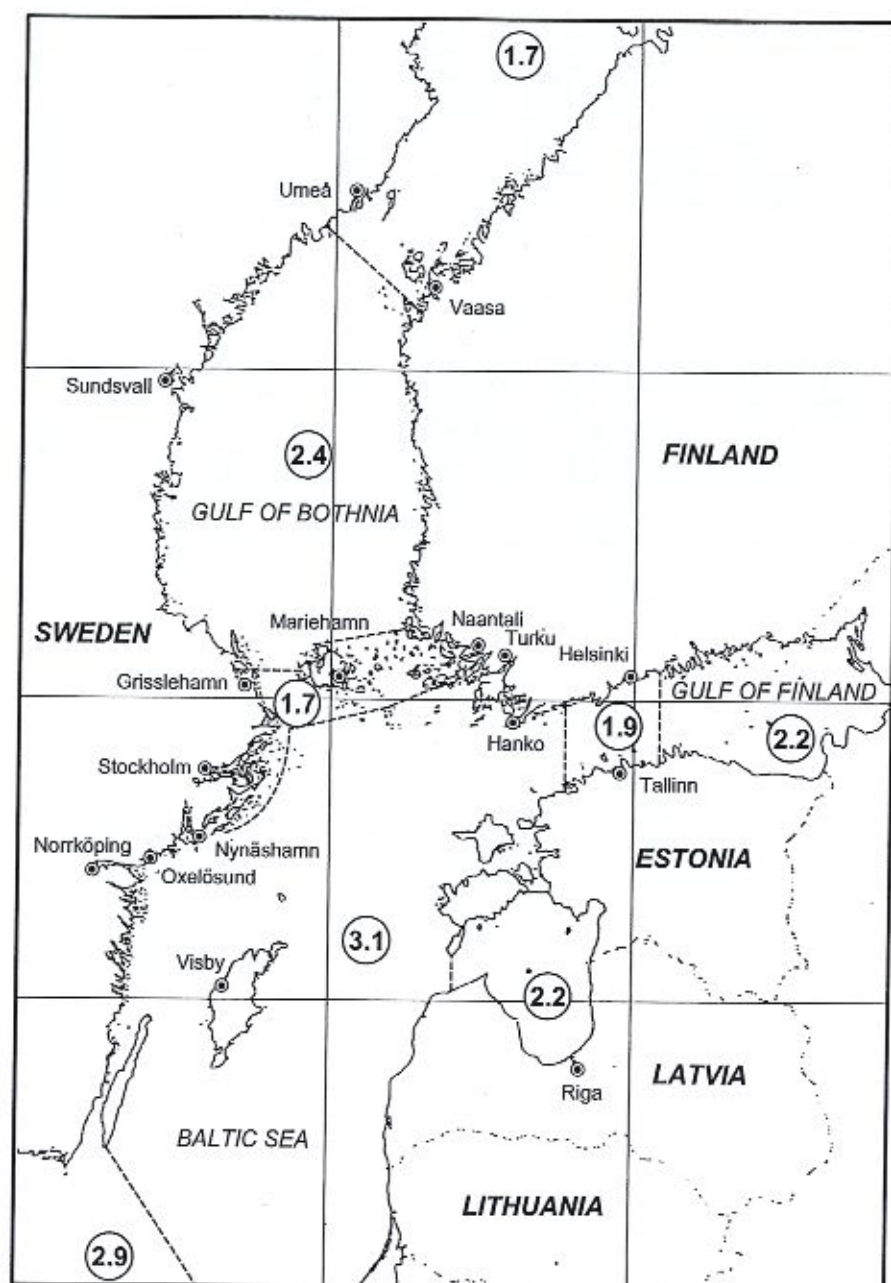
The main part of the Tallinn—Stockholm route was in open sea, while the open-sea part was considerably shorter on the two previous routes. Table 2.2 summarises the route information for all the

three routes.

No wave statistics exist specifically for the vessel's three operating areas. Some indication of the differences between sea conditions on the three routes may be obtained by comparing the significant wave heights which are exceeded at a probability of 10 % in the different sea areas (Figure 2.3). The wave heights were estimated by the Finnish Institute of Marine Research (MTL). The Institute also predicted wave statistics for the three routes on the basis of their experience, wind statistics, fetch and wave measurements at Bogskär in the northern Baltic Sea (for position, see Figure 13.1) and at Sandbäck in the southern Gulf of Bothnia.

Table 2.3 presents wave statistics for

Figure 2.3 Significant wave heights in metres, with 10 % exceedance probability.



each route on the area where the worst wave conditions are encountered. The table also shows statistics measured at Bogskär for significant wave heights exceeding 2, 3 and 4 m.

Figure 2.3 indicates that the probability of encountering high seas on the Vaasa–Umeå route is significantly lower than on the Vaasa–Sundsvall route which was run only occasionally and mainly in the summertime. In addition, a review of the weather data from the Gulf of Bothnia for the period when the vessel was operating there indicates that strong winds generating high waves had not existed at any time during this period.

An upper estimate of the time the *ESTONIA* had spent in rough sea is obtained by combining the time spent in the open sea (Table 2.2) with the probabilities of significant wave height exceeding 3 or 4 m. The times in rough sea are given in Table 2.4 for the operation in the Turku–Stockholm and in the Tallinn – Stockholm traffic. The estimates for the latter traffic assume that the vessel had spent equally long times in the wave climates represented by the Bogskär and by the south-of-Utö wave statistics.

The vessel may have encountered these high seas from any direction. In the Åland Sea area, heavy seas can only be generated in south–south-easterly or north–westerly directions, thus creating beam seas for vessels sailing on the Stockholm–Mariehamn–Turku route. In the Northern Baltic most of the high sea states are generated in the south to west sector. This means in general port bow or beam seas for a passage from Tallinn to Stockholm and following or beam seas in the opposite direction. The probability of encountering high waves diminishes towards the ends of the open sea part.

CHAPTER 3

THE VESSEL

3.1 Background

3.1.1 Contract, specification, building and delivery

The vessel was built by the shipyard Jos. L. Meyer at Papenburg in Germany in accordance with a building contract signed on 11 September 1979 between the yard and Rederiaktiebolaget Sally (Supplement). The contract referred to a building specification number 5675/79, dated 5 September 1979. The contract followed a standard format originally developed by the Swedish Shipowners' Association.

The vessel was ordered and built for the rapidly expanding ferry traffic between Finland and Sweden. She was built during a period of rapid growth in the size of ferries and in their operating speed and was, when delivered, for a time the second largest ferry operating in the Baltic Sea. Only the gas-turbine-powered FINNJET, specially built for operation between Helsinki and Travemünde, was bigger.

The vessel was to be built within an unusually short delivery time and substantial parts of the hull and the superstructure were subcontracted with other yards. The bow visor and its attachments were however built by the Meyer yard.

The vessel had newbuilding number S.590, delivered after newbuilding S.592, named DIANA II, which had been ordered by Rederiaktiebolaget Slite, the Swedish partner in the Viking Line consortium.

The two vessels had large similarities, primarily in the main hull below the main deck and in machinery. These similarities were a condition for meeting the desired short delivery time, 30 June 1980, for newbuilding S.590. The keel was laid on 18 October 1979. The two vessels were, however, not built to similar specifications. Newbuilding S.592 was built to a specification with Swedish origin whereas newbuilding S.590 was built to a specification developed from one used

by the shipping company for other ongoing newbuildings at a Finnish yard. Newbuilding S.590 was furthermore lengthened compared to newbuilding S.592 by extension of the parallel midship section by 18.4 metres. Related differences in the main hull were an increased length of the bulbous bow by 0.83 m and a related increase of the length of the forward ramp by 0.725 m.

Both vessels were built to the rules of Bureau Veritas with class notation "I 3/3 E + Passenger Ferry Deep Sea Ice 1A (Aut)".

According to the building specification, the vessel was to be built to the rules and regulations of the Finnish Maritime Administration and additionally to the following international conventions and national regulations:

- Safety of Life at Sea Convention (SOLAS), 1974.
- Load Line Convention (TLLC) of 1966 with amendments of 1971 and 1975.
- Tonnage Measurement Convention of 1947.
- Marine Pollution Prevention Convention (MARPOL) of 1973.
- Collision Prevention Convention (COLREG) of 1972.
- Finnish regulations for Safety Ship Labour 77:33.
- US regulations regarding sanitation (as reasonably applicable).
- Helsinki Convention on the Protection of the Marine Environment of the Baltic Sea, 1974/232.
- IMCO resolution A 325 (IX) 1975 concerning machinery and electric installations in passenger vessels and cargo ships.
- USCG requirements for passenger vessels, as reasonably applicable.
- Finnish Maritime Administration rules and recommendations for noise level criteria.

The 1974 issue of the SOLAS Convention was specified in lieu of the 1960 issue even though the 1974 issue had not yet entered into force.

The contract specified that "Scandinavian standard for car/passenger ferries shall

apply to all equipment, materials etc.”.

The vessel was built and delivered according to schedule, but not all the passenger cabins were finished at the time of delivery. It was nevertheless considered important by the shipowner to be able to put the vessel in service before the summer season of 1980. The vessel was therefore delivered with a Passenger Ship Safety Certificate for a reduced number of passengers, originally 1100, and the number was increased as the interior work progressed whilst the vessel was in service.

The vessel was named VIKING SALLY and was delivered on 29 June 1980.

3.1.2

Newbuilding inspection

The ship was built to the rules of Bureau Veritas and to the special survey standard of the classification society. This included, in addition to surveys at the yard, inspection of main materials and equipment at the respective works prior to delivery to the shipyard. Bureau Veritas was requested by the yard to survey the ship for conformity with the classification rule requirements applicable to the marks and notations mentioned below:

- 1/3/3 E + Passenger Ferry Deep Sea Ice 1A (Aut).
- Class notation “I” indicates that the vessel complies with all class construction requirements.
- Class notation “3/3” indicates that the vessel and its equipment met the full standard of the class rules with no restrictions.
- Class notation “E” indicates that the anchors and anchor chains were of approved standard.
- Construction mark “+” indicates that the vessel was constructed under Bureau Veritas survey from the beginning of the construction.
- Notation “Passenger Ferry” indicates that the vessel was a passenger ship with ro-ro car facilities.
- Navigation notation “Deep Sea” indicates that the vessel had no restriction regarding areas or conditions of oper-

ation.

- Notation “Ice 1A” indicates that the vessel satisfied the “Finnish Swedish ice class rules 1971”.
- Notation “(Aut)” indicates that the vessel was equipped with automated systems in the engine room areas for remote operation in open sea.

Bureau Veritas was authorised by the Finnish Maritime Administration to survey the vessel and its construction for compliance with the International Convention on Load Lines. The shipyard made a formal request to Bureau Veritas to perform this survey. The main responsibility remained, according to SOLAS and other conventions, with the Finnish Administration even when a classification society was authorised to perform certain functions.

The class survey took place from September 1979 until and including delivery in June 1980. Surveying of the installations for automated machinery went on also after delivery and was completed in December 1980.

The survey by the classification society did not encompass day-to-day detailed survey of the construction and the installation work in the ship. The classification society surveyor was to check conformity with the classification rule requirements and with approved drawings. He was also to ascertain that remarks regarding construction made on drawings were dealt with by the shipyard.

The Finnish Maritime Administration retained the responsibility for surveying the ship for compliance with international conventions and also with national safety rules and requirements on accommodation spaces. This surveying activity was done at intermittent visits to the yard.

The owners were represented at the yard throughout the construction period by shipowner's superintendents and the master and chief engineer assigned to serve on the vessel.

3.2

General description and data

This section contains a general description and data of the vessel. Details of the various areas are dealt with separately in 3.3–3.6. The general arrangement of the vessel is shown in Figure 3.1.

3.2.1

General arrangement

The VIKING SALLY was built as a development from previous ro-ro ferry designs. She was classified in shipping registers as a passenger/cargo ro-ro ferry. She was built with a continuous vehicle-carrying space on the main deck (A-deck). Below the main deck an economy accommodation area was arranged on deck number 1 (tween-deck) and an extensive sauna and pool area on deck 0 (tank-deck). The main passenger accommodation areas were on decks 4 (C-deck), 5 (D-deck) and 6 (E-deck). The crew accommodation was generally on decks 7 (F-deck) and 8 (G-deck) and the navigation bridge was on deck 9 (H-deck).

The ship was built with one bow loading ramp on the car deck, enclosed by a hinged bow visor that opened upwards, and two stern loading ramps. Passenger entrance doors were arranged on decks 4 and 5 and pilot and bunkering doors on the car deck.

The ship had the following main particulars according to building specification and certificates:

• Length, over all	155.40 m
• Length between perpendiculars	137.40 m
• Breadth, moulded	24.20 m
• Depth to bulkhead deck, moulded	7.65 m
• Maximum draft	5.60 m
• Deadweight at max. draft	3,006 dwt
• Light weight	9,733 t
• Gross tonnage	15,598
• Propulsion power	4 x 4,400 kW
• Electrical power	4 x 1,104 kW
• Bow thrusters	800 + 590 kW

Figure 3.1 General arrangement of the ESTONIA.

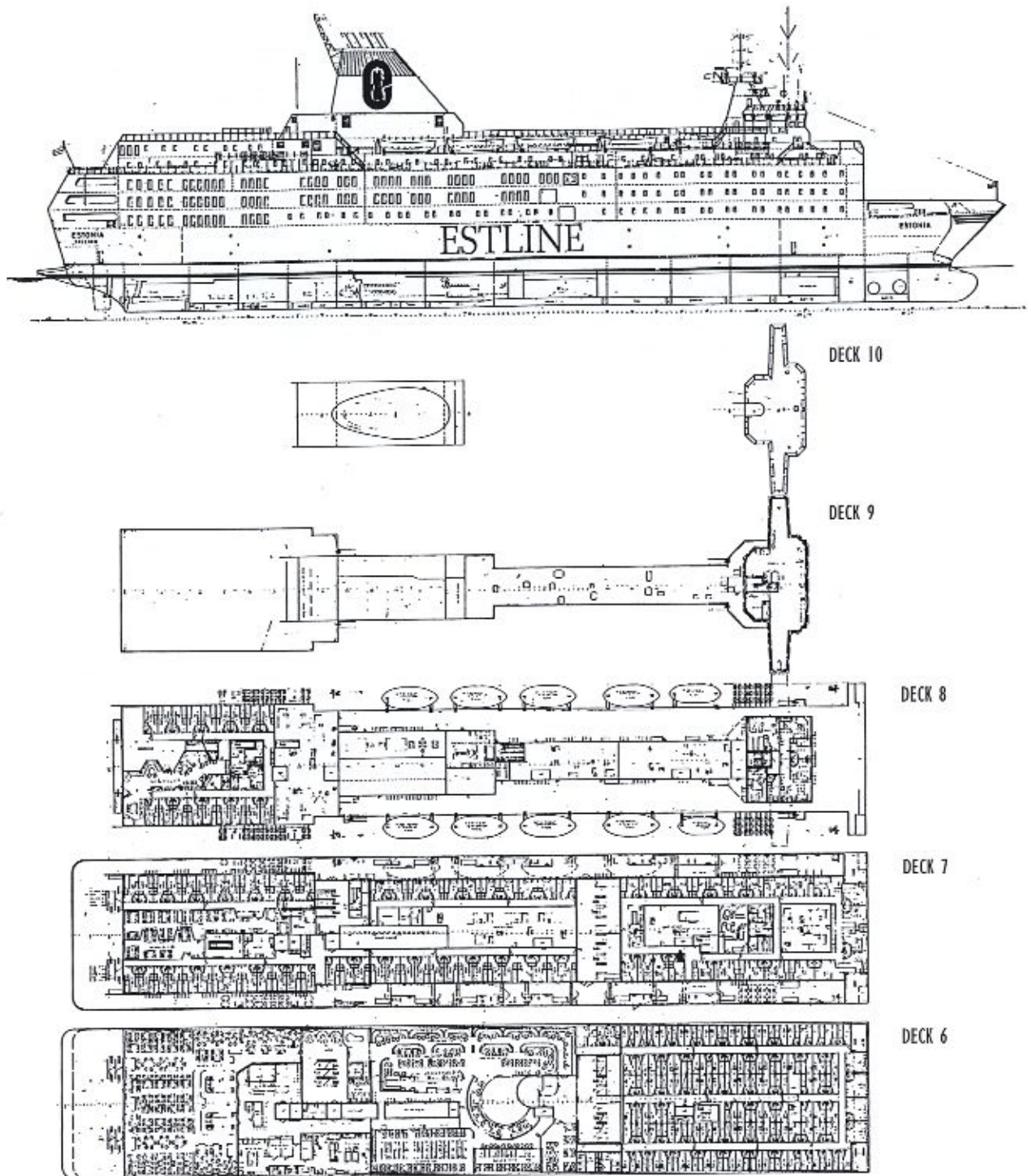
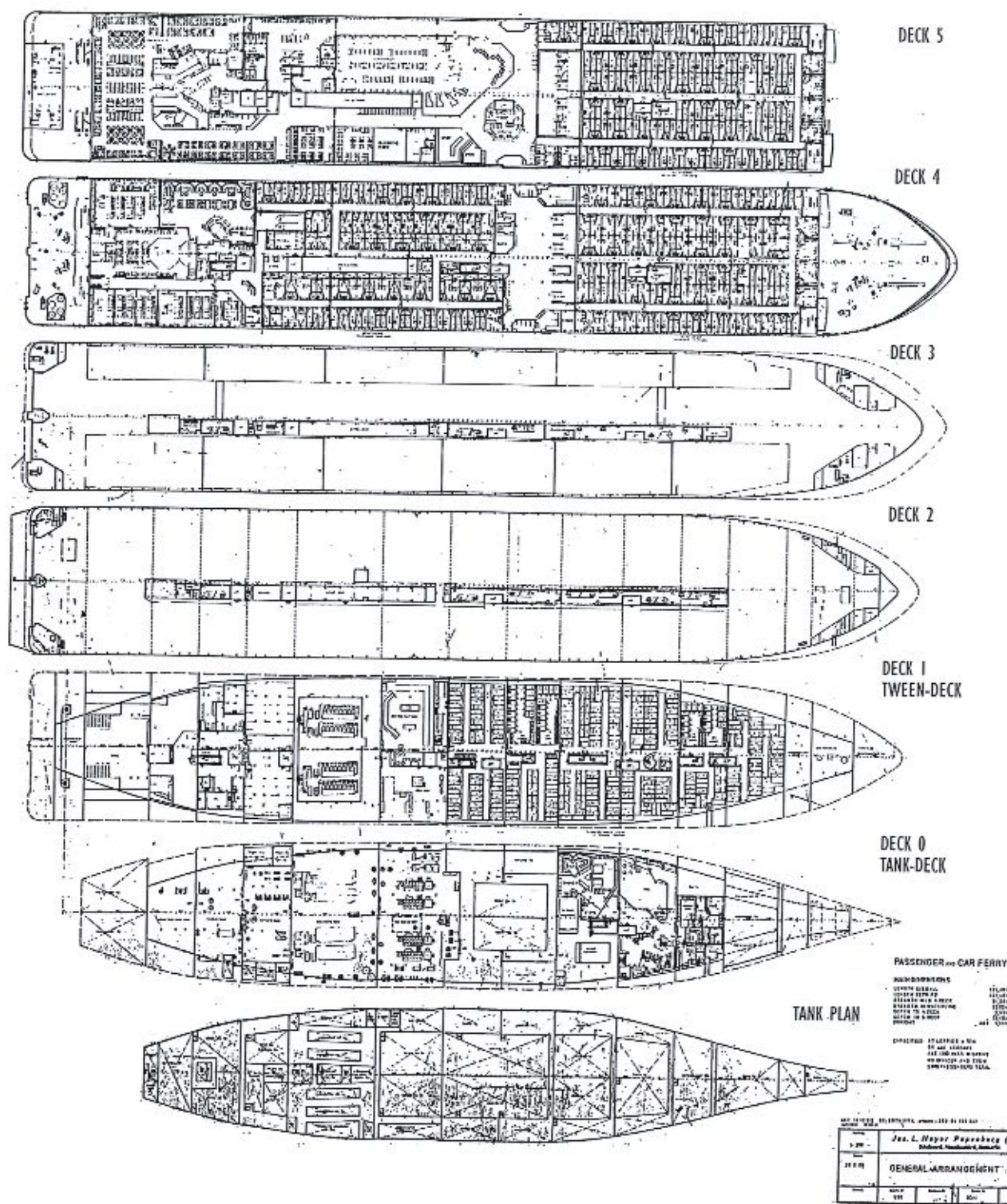


Figure 3.1 (continued)



- Maximum number of passengers 2,000
- Maximum service speed 21 knots
- IMO number 7921033

3.2.2 The hull and deck arrangement

The hull was built to Bureau Veritas rules and to the Load Line and SOLAS Conventions regarding watertight subdivision. It was designed with a slender forebody extending into a bulbous bow and a "pram type" afterbody with two propellers and two rudders. Two bow thrusters were installed. The afterbody was modified during drydocking in 1985 by a "duck tail" extension giving increased

buoyancy in the afterbody and a better hydrodynamic flow condition, preventing the stern from setting down at high speed. This was a problem in the original configuration unless forward located ballast tanks were filled.

The forebody had an extensive "flare", especially below the knuckle line at the car deck level. Such flares were increasingly applied at the time to provide full width of the car deck and accommodation area as far forward as possible. The hull form is shown in Figure 3.2.

An active roll-stabilising system with fins was installed in January 1994. Provisions for such installation had been made already at the newbuilding stage.

The hull below the bulkhead deck was subdivided by fifteen watertight transverse bulkheads, equipped with

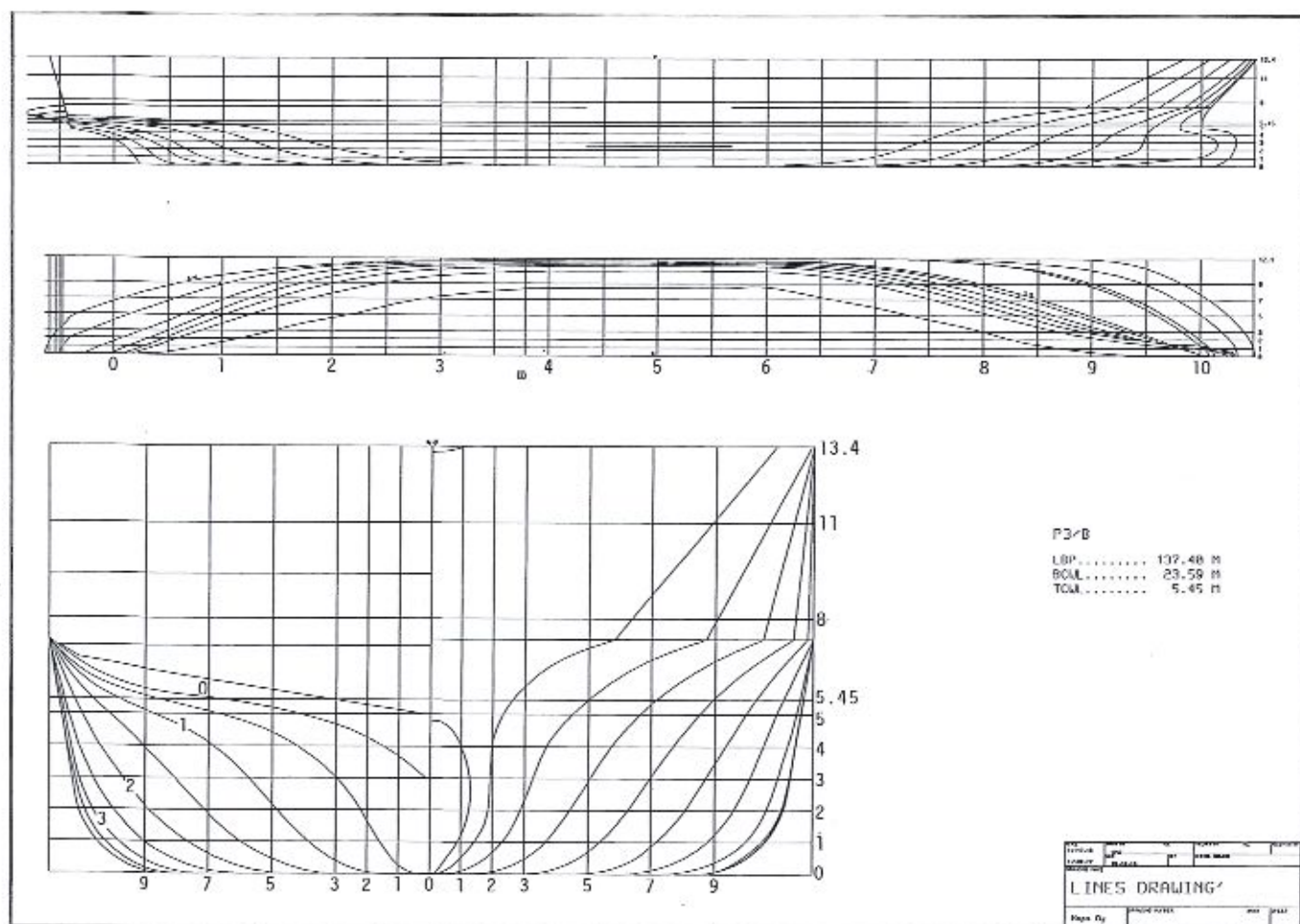
watertight doors as required.

The double-bottom spaces were arranged for fuel oils and other liquids and some were designated as empty tanks. Fuel oil tanks were also placed above the inner bottom.

Deck 0, the tank-deck, contained – from forward – the forepeak, the bow thruster room, an extensive sauna and swimming pool area and – in the aft half of the ship – the generator room, the engine room, the fuel purifier room and other machinery-related spaces. The deck next above, deck 1, contained – in the forward half – economy class cabins for 358 passengers. The aft half of the deck contained the engine control room, workshop, main engine room and various utility spaces.

The car deck was one open space,

Figure 3.2 Lines plan of the ESTONIA.



with the exception of a centre casing, located slightly to starboard. Loading ramps were arranged one at the forward end and two at the aft end of the deck. The centre casing contained staircases from the spaces below the car deck, lift trunks and various utility spaces for machinery and catering functions. Five lifts were installed, extending from the passenger spaces below the car deck and from the car deck to deck number 7. Six sets of stairs led from the lower passenger spaces to a common passageway inside the casing. Four sets of stairs led from this passageway to deck 4 and six sets led upwards to higher decks. Stairs were also arranged at the aft open-air deck spaces from deck 4 upwards to deck 8. Emergency escape trunks from the engine room area were arranged inside the casing. Hanging car decks were arranged whereby the car deck space could be divided into two lower-height decks for cars. Access from the staircases to the hanging decks was via four doors on the starboard side and via two doors and gangways on the port side.

Smaller service spaces for power supply to the ramp and bow visor operation and the hoistable car decks were arranged on the car deck port and starboard, forward and aft. An office for the cargo officer during loading and discharging was arranged in the aft service space.

Deck 4 contained many passenger cabins and, aft, conference rooms, a cafeteria and passenger seats. The enclosed deck area terminated with two public exits to the open-air aft deck. Decks 5 and 6 had passenger cabins covering the forward third and the remaining parts were used for tax free shop, information desk, restaurants, bars and entertainment areas. Both decks had two double-door public exits to the open-air aft decks. The accommodation spaces on decks 4, 5 and 6 extended from side to side without any open-air passage or other open-air spaces except the aft decks.

Deck 7 contained the main part of the crew accommodation. This deck did not extend to the sides of the vessel, giving

room for an open deck area on both sides. On the open deck there were the rescue stations and the embarkation area for lifeboats. The deck was accessible to passengers via two main staircases and staircases between the aft open-air decks. The passageways contained cradles for liferafts and bins for lifejackets for passengers and crew. Forward on deck 8 was accommodation for the senior officers and, aft, additional crew accommodation spaces. The intermediate space was taken up by ventilation equipment and other service functions. The lifeboat davits and additional liferaft bins were located at the sides of this deck. Deck 8 was accessible to passengers only via external stairs from deck 7.

The navigation bridge was on deck 9.

3.2.3

Propulsion system and control

The propulsion system consisted of four medium-speed diesel engines, connected in pairs to two propeller shafts via gearboxes. The engines were four-stroke turbo-charged engines with eight cylinders and a maximum continuous output of 4400 kW each. They were designed to operate on heavy fuel oil. Maximum continuous operating speed was 600 rpm.

Each propeller shaft carried one controllable-pitch propeller with a diameter of 4.0 m. The shafting had flangeless couplings and was arranged with the necessary sealing arrangements at bulkhead penetrations and oil-lubricated stern tube seals. Each shaft could be locked with a brake for operation with only one propeller. The port-side propeller rotated clockwise and the starboard-side one counter-clockwise.

The pitch control of the propellers was hydraulic, separate for each propeller. Each system had duplicate oil pumps and the necessary hydraulic components. The control was effected electrically by power selector levers on the main control console on the bridge, on the bridge wings and in the engine control room. The control signal from the power selector affected the engine speed as well as

the propeller pitch via an electro-hydraulic combinator. Speed and pitch both increased at increasing power settings up to about 70 % power, when maximum continuous engine speed was reached. After that, higher power settings only increased the propeller pitch.

All the normal indicators, alarms and control devices were on the bridge and in the engine control room. The installation qualified for unmanned machinery space at sea in accordance with the classification requirements, but actual operation was at all times conducted with the engine control room manned by one engineer and one motorman.

The total fuel oil tank capacity was 940 m³ of heavy fuel oil and 291 m³ of marine diesel oil. Bunkering for a complete round trip was always done in Stockholm.

3.2.4

Electrical system

The three-phase, 380 V, 50 Hz electrical system was fed by four main electrical generator sets. They had an output of 1065 kVA each and were of the brushless type, self-exciting and self-regulating, and capable of parallel operation.

The generators were driven by four-stroke trunk diesel engines, each supplying 1104 kW at 750 rpm. The engines had superchargers and intercoolers, and could run on heavy fuel oil. They had all the necessary instrumentation and controls for automatic operation.

Transformers provided 220 V single-phase power for lighting and utility functions. The main electrical switchboard was in the engine control room.

An emergency generator set in compliance with the SOLAS requirements was installed in a separate room on deck 8 near the engine casing. The generator was powered by a diesel engine with an output of 312 kW at 1500 rpm. It supplied the emergency lighting system and also essential bridge equipment, including engine control, steering system, radars, gyrocompass, logs, echosounder, navigation lights, search lights, radio sta-

tion, telephone system and public address system.

The emergency generator unit was designed to start automatically in case of loss of electrical power in the main network. The total starting and switch-in time was about 15 seconds. The unit could also be controlled manually from an emergency switchboard in the emergency generator room.

Accumulators for emergency power in case of loss of all other electrical supply were installed in compliance with the SOLAS requirements.

3.2.5 Ballast system

Two centrifugal ballast pumps were installed, each with a capacity of 300 m³/h. The pumps served ballast tanks which were the forepeak tank, the forward trim tank, two double-bottom tanks, one pair of heeling tanks and the aft peak tank, giving a total capacity of 1212 m³.

The heeling tanks were side tanks with a capacity of 183 m³ each and intended for adjusting the list of the vessel as needed. The list that could be compensated for with one heeling tank full and the other empty was about eight degrees. The connecting valve between the heeling tanks was designed to close in case of failure of electrical power.

The separate heeling tank pump could be operated from the deck office at the aft ramp and from the engine control room.

3.2.6 Car deck arrangement

The vessel had a deck for loading trucks, cars and other wheeled cargo. The car deck was the vessel's freeboard deck and identified as deck number 2. It extended from side to side and from bow to stern, with a centre casing immediately starboard of the centre line. The available deck space was divided into four lanes on the port side and three on the starboard side.

Hanging car decks were arranged, stowed hoisted underneath deck number

4. When lowered to deck position number 3, the hoistable decks could be used for passenger cars. The starboard hoistable decks extended over the full deck width between the ship's side and the centre casing and the port decks from the ship's side for the width of the two outer lanes. These decks at each side were divided transversely into six sections, the foremost and aftmost ones being sloping ramps to the elevated decks.

Lashing fittings were mounted along the lanes on the car deck.

Personal access to the car deck was via stairs and lifts in the centre casing. Four of the lifts had doors leading to the starboard side of the car deck and one had doors to the port side. A total of eleven doors, six starboard and five port, led from the car deck to the stairs inside the casing. The doors were sliding-type steel doors, meeting the SOLAS fire resistance requirements. The locks of the doors were remotely operated from the information desk on deck 5. The doors were locked at sea. They could, however, always be opened for passage from the car deck to the casing. Similar doors served the hoistable car decks.

The car deck space was ventilated by electrically driven fans, located on both sides at the forward and aft ends of the

deck area and terminating at deck 4. The fans were together capable of providing 20 air changes per hour. The fans could be reversed and used for evacuation or for forced ventilation.

A smoke detection system covered the entire area. The system had its control and alarm panel at port side of the bridge.

A fire-fighting system was installed, based on water sprinklers mounted to cover all areas including the hanging car decks.

Twelve closable 4" scuppers were installed along each side of the deck. The scuppers were normally left open.

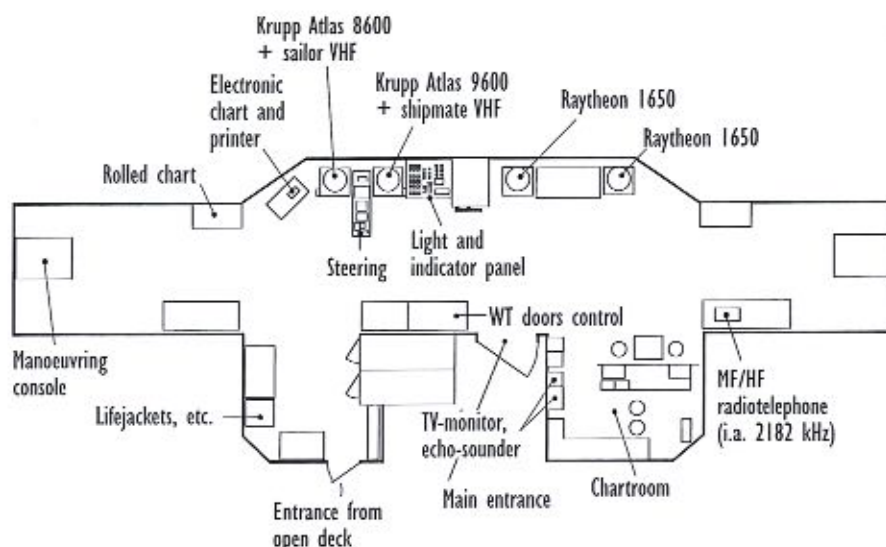
TV cameras for monitoring the car deck area were mounted as described in 3.3.5.

3.2.7 Bridge layout

The navigation bridge (Figure 3.3) was on the uppermost deck (deck 9), 9.2 m aft of the forward end of the superstructure. The bridge wings extended over the ship's sides by about 1.5 m and were fully enclosed.

The central part of the bridge extended forward of the wings by about 2 m. In the original design there was a console containing all major navigation and con-

Figure 3.3 Layout of the bridge.



trol equipment at the front bulkhead, just below the windows. The steering console was located on the centreline, just behind the front windows.

The bridge was rebuilt in January 1994 and some of the navigation equipment was renewed. The navigation console at the front bulkhead was partly removed, and a new conning station was constructed port of the centreline. The design of the conning station was of the Pilot-Copilot type, commonly used in Baltic ferries.

The new console contained two ARPA radars, DGPS (Differential Global Positioning System) receivers, the main autopilot, propulsion control levers, VHF telephones, mobile telephones and equipment for internal communications. From the two navigators' seats, and the captain's seat, normally placed to the port of the conning console, the panel with indicator lamps for visor and ramp was within sight.

The fin stabilisers and associated controls were also installed in 1994. The original "Roll-Nix" stabilisation system had been found inadequate. It was, however, not removed and had sometimes been used in strong following wind.

A separate chartroom was located on the starboard side, in the aft part of the bridge. The corresponding space on the port side was an open area containing the fire alarm centre and various cabinets for storage etc.

The main entrance to the bridge, from the accommodation, was on the centre line at the aft end of the bridge, where a door to the staircase connected the bridge with the officer and crew accommodation on decks 8 and 7. On the port side at the aft end of the bridge there was a door to the open deck.

Because of the retracted position of the navigation bridge, the bow of the vessel was not visible from the conning station, as Figure 3.4 indicates.

A monitor for the internal TV surveillance system was placed in the entrance to the chartroom and facing starboard. The monitor picture could not be viewed from the conning station.

3.2.8 Navigation equipment and systems

The navigation equipment was of a high standard, and met the requirements for the intended traffic.

The equipment had been upgraded and/or renewed on several occasions, and at the time of the accident the following equipment was installed on the bridge for navigation and vessel control:

- Radar, Atlas 9600 Arpa X-band
- Radar, Atlas 8600 Arpa S-band
- Radar, Raytheon 1650 12 SR Raycas
- Radar, Raytheon 1650 SR (slave to item 3)
- 2 Gyrocompasses, Sperry MK 36
- Magnetic compass, Plath
- Autopilot, Kockum Steermaster 2000
- Autopilot, Sperry Universal
- Speed Log, Raytheon Doppler Sonar (one axis)
- Echo sounder, Simrad DSN 450
- Radio direction finder, Debeg ADF 7410
- Antiroll system, Roll Nix (SSPA)
- Stabilisers, Brown Brothers folding fins

- Navigation computer, Navi Master NM-1000
- GPS receiver, Shipmate 5800 C
- DGPS receiver, Shipmate 5360
- DGPS receiver, Magnavox 200
- Speed/Fuel Consumption Optimisation Computer, ETA-Pilot

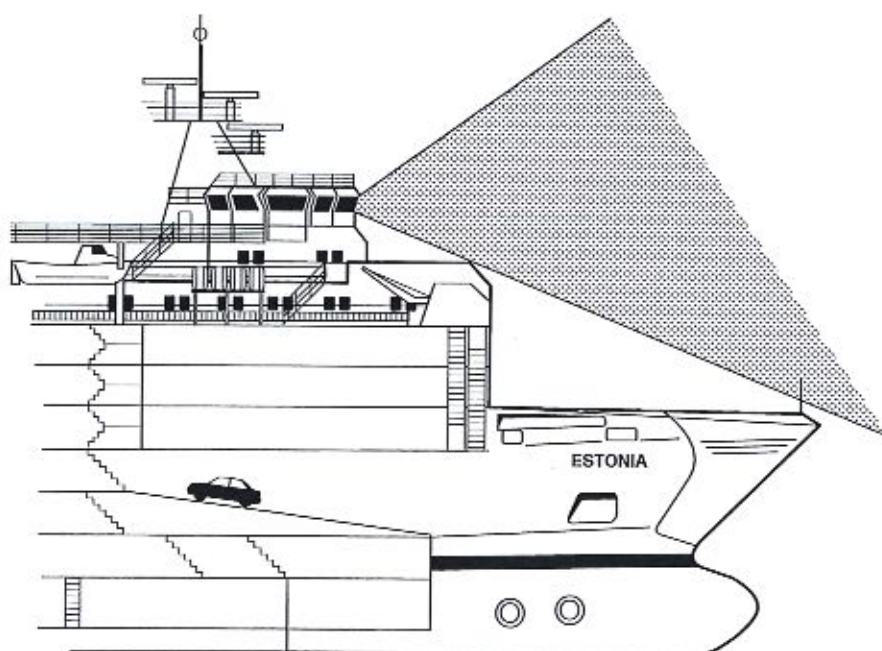
3.2.9 Communication equipment

The communication equipment was divided between the bridge and the radio room.

The vessel's radio room was on deck 8, aft of the captain's cabin. The radio room was mainly used for commercial communication, and contained the following equipment:

- Main Transmitter, Standard Radio ST-1680 A
- Main Receiver, Skanti AS SR-51
- Emergency Transmitter, Standard Radio ST-86 B. A1, A2, A3
- Emergency Receiver, RI. Drake RR - 11
- Autoalarm IMR A4 734/SRT B-2290 1000
- VHF Svensk Radio STR-40 - ME62

Figure 3.4 Approximate field of vision from the bridge.



In addition to the equipment in the radio room, the following was installed on the bridge:

- MF/HF radio telephone
- VHF Svensk Radio STR-40-ME62
- VHF Sailor (1 master and 3 slaves)
- VHF Skanti
- Watch Receiver DC-300D
- NAVTEX receiver
- Lifeboat Radio IMR SOLAS III A
- Mobile Telephone NMT 450
- Weather Fax Receiver

Two Emergency Position-Indicating Radio Beacons (EPIRB) were mounted, one on each side of the top of the bridge. These EPIRBs are discussed in detail in 3.4.4 and 8.1.1.

3.2.10

Maintenance, modifications and damage

The vessel was maintained by the owners to class satisfaction in line with common practice and requirements. The surveys for maintenance of class were carried out by Bureau Veritas on a continuous five-year timetable for hull and machinery in combination with a schedule of annual surveys. On average, the surveying programme involved five to six on-board survey visits per year.

The vessel was also subject to the Port State Inspection programme in compliance with the Paris Memorandum of Understanding on Port State Control (see about Paris MOU in 9.1). Technical Port State inspections were carried out in February, April and December 1993 and March 1994. The first inspection was in connection with the start of traffic on the Tallinn–Stockholm route and did not give rise to any remarks. The next inspection was the consequence of an oil spill in the Stockholm Archipelago, the cause of which was a leaking stern tube seal (see below). At the third inspection three remarks of less significance were noted. The last inspection did not give rise to any remarks.

The annual drydockings were mostly at the Turku Repair Yard. Two were at the

Valmet Helsinki Yard, one after grounding damage in 1984 and one in 1985 for repair of ice damage and for modification of the stern area of the hull by incorporation of the "duck tail" extension. Two drydockings were made in Stockholm, one in 1985 for repair of a leaking propeller shaft seal and one in 1988 for repair of grounding damage. The damage was surveyed and repaired in dry dock following normal practice.

Besides the ice damage in 1985, two other occasions of ice damage were recorded, during the winters of 1982 and 1987.

The drydocking in conjunction with transfer to the Effjohn Group was done in 1990 at the Naantali branch of the Turku Repair Yard.

The vessel was laid-up at the Perno shipyard outside Turku for some months at the beginning of 1991 before she was put in service on the Vaasa trade. The interior was upgraded and the sound proofing in the cabin area was improved during this time.

The drydocking in connection with delivery to E-line in 1993 took place in Turku. On this occasion all signs and instructions were replaced by new ones in Estonian, Swedish and English. New surveys for certificates were carried out and the fire protection installations were upgraded to satisfy new, more stringent, SOLAS requirements.

The vessel was dry-docked twice in Turku – in March and April 1993 – to correct a leaking stern tube seal.

A public area on deck 5 was rebuilt during service in 1993 to accommodate a new bar and an area with airline-type seats.

The fin stabilisers were installed in dry dock at Naantali in January 1994.

One or two replacements of propeller blades in conjunction with drydockings have been reported. Minor on-board repairs of cracks in the ramp locking devices were reported a couple of times. Damage to a visor hinge pin was once repaired at the Finnboda yard in Stockholm. For further details regarding damage of the bow visor and the ramp, see 3.3.6.

No other damage to the vessel has been reported throughout her history.

Individuals concerned with maintenance of the ship during the various periods of her life have generally expressed satisfaction with the vessel as a sound and trouble-free one.

3.3

Bow visor and ramp installation

3.3.1 General

The bow visor and ramp installation of the ESTONIA was of a configuration common on ferries in traffic between Finland and Sweden at the time of her construction. The installation comprised an upward-opening bow visor and a loading ramp, hinged at car-deck level and closed when raised. In closed position, the upper end of the ramp extended into a box-like housing on the deck of the visor.

The complete bow ramp and the operating and locking devices for the visor as well as the aft ramps and the car platforms were designed and delivered by an independent company, von Tell AB, an established supplier of cargo handling equipment and systems. The design was based on a detailed specification by the shipyard. Von Tell AB used a subcontractor, Grimmereds Verkstads AB, for manufacturing complete sets of components for the ramps, the car platforms and the visor locking devices. The routine contacts between the yard and the supplier were via von Tell GmbH, a subsidiary of von Tell AB. Incorporation of the system into the ship and manufacture of the attachment structure were shipyard work. The equipment delivered by von Tell was identical to that built for the preceding newbuilding, DIANA II, except for the slightly increased length of the ramp and the changes of the car platforms dictated by the greater length of the vessel. According to available in-

formation the visor operating and locking system design for DIANA II was the first delivered by von Tell AB.

The Bureau Veritas rules valid at the time had no details regarding procedures for calculating sea loads on the bow visor installation. It was stated in general wording that doors should be firmly secured and that structural reinforcements should be made to attachment points of cleats, hinges and jacks. The general wording in the rules also specified that the scantlings of the visor structure should be equivalent to that of the hull itself.

The vertical and longitudinal sea loads to which the bow visor could be exposed were calculated separately by the yard and by the von Tell company. The Bureau Veritas rules gave no detailed guidance for such calculations. The yard therefore used for this purpose nominal "pressure heights" given by Bureau Veritas in a note (Note Documentaire BM2, 5.4.1976), originally issued as general guidance for determining the loads on the bows of large ships.

The von Tell company used nominal pressure heads per unit of projected area specified in the rules of Lloyd's Register of Shipping, valid at the time. It has not been possible to verify in detail what exchange of information on this issue took place between the yard and the supplier prior to the detailed design of the von Tell equipment.

The general arrangement of the ramp and visor installation is shown in Figure 3.5.

3.3.2

Detailed technical description of the bow visor

The visor

The visor was the most forward part of the vessel's hull and was a steel structure similar to the normal bow structure of a vessel. The general shape and design are shown in Figure 3.6. The visor consisted mainly of the shell plating, being an extension of the ship's shell plating and contour, the deck part, the bottom part,

Figure 3.5 Bow visor and ramp installation.

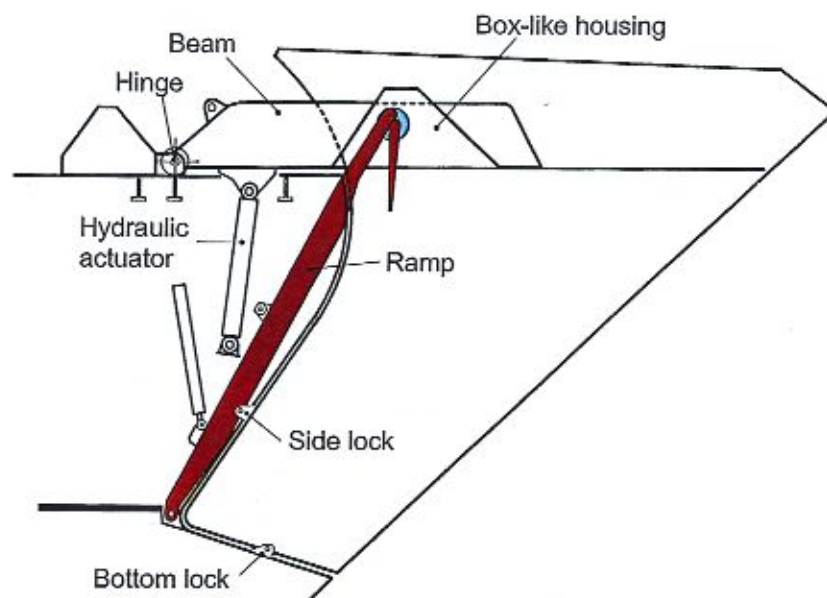
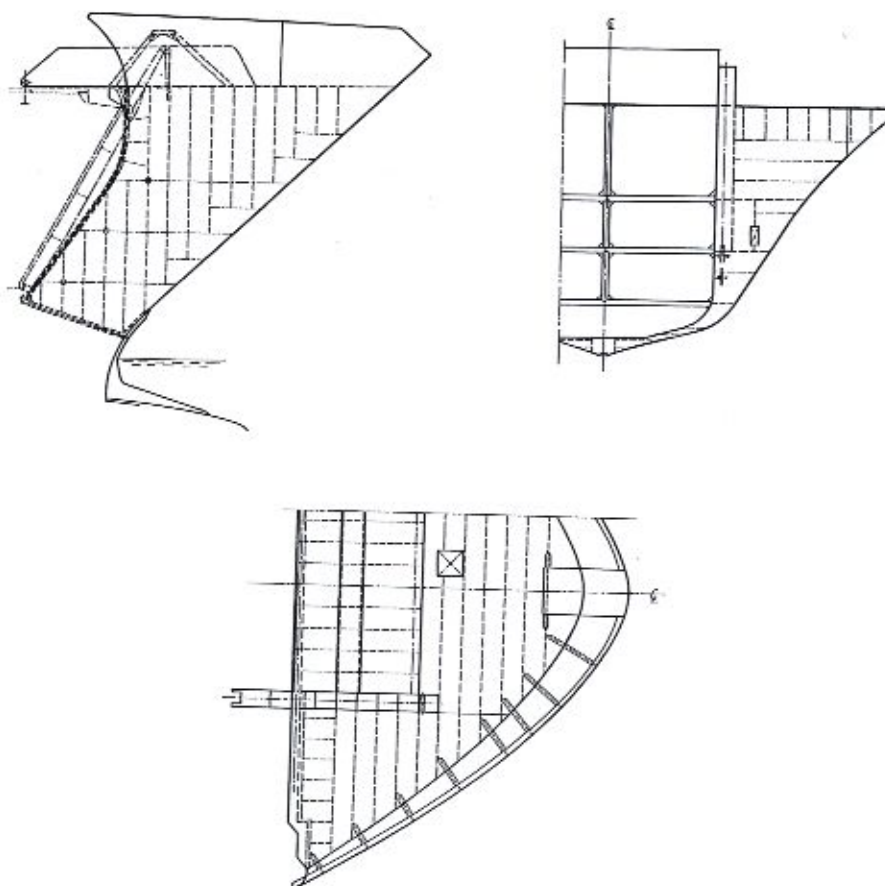


Figure 3.6 Bow visor general arrangement and structure.



the aft bulkhead and internal horizontal stringers, vertical partial bulkheads and transverse stiffeners. The internal structure was connected with a stiff tubular framework. Two beams on deck extended aft of the visor aft end and carried the hinge arrangements for the pivoting points of the visor. The lowest strake of shell plating was reinforced in order to satisfy the ice class requirements. The visor weighed about 56 t.

The visor including attachment devices was built of grade A mild carbon steel (yield strength minimum 235 N/mm², ultimate tensile strength 400–490 N/mm²).

The deck of the visor had a box-like housing between the two beams, enclosing the upper part of the ramp when the ramp was closed. The geometry was such that the ramp had to be fully closed in order not to interfere with the visor during its opening and closing.

The visor pivoted around the two hinges on the upper deck during its normal opening and closing. It was secured in the closed position by three hydraulically operated locking devices at its lower part. One of these was mounted

on the forepeak deck and the other two on the hull front bulkhead with mating lugs on the visor. Additionally, two manual locking devices were located in the area of the hydraulic side locks. Three locating horns, one on the forepeak deck and two on the front bulkhead, engaged recesses in the visor in order to guide the visor to its proper position when being closed and to absorb lateral loads.

The visor was supported vertically in the closed position by the two deck hinges and rested further on three points on the forepeak deck. One of these was the solid stem post of the visor, resting on the ice-breaking stem on top of the bulbous bow, the other two were steel pads on the forepeak deck. The three locking devices kept the visor down in its closed position and the locating horns absorbed any side loads that might develop. Longitudinal loads were carried by the hinges, the locking devices and possibly by direct contact between the visor and the front bulkhead of the hull.

The visor was supported in the open position by the two hinges and two parking devices consisting of hydraulically operated bolts engaging lugs on the hinge

beams.

Rubber seals supported by steel flat bars were installed on the forepeak deck and the front bulkhead, together making a continuous seal against which the visor abutted when closed.

The bottom lock

The bottom locking arrangement is shown in Figure 3.7. The bottom lock was sometimes named the "Atlantic lock" as it was not in common use in early ferries but was later introduced to enable similar ferries to cross open oceans. The "Atlantic lock" had become established by the time the ESTONIA was built. The locking device consisted of a locking bolt, movable horizontally in a transverse direction, guided in a bolt housing. In extended position the tip of the bolt engaged a support bushing. The bolt housing was fixed to the forepeak deck by means of two steel lugs and the bushing was installed in a third similar lug. A mating lug, attached to the bottom structure of the visor, was located between the bolt housing and the support bushing when the visor was closed and the extended bolt then engaged the hole in the mating lug.

The bolt was moved in the bolt housing between the retracted position and the extended position by means of a hydraulic actuator, operated from the visor and ramp control panel as described in 3.3.5. A spring-loaded mechanical plunger, movable perpendicularly to the bolt, engaged grooves in the bolt in the open and closed positions respectively, thereby securing the bolt mechanically in its extreme positions regardless of hydraulic pressure. The bolt was also locked hydraulically at any time because the hydraulic fluid was trapped in the system, regardless of whether the system was under pressure or not.

Two magnetic position sensors were installed, actuated by a magnet attached to a bracket on the bolt. The sensors were actuated when the bolt was fully retracted or fully extended. The hydraulic control system as well as the arrangement and functioning of the sensors and the

Figure 3.7 Bottom locking device installation on forepeak deck.

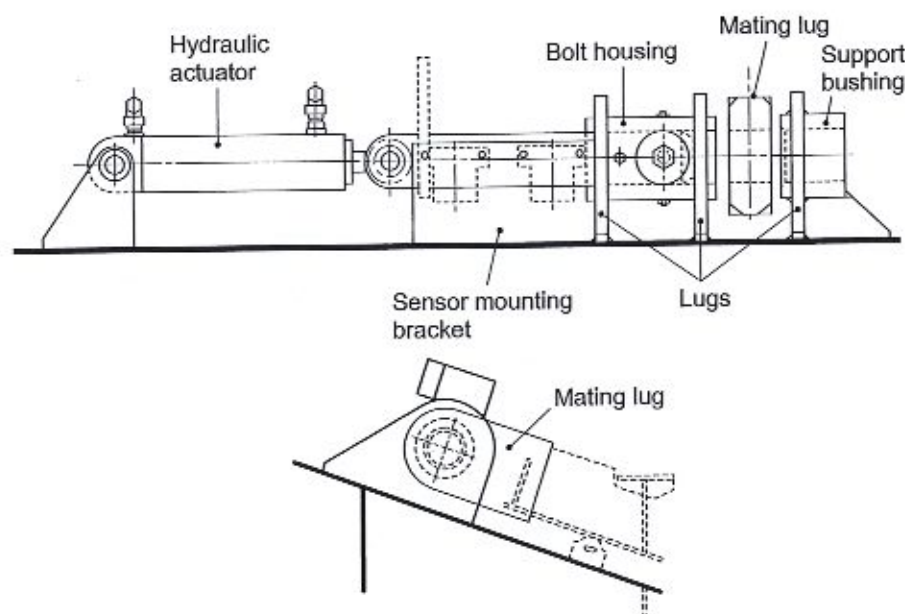
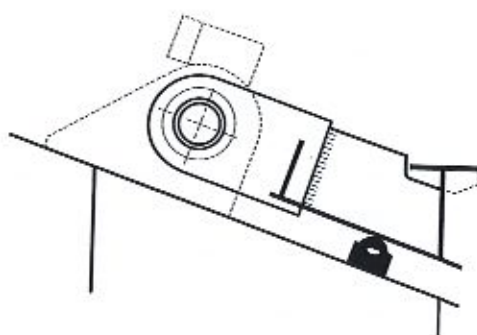


Figure 3.8 Lug of visor, mating the bottom locking device.



position indication and alarm system are covered separately in 3.3.5. The original mechanical switches were replaced by the magnetic sensors in the mid-1980s.

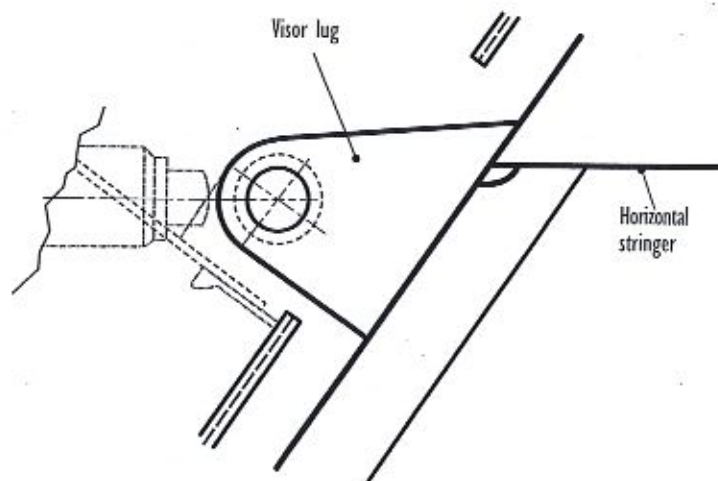
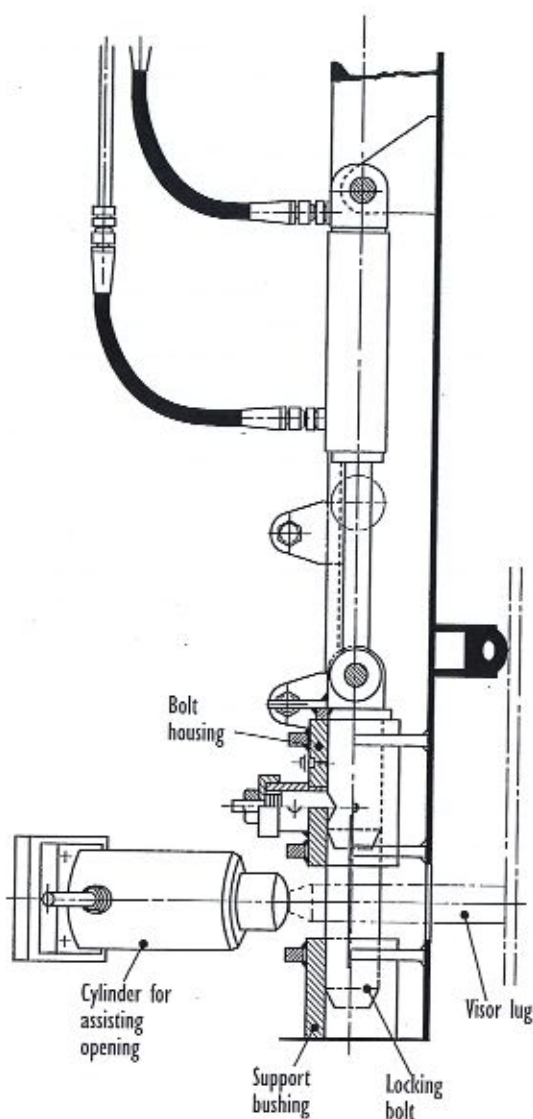
The mating lug in the bottom structure of the visor consisted of a single steel lug, welded to a transverse beam of the visor bottom structure and supported by a bracket as shown in Figure 3.8. The diameter of the bolt was 80 mm in the original von Tell drawing. The lug had a hole for the locking bolt with an original diameter of 85 mm.

The failure mode of the bottom lock installation and related findings are covered in Chapters 8 and 15.

The side locks

The side locks consisted of two lugs, attached to the aft bulkhead of the visor and extending, when the visor was closed, into two recesses in the front bulkhead of the hull, one at each side of the ramp opening. The visor lugs overlapped a horizontal stringer. In the closed position, hydraulically-operated bolts engaged holes in the lugs. The arrangement is shown in Figure 3.9. The hydraulic bolt installations were similar to that of the bottom lock, i.e. a bolt moving in a housing and, when extended, engaging a support bushing. The visor lug inserted between the bolt housing and the support bushing. The bolt was moved by a hydraulic actuator. A spring-loaded mechanical plunger was installed. The posi-

Figure 3.9 Side locking device, port and starboard.



tion of the bolt, fully retracted and fully extended, was sensed by magnetic position sensors.

Additional hydraulic cylinders were installed at each side to push forward on the visor lugs when the visor was to open. This installation was intended to assist in breaking the visor open in case it had become stuck in the closed position due to icing.

Two local vertical stiffeners on the forward side of the visor bulkhead plating were separated by a distance slightly larger than the thickness of the lug itself. These stiffeners were installed to satisfy a Bureau Veritas surveyor's requirement, as written on the bow visor assembly drawing, for "local reinforcements of the ship's structures in way of locking devices". The fillet weld of one of the stiffeners had some overlap with the fillet weld of the side-locking lug on the opposite side of the bulkhead plating. No other arrangements were made in the design to transmit forces from the lugs into the structure of the visor.

Manual visor locks

Two manual locks were installed, one at each side and mounted just below the hydraulic side locks. Each lock consisted of two lugs welded to the aft side of the visor and a hinged eye bolt with nut, mounted between two lugs in the front bulkhead as shown in Figure 3.10. In

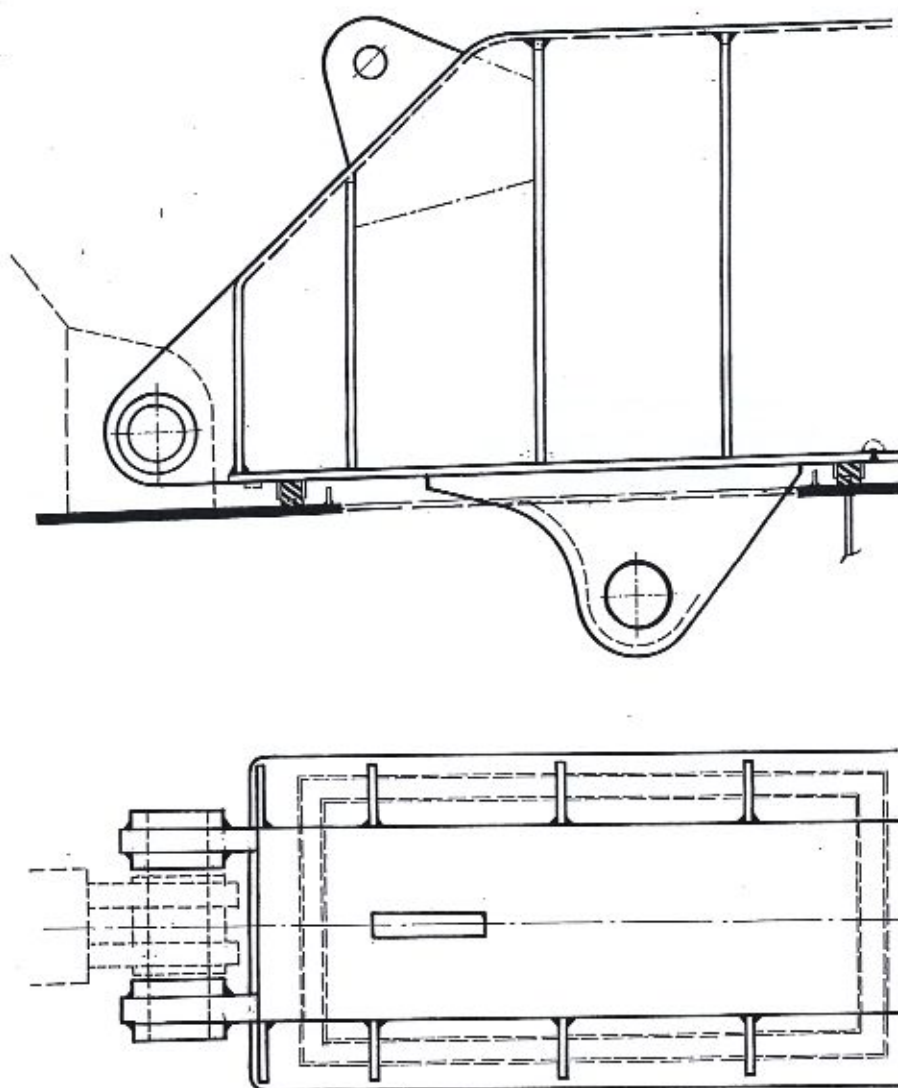
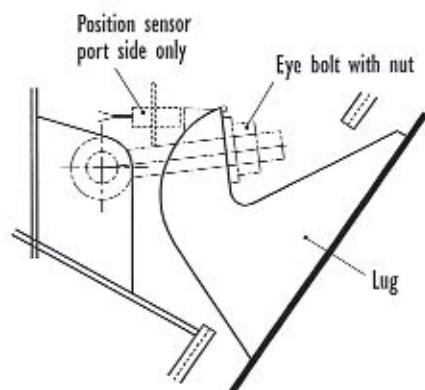


Figure 3.11 Arrangement of deck hinges and deck beams.

Figure 3.10 Manual locking device, port and starboard.



closed position the eye bolt was swung into position between the two lugs in the visor and the nut was tightened down. The locks had no remote position indicating devices.

The manual locks were described in the supplier's instruction manual as "reserve". No advice was given anywhere in instructions from the maker, the shipyard or operators as to the use of these manual locks.

The deck hinges

The two beams on the deck of the visor extended about 3 metres aft of the visor. Each beam had a box structure, including heavy-gauge side plates, top and bottom plates and various internal and external brackets and stiffeners. The ends of the beam side plates carried the hinge arrangements (Figure 3.11). A heavy steel bushing was welded into a hole in each of the two side plates of each beam. The

bushings had a bore, carrying a bronze bushing.

The deck part of the hinge consisted of two lugs welded to the deck, carrying between them a steel housing. This deck part was located, in the installed arrangement, between the two bushings of a visor beam. A steel shaft was installed through the entire assembly, secured by locking plates bolted to the outer ends of the hinge bushings. The bearings were lubricated through drillings in the shaft and grease nipples at its ends.

3.3.3

Design documentation for the bow visor and its locking devices

As mentioned in 3.3.1 the shipyard calculated the vertical and longitudinal total forces on the bow visor. The loads so arrived at were assumed to act in the centre of the projected areas. The total vertical force, 536 t, was in the calculations (see Supplement) distributed evenly between all five attachment points, including the hinge points. The total longitudinal force was calculated to 381 t. By a procedure analysed in more detail in Chapter 15, the calculations arrived at a design load of 100 t per attachment point.

These calculations were hand-written and were intended to determine design data for minimum effective cross-section of a lug. By assuming high-tensile strength steel, an allowable tensile stress of 164 N/mm² was used, indicating a required minimum cross-section of 6100 mm² in the loaded direction of the locking device. These calculations were not dated and they were not submitted to Bureau Veritas for examination.

The normal drawings were submitted to Bureau Veritas for examination and approval, including the following:

- 590/1103 rev 6, *Bugklappe, Meyer Werft* (Bow visor, Meyer Yard)
- 590/1106 rev G, *Bugklappeverriegelung, Meyer Werft* (Bow visor locking devices)
- 49111-373 *Atlantiksicherung, von Tell*

(Atlantic lock)

- 590/1101a, *Vorshiff, spt 149-vorne bis A-Deck, Meyer Werft* (Foreship from frame 149 to fore end and up to A deck)
- 49111-372, *Automatische und manuelle Verschlussanordnungen für Bugklappe, von Tell* (Automatic and manual locking devices of bow visor)
- 49111-330, *Bugklappe und Bugrampe Zusammenstellung, von Tell* (Bow visor and bow ramp assembly)

The Bureau Veritas surveyor examining the drawings made by the shipyard and by von Tell made various additional notes in conjunction with the examination. On the von Tell assembly drawing for the ramp and the visor it was stated that the arrangement of the locking devices should be subject to approval by the national administration. This drawing was approved by Bureau Veritas in November 1979. The shipyard assembly drawing for the visor likewise had a remark that the arrangement of the locking devices should be subject to approval by the national administration. It further carried a note requiring "local reinforcements of the ship's structures in way of locking devices, cylinders and hinges to the surveyor's satisfaction", and a note requiring that the lifting lugs, the bottom lock visor lug and the side lock lugs should be made of grade St52-3 steel (high-tensile strength steel to cold toughness class 3). This shipyard drawing was not approved until 20 June 1980, as the drawing had only then been submitted to Bureau Veritas. The yard, however, learned informally about the note on the von Tell drawing through the Bureau Veritas site surveyor in March 1980.

There was also correspondence about approval of the drawings in December 1979 when the von Tell company asked the Finnish Maritime Administration which drawings the Administration wanted to examine and approve. The Administration replied that it assumed that all drawings had been approved by Bureau Veritas and that it was satisfied with this unless any matter of interpretation of the

rules should arise. No reference was made in this correspondence to the Bureau Veritas note about approval of the locking devices.

Further telex communication about approvals took place between Bureau Veritas and von Tell in March 1980 when von Tell was questioned about the loads applied in the design of the locking devices. The von Tell design office explained that it had, lacking detailed guidance in the Bureau Veritas' rules, used the Lloyd's Register of Shipping rules. These calculations had indicated a load on each locking device of about 80 t, and this value had been used in the design of the locking bolts. In the same telex, von Tell expressed their concern about the stresses, presumably in the locking bolts, which were slightly above the stresses permitted by Lloyd's Register of Shipping. These calculations were not submitted to Bureau Veritas for examination.

The von Tell company made detailed and assembly drawings for the various part systems and components delivered by them. In the case of the bottom lock the assembly drawing indicated three mounting lugs to the ship structure, compatible with the overall design of the locking device. Similarly the side locking lugs were identified on the assembly drawing for the side locking devices. The parts were identified as "Werfllieferung" (shipyard supply) on the drawings. Main dimensions of these parts were indicated although no normal manufacturing information. The drawings did not make it clear whether the information given was for reference purposes only or was intended as guidance for manufacturing.

The shipyard steel drawing for the bow visor (590/1103) indicated the mounting of the mating lug for the bottom lock and also the lugs for the side locks. No welding instructions were given for these detailed parts on the shipyard drawing, nor in von Tell drawings 49111-372 and 49111-373. No arrangements for structural continuity behind the devices were shown.

A group of experts appointed by the shipyard to investigate the ESTONIA

accident have commented on some of the conclusions in the Commission's Part-Report and inter alia stated the following:

" a.) Contrary to the practice of other newbuilding yards Meyer Werft designers do not state the required thickness of welding seams individually on the respective drawings, but make up a so-called "welding table" for each newbuilding. In this table the minimum thickness of welding seams for particular structural parts is stated. The table is approved by the class. - b.) In case the particular structural part to be welded does not fall under the categories listed up in the welding table, the welder follows the yard welding standard. - c.) The yard welding standard requires a welding seam thickness for structural parts accessible from both sides, e.g. bushings to be welded into the lugs of the Atlantic lock, to correspond to at least 50 % of the thickness of the part to be welded and 70 % as a maximum value. In other words, a structural part welded respectively is connected by welding seams corresponding to at least 100 % of its own cross-section".

No detailed assembly drawing existed for the side locks although an extract from the von Tell assembly drawing for the side lock and with the lug bottom length of 370 mm added is said to have been released to the workshop for manufacturing. The length indicated on the yard assembly drawing of the visor was about 550 mm. The lugs for the side locks were shown fitted by fillet welds to the flat surface of the aft bulkhead of the visor, being a plate of 8 mm in thickness.

Some other discrepancies have been noted between the steel drawing for the visor and the actual installation in the visor as recovered. These include the absence of some longitudinal and transverse stiffeners in the bottom structure of the visor. This matter is further covered in 8.12.

3.3.4 Detailed technical description of the bow loading ramp

The ramp was a steel design with four longitudinal beams and a number of transverse beams. A steel plate made up the upper surface of the ramp. Additional stiffeners were arranged between the main beams.

The ramp was longer than the available deck height and therefore protruded by about 1.2 m above the level of the upper deck (deck 4) when in the raised, i.e. closed, position. This extension was enclosed in the box-like housing on the visor deck. Flaps at the tip of the ramp were hinged along its front end and were controlled by means of steel cables to extend when the ramp was lowered. The cables were engaged on bellcranks at the ends of the flap axis. When the ramp was closed these flaps hung down to keep its total length as short as possible.

The ramp was hinged at its aft end to the hull structure by four hinges. Each hinge consisted of a steel lug welded to the hull and two lugs welded to the aft beam of the ramp. Bushings and hinge pins completed the hinge installation. The outer hinges were heavier than the two inner ones.

Raised bars were welded onto the sides of the ramp. Fixed railings were mounted on each side.

The ramp was manoeuvred by two hydraulic actuators, one at each side. Preventer wires served to avoid excessive opening. When in the raised, closed, position the ramp was pulled in by two locking hooks, engaging pins in the side beams of the ramp. These hooks were hydraulically operated via a lever mechanism arranged to move past its dead centre during the locking movement and to stay in this mechanically secured position.

Two additional wedge-shaped locking bolts were mounted along each side of the ramp. These were hydraulically operated, moving transversely in the ramp coaming. In the extended position they engaged box-like extensions on the ramp

side bars. Mechanical friction plungers were installed in each locking bolt housing.

All the locking devices had position sensors for their retracted and extended positions as described separately in 3.3.5.

A rubber seal, supported by steel flat bars, was arranged in the ramp coaming and formed a weathertight seal against the surface of the ramp when the ramp was in the closed position.

3.3.5 Actuating, monitoring and control systems for the bow visor and the ramp

A control system served the ramp and visor installation. The system was supplied by the maker of the ramp and visor actuating systems. It was described in an instruction booklet issued by the supplier.

The control system consisted of a high-pressure hydraulic system with tank and three pumps plus the normal components of a hydraulic power system, providing hydraulic power to a control panel and to the visor and ramp operating and locking devices. The original hydraulic pumps which had been set to provide 180 bar pressure had been replaced in the mid-80s due to their inability to give adequate pressure. The new pumps had a maximum pressure rating of 400 bar and were set to deliver 225 bar to the system.

The two cylinders for opening the visor operated in parallel, the operating speed limited by restrictor valves. No other devices were incorporated for ensuring that operating speeds of the two cylinders remained equal.

The control panel was mounted on the car deck at the port side, just aft of the ramp. It contained manual control levers for separately operating:

- the visor bottom lock
- the visor side locks
- the open visor parking plungers
- visor opening/closing
- the ramp pull-in hooks and locking bolts
- ramp opening/closing.

The opening/closing control for the ramp and the visor was effected by solenoid valves so connected that the visor could only be manoeuvred when the ramp was closed and the ramp could only be opened when the visor was open. The interlock system further ensured that the ramp and the visor, respectively, could only be manoeuvred when the related locking devices were open.

In normal operation the indicator lamps were monitored by the operator for proper function of each step during opening or closing, before the next step was activated.

The panel had red and green lights, powered via the sensors at the actuators for the visor and ramp locking devices. Position sensors were also installed to sense fully closed or fully open visor and fully closed ramp, respectively. The panel had red and green lights separately for the bottom lock, the side locks, the parking devices, the ramp locking devices, and the positions of the visor and the ramp. The lamps for the locking devices were controlled separately by one position sensor for retracted position and one for extended.

The sensors for the visor side locks were wired in series as were those for the parking devices. Should any locking bolt be in an intermediate position no switch was activated and neither the red nor the green lamp was illuminated for that function.

Visor position was indicated by two sensors, one for "fully closed" and one for "parked". The "fully closed" sensor was mounted on the port manual locking device. Both positions were indicated with green lamps. A red "parked visor" lamp was on at all times when the parking bolts were retracted and was thus on at sea.

The panel section for ramp operation had red and green lamps for the locking devices, all wired in series. A red or a green lamp would come on only when all the locking devices had moved to the required position. If one device was in an intermediate position no lamp would come on. An independent position sen-

sor mounted at the upper port side of the ramp coaming indicated fully closed ramp by showing green. There was no lamp for open ramp.

It has been stated that the lower locking bolt on the port side of the ramp sometimes failed to go to fully extended position. The standard procedure was then to retract the bolt and again command it to locked position, whereby it would normally go to fully extended position and the green indicator lamp would come on.

The position indicators for the visor side locks and for ramp locking were also wired to the bridge, with one set of red and green lamps for the visor side locks and one set for the ramp locking devices. The actual position of the visor itself or the ramp itself was not shown on the bridge indicator panel, nor was the position of the bottom locking device. The lamps on the bridge would only come on if all the devices wired in series for that function, i.e. both side locks for the visor and all six locking devices for the ramp, respectively, were in the required position.

The indicator panel was mounted in the front console of the bridge, starboard of the seat of the officer of the watch.

Four TV cameras were installed for monitoring the car deck. One fixed camera monitored the area of the forward ramp and one the aft ramps. One turnable camera admidships at each side of the casing was for monitoring the rest of the car deck area. The cameras were operated independently from a control panel with monitor on the bridge. A second monitor and control panel were installed in the engine control room.

The indicator lamps on the bridge for the bow visor and ramp had been installed from the beginning. The monitoring cameras had been fitted later as a consequence of more stringent requirements following the HERALD OF FREE ENTERPRISE accident. The original indicator lamps on the bridge had been found adequate by the Finnish Maritime Administration for compliance with the new SOLAS Reg II-1/23-2 as applicable to existing ships.

3.3.6

Surveys, maintenance, damage and repairs

Survey of the bow visor and ramp for class was part of the continuous hull survey scheme. The bow door area was last inspected under this five-year rolling scheme in October 1993. No remarks related to the bow visor and the ramp have been recorded from any of these surveys.

Maintenance of the operating and control system was, after the one-year guarantee period during the Finnish flag period, carried out by the Turku service base of the MacGregor group. The piston rod end bearing and pin for the port visor opening actuator were renewed in May 1990 due to play. New rubber seals for the visor and ramp had been supplied almost yearly. No other discrepancies had been recorded or other work carried out.

The visor locking devices and their operation were inspected every year by the MacGregor service base in Turku. The locking devices operated properly every time. According to information obtained from the service base it is very unlikely that any repair work would have been done on the visor locking devices without their knowledge during the period they maintained the operating and control system.

Just before transfer to Estonian flag at the end of 1992 attention had been given to the strength of the ramp and visor locking devices and a quotation for reinforcing them had been requested by Wasa Line. However, nothing was made to the locking devices.

After transfer to Estonian flag no more service work was carried out by the MacGregor service base in Turku as the regular maintenance was carried out by the ship's crew and, according to the new owners, no need for external service had developed. New rubber seals had, however been ordered. It was known that the play in the ramp hinges was approaching the point where corrective action would be needed.

The locking bolt position sensors of

the visor's locks were originally of mechanical type. These were replaced whilst the ship was still on the Turku-Stockholm route by sensors of magnetic type, being less sensitive to moisture.

Minor routine welding repairs had been carried out on the mating boxes for the ramp locking bolts whilst the ship was in service in the Gulf of Bothnia. Local welding of a crack in a stiffener underneath the mounting platform for the port side visor actuator has been noted.

One of the visor hinge pins had, according to verbal information, a tendency to move out of position, breaking away the locking plate. This was repaired once at the Finnboda yard by pushing the hinge pin back in place and drilling for new locking bolts.

No other repair was, according to available information and extensive search, carried out during the lifetime of the vessel on or in the areas of the various operating and locking devices for the ramp and the visor.

As mentioned in 3.2.10, damage due to ice was recorded in 1982, 1985 and 1987. Damage to the bow visor occurred

at those times. The first-mentioned was minor and was not claimed from the hull insurance company. The last one was the most extensive and included replacement of the strake of plating next above the one originally reinforced, i.e. the second-lowest strake on the visor and at the corresponding level somewhat aft of the visor. The thickness of the plating was increased from the original 14 mm to 20 mm (the thickness of the lowest strake was 28 mm). The extent of this repair is illustrated in Figure 3.12. No damage was recorded and no work was done to the bottom or the stem post of the visor, or to the locking devices.

3.4 Emergency and life-saving arrangements and equipment

3.4.1. General

The requirements for emergency and life-saving equipment are governed in detail

by the SOLAS convention. The vessel was specified to be built to SOLAS 1974 but the first certificate was issued under SOLAS 1960. The Finnish Maritime Administration surveyed the vessel for compliance with the requirements whilst she flew the Finnish flag, and Bureau Veritas surveyed on behalf of the Estonian Administration during the following period. The surveys were annual and the one conducted on change of flag was extensive.

3.4.2 Lifeboats and rafts

The vessel was equipped with ten motor-driven lifeboats of open type and of fibre-glass construction. The five boats on the port side were approved for in total 368 people and the five on the starboard side for in total 324 people. One of the boats on the starboard side was a man-over-board (MOB) rescue boat. Two boats were equipped with searchlights. The boats were suspended under davits on deck 8. Embarkation was from deck 7.

The vessel carried 63 inflatable rafts, approved for a total of 1575 people. They were packed in containers stowed on decks 7 and 8 and were equipped with hydrostatic release mechanisms. Twelve rafts were equipped to be launched by davits, four of which were installed on deck 7. The remaining rafts were intended to be dropped into the sea. With one exception, the rafts were manufactured in 1980 and delivered to the VIKING SAILLY during construction. They were serviced once a year in rotation. The service was carried out by a Swedish company, authorised by the manufacturer and approved by the Swedish Maritime Administration.

Lifeboats and rafts provided on board satisfied the SOLAS 1974 requirements as to number and standard.

The lifeboats and rafts were surveyed every year in conjunction with the issuance of the Passenger Ship Safety Certificate. The last survey was in June 1994.

The vessel also carried six rigid floats on the uppermost deck. They were able

Figure 3.12 The extent of ice damage repair in 1987.



to support 20 persons each. They were installed to comply with the SOLAS 1960 requirements for "buoyant apparatuses".

All launching instructions had been renewed during the change of flag to reflect the new languages to be covered.

3.4.3

Lifebuoys and lifejackets

The vessel was equipped with 18 lifebuoys, nine of them with self-activating lights. One lifebuoy on each side of the ship was equipped with a lifeline and with self-activating light and smoke signals.

There were 2298 lifejackets for adults and 200 lifejackets for children on board. All the jackets were equipped with whistles. There were no lights on the lifejackets. This was not required on vessels trading on short international voyages (3.6.1).

On the open passage on deck 7, rescue stations and bins containing lifejackets were located on both sides of the ship. There were also lifejackets on the bridge and in the engine control room for the watch personnel. Donning instructions were placed where the lifejackets were stowed and in all passenger cabins. Crew members were assigned to assist passengers in putting on the lifejackets.

3.4.4

Emergency beacons

The ESTONIA carried two emergency beacons (EPIRBs) of type Kannad 406E.

The last check of the radio beacons was reported to have been made about one week prior to the accident by the radio operator. The check confirmed that the EPIRBs were in full working order.

3.4.5

Emergency alarm systems

The ship had an alarm system incorporating 197 alarm bells and 11 alarm sirens. Each alarm unit was equipped with a fuse, whereby a fault in a single alarm would not disable the rest of the system.

The alarm system was functionally checked once a week. The audibility of the system against the background noise in the accommodation areas had been judged to be adequate although no documented measurements had been made.

Alarms were installed in the passageways and public spaces as well as in non-passenger areas.

The alarm system operated on the 220 V system and was connected to the main and emergency generator systems. The alarm system was not powered by the emergency accumulators.

Alarm buttons were installed on every deck, including the sections and work rooms of the crew. By pressing an alarm button an audible signal was triggered on the navigation bridge and an indicator showed which section the alarm was coming from. In case of no reaction within 30 seconds, the alarm in the entire vessel was automatically activated. The receipt of one signal on the bridge did not prevent the receipt of additional signals from other alarm buttons.

The vessel had a fire and smoke detection system with a total of 1212 sensors. The sensors on the car deck and in the engine and boiler rooms were smoke-sensitive whereas the other sensors were heat-sensitive, set to give alarm at a temperature of 65°C.

The public address system was operated from the navigation bridge and also from the information desk. The microphone on the bridge had priority over the one at the information desk.

A separate personal paging system for crew members was installed.

3.4.6

Escape routes and instructions

The escape routes led to 18 rescue stations located on deck 7. The routes were marked with signs on the walls and fluorescent tape along the corridors.

Instructions for handling life-saving equipment were posted at the rescue stations. The detailed instructions for the crew were given in the Training Manual and Safety Manual, described in 4.3.

3.4.7

Passenger information

Each passenger cabin was supplied with an instruction pamphlet in Estonian, Swedish and English on safety measures, describing how to act in the event of an emergency. There was also an evacuation scheme posted in each cabin, indicating the escape routes and the particular rescue station for the passengers accommodated in that cabin. The exits and emergency exits were marked by arrows in passageways, on staircase landings and in recreation areas as well as by signboards on exit doors.

In any distress situation, besides alarms given only to the crew, the passengers should according to the Safety Manual be given general information and instructions through the public address system.

3.5

Cargo handling system

3.5.1

Cargo lashing equipment

The vessel was equipped with standard lashing belts for securing heavy vehicles and containers. Chocks were available on board for additional securing of heavy vehicles and for securing passenger cars on the hoistable car decks and on sloping deck surfaces.

The lashing equipment was inspected every three months and was renewed as necessary. The equipment was stored in the service areas at the forward and aft ends of the car deck.

3.5.2

Operating practice and instructions

The chief officer had the responsibility for cargo handling and planning loading operations. Both second officers were engaged in the actual loading and unloading on the car deck and all lashing of

cargo was performed under their supervision.

Besides the second officers, the boat-swain was directly engaged in lashing operations together with the deck hands.

No standard cargo loading plan was followed on board – but there was a general scheme – and a sketch of the cargo allocation was made before loading started. The overall guidance for lashing the cargo, given in IMO Resolution A 581 (14) "Guidelines for Securing Arrangements for the Transport of Road Vehicles on Ro-Ro Ships" and in IMO Resolution A 714 (17), was applied. The vessel also carried a cargo securing manual, issued by Estline AB.

Light passenger cars on the car deck were to be parked in low gear with the handbrakes on. The same precautions were applied to the light cars on the hoistable platforms where, additionally, chocks were used.

During the voyage the cargo was checked by the seaman of the watch on his watch round. The car deck could also be checked on the bridge and in the engine control room by means of the cameras covering the cargo area.

3.6 Certificates and inspections

3.6.1 Compliance with international conventions

The ship was built to comply with the conventions mentioned in 3.1.1.

The 1974 version of the SOLAS convention entered into force internationally on 25 May 1980 and in Finland on 21 February 1981. The 1960 version of SOLAS was in force at the time of the vessel's building. The 1973 MARPOL Convention and the related protocol of 1978 did not come into force internationally until October 1983 as far as the oil pollution annex is concerned. The building specification of 1979 included

these conventions in expectation of their entering into force.

Compliance with relevant requirements of the conventions was verified in the stipulated certificates. The first Passenger Ship Safety Certificate (Supplement) to verify compliance with Chapters II-1, II-2, III and IV of SOLAS was issued by the Finnish Maritime Administration on 27 June 1980. It contained a restriction of the permitted number of passengers to 1100 as the accommodation spaces were not fully completed. At the same time a restriction was ordered that the vessel was not allowed to sail more than 20 nautical miles from the nearest land. The first certificate was shortly thereafter replaced by a new one, dated 16 July 1980, permitting 2000 passengers. The certificates were valid for "short international voyages", defined in the SOLAS convention as a voyage of no more than 600 nautical miles and during which the ship is no more than 200 nautical miles from a port or place where passengers and crew can be placed in safety. In some later certificates, the traffic area was defined as "short international voyages between Finland and Sweden". Translated into Swedish and Finnish, the wording corresponds in English to "coastal traffic between Finland and Sweden". This wording, however, does not refer to the SOLAS Convention but to the Finnish national law. In coastal traffic, where the ship was sailing all the time, the requirements as to officers' qualifications were lower than on vessels on short international voyages.

The permissible number of passengers was also dealt with in a separate resolution by the Finnish Administration on 26 May 1980. This resolution stated that the permitted number of passengers should be 2000, taking into account the requirements of Chapter III of SOLAS.

For reasons of comfort the Estline operators had lowered the number of passengers. The limit was set at 1456 bookable passengers, compatible with the available number of beds and sleeping seats installed. In the summer season an additional 100 deck passengers were al-

lowed. This number did not include the crew or any non-paying persons on board.

The Passenger Ship Safety Certificate was renewed every year in compliance with the rules. The certificates were issued in the format stipulated by the 1974 SOLAS Convention from 1981 onwards. An exemption certificate was issued for the radiotelegraph equipment in the certificate issued in October 1992. This exemption certificate restricted the operation of the vessel to voyages within the Baltic Sea in accordance with the provisions of Regulation 5 of Chapter IV of the 1974 SOLAS Convention. This exemption was not extended when the ship's flag was changed to Estonian as the vessel had from that time again a radio officer.

From the beginning the vessel had an International Load Line Certificate, the first one based on a survey for freeboard carried out by Bureau Veritas, dated 23 April 1980. The certificate was issued in accordance with the 1966 version of the ILL Convention and was valid for five years, subject to periodic inspections. The certificates issued in 1985 and 1990 by the Finnish Maritime Administration were based on surveys carried out by Bureau Veritas.

3.6.2 Certificates valid at the time of the accident

International certificates cease to be valid when a ship changes flag. New certificates were therefore issued when the ship became Estonian in January 1993. Two new classification certificates (hull, machinery) were issued by Bureau Veritas in January 1993. The Estonian Maritime Administration had authorised Bureau Veritas in August 1992 to perform the surveys on its behalf and to issue certificates under the 1966 Load Line Convention, the 1974 SOLAS Convention, the 1973 MARPOL Convention and the 1969 Tonnage Convention. The status of the certificates at the time of the accident was as follows.

Passenger Ship Safety Certificate. As a new trim and stability manual was under

development, the vessel carried an interim Passenger Ship Safety Certificate, issued on 26 June 1994.

Load Line Certificate. For the same reason the Load Line Certificate was interim, issued on 9 September 1994.

International Oil Pollution Prevention Certificate. A conditional IOPP certificate was issued by Bureau Veritas on 14 January 1993. The validity was conditional on the issuance of a Passenger Ship Safety Certificate.

International Tonnage Certificate. Bureau Veritas issued, on behalf of the Estonian Government, a tonnage certificate under the Tonnage Convention of 1969. The certificate valid at the time of the accident was dated 29 August 1994.

At the request of the owners Bureau Veritas had also issued a *Cyprus tonnage certificate*, dated 8 June 1993, according to the Cyprus Merchant Shipping Regulations requirements. Bureau Veritas also issued, under the same authority, a Certificate of Survey pursuant to the Republic of Cyprus Merchant Shipping Law of 1963.

The valid certificates at the time of the accident are shown in the Supplement.

3.6.3

Collision bulkhead compliance

The SOLAS Convention requires passenger ships to have a collision bulkhead, and an upper extension of the collision bulkhead in ships with long forward superstructure, located at a distance from the forward perpendicular of minimum 5 per cent of the length of the ship between perpendiculars and maximum 5 per cent of the length of the ship plus 3 m. This requirement was formulated at an early stage and remained basically unchanged during the further development of the SOLAS Convention. However, in the 1981 Amendments to SOLAS 1974, which entered into force on 1 September 1984, the rule was extended to include cargo ships and modified to allow taking into account a bulbous bow. This was done by adding wording permitting the datum line from which the position of the collision bulkhead is determined to be moved forward from the forward perpendicular by half the length of the bulbous bow, by 1.5 per cent of the length of the ship or by 3 m, whichever was the shortest. The 1981 Amendments considered also for the first time especially the use of the ramp as an upper extension of the collision bulkhead. It was stated that the part of the ramp which is more than 2.3 m

above the bulkhead may extend forward of the limit specified above.

The position of the bow ramp of ESTONIA did not satisfy the SOLAS requirements for an upper extension of the collision bulkhead. No exemption was issued. Such an exemption could be given on condition that the vessel in the course of its voyages did not proceed more than 20 nautical miles from the nearest land.

The building specification stated that a "partial collision door" was "for the intended service not required by the Finnish Board of Navigation". An upper extension of the collision bulkhead, complying with the SOLAS 1974 rules, should have been located minimum 4.27 m and maximum 7.27 m aft of the position of the lower end of the ramp (Figure 3.13). Complying with the 1981 Amendments to SOLAS 1974 the upper extension of the collision bulkhead could have been about 2 m further forward.

The surveys under the SOLAS convention were, during the period under Finnish flag, carried out by the Finnish Board of Navigation. Bureau Veritas had no authorisation to survey the vessel for compliance with the SOLAS Convention. When Bureau Veritas surveyed the vessel for change of flag this was done in accordance with the requirements to the extent of a periodic survey, which did not include examination of construction drawings. The location of the extension of the collision bulkhead was thus not considered during this survey.

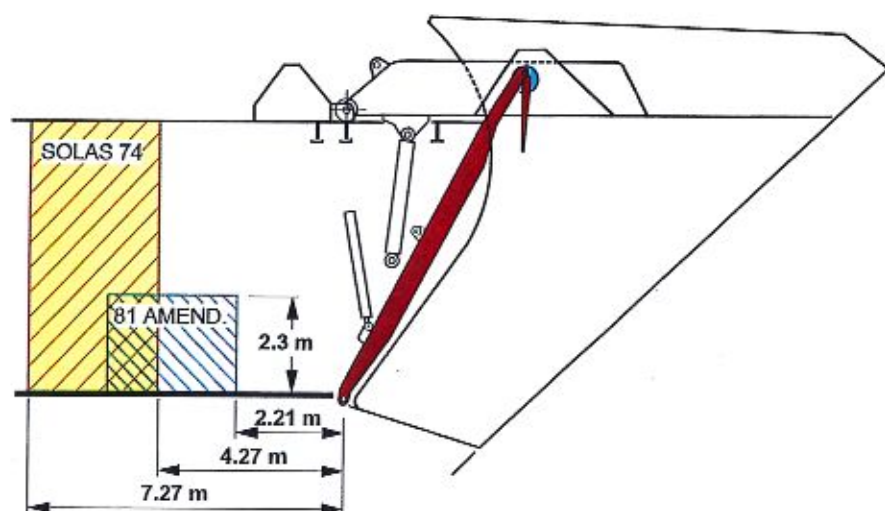
The background and likely circumstances related to the location of the ramp are covered in Chapter 18.

3.6.4

Statutory inspections

The inspections of the vessel regarding compliance with international conventions and national regulations were, during the period under Finnish flag, carried out by the Finnish Maritime Administration except for compliance with the International Load Line Convention and the MARPOL Convention. The authority

Figure 3.13 Positions of the upper extension of the collision bulkhead complying with the SOLAS 1974 rules and 1981 Amendments.



to perform surveys under these conventions was given to Bureau Veritas.

Bureau Veritas carried out the first load line survey at the time of delivery of the vessel. The compliance with the load line convention requirements was verified at the stipulated annual surveys and the five-year periodic surveys. The load line certificate was renewed when the ship changed flag in January 1993. The last annual inspection for verification of the load line certificate was carried out on 9 September 1994.

The Finnish administration

Between 1980 and 1992, the Finnish authorities carried out annual seaworthiness surveys, machinery surveys and certain other surveys required by Finnish maritime legislation. On the basis of these surveys, the Finnish Maritime Administration annually issued the vessel a SOLAS Passenger Ship Safety Certificate demonstrating that the vessel met the requirements of the SOLAS Convention.

However, the records of the seaworthiness surveys carried out by the Finnish authorities regularly include a note that the surveyors have not carried out surveys of the hull or boiler, since these were done by the classification society.

In Finland, a Commercial Vessel Decree was originally issued in 1920 and reformed in 1924. According to section 45 of both decrees, a vessel is exempt from a hull survey if it has a valid classification certificate issued by a classification society approved by the Finnish Maritime Administration. On 18 January 1921, when the decree entered into force, the Administration approved certain classification societies, among them Bureau Veritas, so that certificates issued by them exempted the vessel from the Administration's hull survey.

Before issuing the SOLAS Passenger Ship Safety Certificate, the Finnish Maritime Administration verified that the classification certificate was valid and that the classification society had carried out the hull survey.

Bureau Veritas also carried out machinery surveys on the vessel. However,

the focus of the classification society surveys had been on issues related to the soundness of the machinery, while the Finnish Maritime Administration surveys concentrated on equipment, for example fire safety equipment.

In 1983, a new decree was issued on ship surveys, which superseded the 1920 Commercial Vessel Decree. The new decree lacks provisions comparable to section 45 in the 1920 Decree. The practice of accepting classification society inspections as part of the basis for issuing a Passenger Ship Safety Certificate has, however, been retained under the new decree.

The Estonian administration

By an agreement signed on 18 August, 1992, the Estonian administration authorised Bureau Veritas to perform the statutory inspections on Estonian vessels being classed with that society. This explicitly included inspections to verify compliance with the SOLAS, MARPOL and Load Line Conventions. Bureau Veritas accordingly performed inspections and issued new certificates as listed in 3.6.2 above.

Based on an agreement between Bureau Veritas and the technical managers it was also arranged for certain items not covered by the conventions to be taken care of. Lifts for instance were inspected by the relevant Swedish authority.

The Estonian administration issued the Certificate for safe minimum manning of the vessel. The Estonian authorities also made their own inspection of crew accommodation arrangements and sanitary installations.

3.6.5 Classification society inspections

Bureau Veritas inspected the vessel for compliance with class requirements in accordance with their rules and standards. The main inspection period was five years and the items to be inspected were divided so that about one fifth of the total inspection work was carried out

each year on a rolling schedule. The bow area was inspected under this programme in 1983, 1988 and 1993. No discrepancies were recorded during any of these inspections.

3.7 Operational characteristics of the vessel

3.7.1 General observations

The vessel was equipped with two controllable-pitch propellers, two rudders and two bow thrusters. It was designed for berthing and unberthing without external assistance. Senior officers who have served on board the vessel have generally expressed satisfaction with the handling characteristics of the vessel. The fact that the navigation bridge was located aft of the front bulkhead of the superstructure in such a way that the bow of the ship was not visible from the bridge has not been reported as a disadvantage.

3.7.2 Speed resources

The ship had a contractual speed of 21 knots at 90 per cent of maximum continuous rating. The practical maximum operating speed of the ship in later years was considered to be 19 knots. This was adequate for the service in which the ship was engaged. To meet the timetable, the average speed in open sea was required to be about 17.0 knots on eastbound voyages and about 16.5 knots on westbound voyages.

3.7.3 Stability documentation

The ESTONIA was built to satisfy the two-compartment-damage stability requirements specified for passenger ships in the 1974 SOLAS Convention. In the shipyard's trim and stability book, seven loading conditions were given in which

the damage stability conditions were checked and found adequate. These included residual metacentric height, heel angle and freeboard to the margin line.

A new trim and stability manual was developed, based on inclination tests carried out in Turku on 11 January 1991. The new manual was approved by the Finnish Maritime Administration. It was subsequently approved by Bureau Veritas in conjunction with the change of flag.

The Commission has noted that at the inclination test, the ship's centre of gravity was positioned to starboard to such an extent that the port-side heeling tank was filled with about 115 t more water than the starboard tank in upright condition. The load cases in the trim and stability manual, however, include the

heeling tanks as being either both empty or both full.

Damage stability was checked by Bureau Veritas for compliance with the requirements in the 1992 Amendments to SOLAS and it was concluded that the vessel also complied with the new requirements for existing vessels, i.e. the damage stability index met to 95 % that required for new passenger ships. These additional damage cases were intended to be incorporated in the trim and stability manual and were approved separately on 16 September 1994.

In normal sailing condition the vessel had a transverse metacentric height of about 1.2 m in combination with a slight trim by the stern and a draft of about 5.5 m.

3.7.4

Seakeeping characteristics

The vessel had extensive flare in the bow area. This gave rise to wave impacts during running in heavy seas. The flare slamming was noticed on board as heavy bangs and shaking of the entire ship.

Senior officers who have been interrogated on the issue of the vessel's seakeeping behaviour have generally expressed satisfaction with the vessel, with the remark that one had to reduce speed or change course in heavy head seas for the comfort of passengers.

CHAPTER 4

OPERATIONS ON BOARD

4.1 General

The work schedule for the crew of the *ESTONIA* was in general two weeks' service on board, followed by two weeks ashore. Consequently two full crews were employed alternately and all positions on board were held by two persons.

In the deck department there were, besides the master, five deck officers, one radio officer and eight ratings. Organisationally the ship's doctor was also a member of the deck crew. The engine department consisted of eight engineers and eight ratings. In the catering department there were eight positions with officer's status and 113 other staff.

4.2 The crew

4.2.1 The manning of the ship

Prior to departure on 27 September 1994 a crew list of 186 people was presented to the Tallinn harbour master. Of these 149 comprised the actual crew, which was into the 13th day of its current 14-day duty period. In addition the list contained 6 trainees, 18 entertainers, 9 advisors and 4 crew members of the alternate crew. One of them was the master of the alternate crew, aboard for examination for his pilot exemption certificate.

All members of the actual crew were employed by the Estonian Shipping Company (ESCO). When senior officers were to be employed, Nordström & Thulin was consulted in compliance with the contract on technical management.

Nine advisors (one master mariner with pilot exemption certificate for the two fairways used in the Stockholm archipelago, one advisor with knowledge

of the ship's computer systems and seven with long experience of catering in Baltic ferry traffic) were all employed by the Swedish manning company Rederi AB Hornet. Before employment, catering personnel were recommended by Estline and the pilot and the computer specialist by Nordström & Thulin.

All the deck officers and most of the crew were Estonian citizens. The working language on board was Estonian, and that language was understood by all crew members.

All crew members held certificates required for their positions on board.

4.2.2 Qualifications of the deck officers and the deck crew

The deck officers on board Estonian vessels – as well as on Swedish and Finnish – are called chief officer, second officer, third officer and fourth officer. The *ESTONIA* had two second officers, here designated second officer A and second officer B.

The master

The master was born in 1954. He graduated at the Maritime School of Tallinn¹ in 1973 and started his career at sea in 1974. He served as fourth and third officer until 1977. He studied at the Admiral Makarov Highest Engineering Maritime Academy in Leningrad² from 1977 to 1982. He subsequently served as second and then chief officer until 1986, when he got his master mariner's licence, and his first command as master on general cargo ships in transoceanic traffic.

In 1992 he became master of the passenger ship *GEORG OTS* on the route between Tallinn and Helsinki. When the *ESTONIA* was bought, he was appointed first captain. He was from the

¹ The Maritime School of Tallinn together with the Tallinn Fisheries Maritime School merged to form the Estonian Centre of Maritime Education which was established on 1 January 1992 and is the highest maritime academy in Estonia.

² Leningrad changed name to St. Petersburg in November 1991.

start involved in the transfer of the ship and development of the organisation on board. After Estonia's re-independence and the creation of the new Estonian Maritime Administration, he received in 1994 the first master mariner's certificate issued in Estonia.

He held radiotelephone operator's general certificate, Automatic Radar Plotting Aid (ARPA) certificate and a pilot exemption certificate for the fairway via Sandhamn through the Stockholm Archipelago. He had just before the accident passed his examination for the fairway via Söderarm.

In addition to his formal licence, he had taken relevant courses in, among other areas "Passage planning in narrow waters".

Apart from his native Estonian, he was able to communicate in Swedish, English, Finnish and Russian.

The chief officer

The chief officer was born in 1964. He graduated at the Admiral Makarov Highest Engineering Maritime Academy in Leningrad in 1988. He held a chief officer's unlimited licence. He had served as third officer on general cargo ships 1988–1990 and was third and then second officer on the GEORG OTS 1990–1992. In January 1993 he was appointed second officer on the ESTONIA, and in August 1994 was promoted to chief officer.

He also held radiotelephone operator's general certificate and ARPA certificate. He had taken additional courses in, among other subjects, "Passage planning" and "Bridge Resource Management".

The second officer A

Second officer A was born in 1963. He graduated at the Maritime School of Tallinn in 1988. He held an officer-of-the-watch licence, issued in Leningrad in 1988. He served as third officer on ro-ro vessels between 1988–1992. In 1992 he became second officer on the GEORG OTS. From 1993 he was appointed second officer on the ESTONIA.

He held radiotelephone operator's general certificate and ARPA certificate.

He had also taken additional courses in "Passage planning" and other subjects.

The second officer B

Second officer B was born in 1964. He held a chief officer's unlimited licence, issued in Tallinn in 1994. He graduated at the Admiral Makarov Highest Engineering Maritime Academy in Leningrad in 1991. In 1992 he was second officer on the GEORG OTS and from 1993 held the same position on the ESTONIA.

He held radiotelephone operator's general certificate and ARPA certificate. He had also taken additional courses in "Passage planning" and other subjects.

The third officer

The third officer was born in 1966. He graduated at the Maritime School of Tallinn in 1988 and at the Kotka Maritime College, Finland, in 1992. He held an officer-of-the-watch licence, issued in Helsinki in 1992. He was appointed fourth officer on the ESTONIA in 1993 and in 1994 promoted to third officer.

He held a radiotelephone operator's general certificate, issued in Helsinki in 1992. He also held an ARPA certificate, and had taken additional courses in among other things "Passage planning".

The fourth officer

The fourth officer was born in 1973. He graduated at the Estonian Centre of Maritime Education in Tallinn in 1992. He held an officer-of-the-watch licence, issued in Tallinn in 1994. In 1993 he was appointed quartermaster on the ESTONIA, and in 1994 he was promoted to fourth officer.

The radio officer

The radio officer was born in 1941. He graduated as ship's radio operator and radio navigator at Tallinn Technical School No. 1, in 1962 and at the Tallinn Fisheries Maritime School in 1986. He held a first-class radio operator certificate, issued in Leningrad in 1974. He had served as radio officer in cargo ships 1962–1993. In March 1993 he was appointed radio officer on the ESTONIA.

The deck ratings

The boatswains and all the able seamen had attended the general ship safety course on the training vessels ARZAMASS or KORALL.

The AB seaman of the watch during the critical hours of the accident was born in 1970. He was employed by ESCO in January 1993. Before serving on the ESTONIA, he had worked on board the ro-ro ferry TRANSESTONIA and on the GEORG OTS.

4.2.3

Qualifications of the engineers and the engine crew

The engine officers on board Estonian vessels – as well as on Swedish and Finnish – are called chief engineer, first engineer, second engineer and third engineer.

The chief engineer

The chief engineer was born in 1950. He graduated at the Maritime School of Tallinn in 1972 and at the Admiral Makarov Highest Engineering Academy in Leningrad in 1989. He held a chief engineer's unlimited licence, issued in Tallinn in 1994. From 1972 until 1990 he worked as third, second and chief engineer in different vessels. He served as chief engineer on the ro-ro ferry TRANSESTONIA and on the motor vessel SAINT PATRICK II 1990–1993. From February 1993 he was chief engineer on the ESTONIA.

The first engineer

The first engineer was born in 1952. He graduated at the Admiral Makarov Highest Engineering Academy in Leningrad in 1976. He held a first engineer's certificate, issued in Leningrad in 1976. He also held a certificate from the Advanced Training Course in Leningrad in 1990.

He worked as fourth, third and second engineer in various vessels 1976–1992. In January 1993 he was appointed second engineer on the ESTONIA and in June 1993 promoted to first engineer.

The second engineer

The second engineer was born in 1947. He graduated at the Maritime School of Tallinn in 1968 and at the Admiral Makarov Highest Engineering Academy in Leningrad in 1981. He held a second engineer's certificate, issued in Leningrad in 1972.

He served as third and second engineer on various vessels 1968–1981, and between 1982 and 1992 he was third engineer on a ro-ro vessel. In January 1993 he was appointed second engineer on the ESTONIA.

The third engineer

The third engineer was born in 1964. He graduated at the Admiral Makarov Highest Engineering Academy in Leningrad in 1990. He held a third engineer's certificate, issued in Leningrad in 1990.

He served as fourth and third engineer on different vessels 1990–1993. In July 1993 he was appointed fourth engineer on the ESTONIA and in September 1994 he was promoted to third engineer.

The fourth engineer

The fourth engineer was born in 1966. He graduated at the Maritime School of Tallinn in 1986. He held a third engineer's certificate issued in Leningrad in 1986.

He served as motorman and fourth engineer in cargo ships 1989–1993. In 1994 he was appointed motorman on the ESTONIA and from September he was promoted to fourth engineer.

The electrical engineer

The electrical engineer was born in 1951. He graduated at the Admiral Makarov Highest Engineering Academy in Leningrad in 1974. He held a first-class electrical engineer's licence, issued in 1984.

Since 1977 he had worked on board different types of ship as electrical engineer. In January 1993 he was appointed electrical engineer on the ESTONIA.

The refrigeration engineer

The refrigeration engineer was born in 1959. He graduated at the Tallinn Fisheries Maritime School in 1978. He held a

refrigeration engineer's certificate, issued in Tallinn in 1992.

He worked as refrigeration engineer in a fishing company 1978–1992. In January 1993 he was appointed refrigeration engineer on the ESTONIA.

The systems engineer

The systems engineer was born in 1969. He graduated at the Maritime School of Tallinn in 1991. He held a third engineer's certificate issued in Leningrad 1991. He held positions as fourth engineer 1991–1992. In January 1993 he was appointed systems engineer on the ESTONIA.

The engine ratings

There were eight ratings in the engine department: four senior motormen, two electricians, one welder and one turner. All had passed the general ship safety course on the training vessels ARZAMASS or KORALL.

4.2.4

The catering crew

The highest-ranking officer of the catering crew was the chief purser (sometimes called hotel purser). He was born in 1965. He had been employed by the ESCO since 1985. He had passed the general ship safety course.

The professional qualifications of the catering crew have no relevance for the accident. The only aspect for the investigation is their role in the ship's safety organisation.

4.3

Working routines and organisation

4.3.1

Deck department

The master was responsible for all activities on board the vessel. He reported to the ESCO on all matters regarding navigation, day-to-day operation, personnel and related issues. In technical matters, he reported to Nordström & Thulin.

The master in command on the accident night was the Number 1 master of the ESTONIA, and it was he who, together with his superiors at the office, laid down rules and routines for work on board. According to standing orders laid down by him the various responsibilities and duties, in addition to normal watch duties, were divided between the deck officers as described below.

The chief officer had the responsibility for cargo operations and the planning of these. He was also responsible for the daily work of the deck crew.

The second officer A was responsible for the navigation equipment, and also assisted the chief officer with cargo operations. He led the port lifeboat group and was responsible for associated life-saving equipment.

The second officer B was responsible for stability calculations prior to departure, and assisted the chief officer with the cargo operations. He also led the starboard lifeboat group and was responsible for associated life-saving equipment.

The third officer was in charge of nautical charts and literature, and was also responsible for the calibration of all clocks on board.

The fourth officer was responsible for keeping the log of the working hours of the deck crew, and for keeping lists of certificates of competence and passports for the deck crew. He was also responsible for cargo declarations to the harbour authorities, and for the documentation of cargo operations.

The radio officer was responsible for the radio, including the emergency beacons (EPIRBs), and communication equipment, and in co-operation with the second officer A for the maintenance of the electronic navigation equipment. He was also responsible for making and updating crew lists. The ESTONIA was certified for pre-GMDSS operation (7.3.1), and consequently the radio officer had to keep watch on 500 kHz and 2182 kHz. The watch hours at sea were from 1900 hrs to 0100 hrs.

When the vessel was at sea, there were always two officers and one AB

seaman on duty.

On westbound voyages, the second officer B was on duty between 2000 hrs and 0100 hrs assisted by the third officer, and the second officer A was on duty between 0100 hrs and 0600 hrs, assisted by the fourth officer. For the periods between departure and 2000 hrs and between 0600 hrs and arrival, the bridge watch was taken by the master and the chief officer.

During the sea voyage, the AB seamen changed watches at 2200, 0200 and 0600 hrs. Their duties at sea were to be additional lookouts and to make watch rounds on a defined route throughout the vessel (Supplement). These rounds were made once every hour, starting at 2030 hrs, and lasted for about 25 minutes.

Watch rounds were also made by the security guards. They had no other duties than to ascertain the safety and security of the vessel and the passengers, and they patrolled continuously.

4.3.2

Engine department

The chief engineer was responsible for the organisation and all work in the engine department, for the purchase and storage of spare parts and consumables, and for the technical maintenance of the entire vessel. He reported to the technical superintendent of Nordström & Thulin, and certain parts of these reports were copied to ESCO.

The first engineer was responsible for the maintenance and running of the main engines and the propulsion system.

The second engineer was in charge of the separators, the steering gear and all other hydraulic and pneumatic systems, including the systems for manoeuvring and locking the visor, the ramps and the hull doors.

The third engineer was in charge of the compressors, the bunkering of the vessel, and of the electrical generator sets, including the emergency generator.

The fourth engineer was in charge of boilers, deck machinery and lifeboat engines.

The systems engineer was in charge

of the fresh water distribution systems, the sewage system and the galley equipment.

The refrigeration engineer was in charge of the air conditioning plant and the refrigerating plant for store-rooms.

The electrical engineer was in charge of all electrical systems and installations.

The work schedule in the engine department was a traditional three-watch system. On each watch there were one engineer and one motorman.

The 1200–1600 hrs and 2400–0400 hrs watches were held by the third engineer, the 0400–0800 hrs and 1600–2000 hrs by the second engineer and the 0800–1200 hrs and 2000–2400 hrs by the fourth engineer.

4.3.3

Catering department

The total number of persons employed in the catering department was 121.

Many of them spoke two or more languages. In addition to Estonian, English was compulsory for all persons in positions involving work contact with passengers.

The catering department was managed by the chief purser, who was responsible for the organisation and conduct of the work. He was also responsible for the commercial result of the department. Regarding personnel, maintenance and other operational matters, he reported to ESCO, via the master. His economic reporting was to Estline in Stockholm.

The catering department consisted of five sub-departments with their own managers. The sub-departments were the hotel department including the information desk, the galley, the restaurant department including the conference department, the tax-free shops and the automatic data processing (ADP) administration. The security guards were administered by the hotel department, but they reported direct to the master.

The chef, the restaurant manager, the shop manager, the ADP administrator and the conference purser were employed on behalf of Nordström & Thulin in

accordance with the agreement on ship management between the parties involved. They were formally employed as advisors and were consequently not part of the crew. However, they acted in all aspects as responsible work leaders for their departments. Since they were not crew members, they were not included in the safety organisation of the vessel.

The catering department working hours were adapted to the opening hours of the various restaurants, bars and shops. The information desk was manned 24 hours a day and, during the busy periods 0900–1100 hrs and 1700–2200 hrs, by two pursers.

4.4

Safety organisation

4.4.1

The development of the safety organisation

When the operation of the ESTONIA was taken over by ESCO in 1992, a new safety organisation was established. The new organisation was based partly on the previous owner's organisation plan, and partly on the experience of Nordström & Thulin from their previous vessel on the same route.

All documents, plans and manuals included in the safety system were in both Estonian and English, and the safety organisation was implemented at all crew levels prior to commencement of traffic. The safety organisation was tested during the port state control in February 1993 (see 3.2.10).

The safety organisation and the training and implementation thereof were described in the emergency plan, the safety manual and the training manual.

4.4.2

Alarm signals

Various types of alarm were used on board the ESTONIA. The lifeboat alarm and fire alarm were general alarms, addressed to passengers and crew. Besides

these there was a coded alarm "Mr Skylight" addressed only to the crew and intended to alert relevant parts of the safety organisation.

The alarms were described in the emergency plan and in the safety manual, available at various locations in the crew accommodation such as mess rooms, day rooms and all major workplaces.

Lifeboat alarm

The lifeboat alarm – seven short sound signals, followed by one long one – was given repetitively with the alarm bells and/or the vessel's horn. When the alarm was given, the command group, the port and starboard boat groups, the engine control group and the eleven evacuation groups were alerted.

Fire alarm

The fire alarm – continuous repetitive short sound signals – was also given with the alarm bells and/or the vessel's horn. When the alarm was given, the command group, the two fire groups, the engine control group, the control group, the port and starboard boat groups and the first aid group were activated.

"Mr Skylight"

Without alarming the passengers, the crew could be alerted over the public address system with the coded message "Mr Skylight". This message could also be used with a suffix. Depending on which suffix was used, selected parts of the safety organisation were activated. The boat groups were activated by all Skylight messages.

4.4.3 Alarm groups

The safety organisation was led by a command group mustering on the bridge. The command group consisted of the master, the chief engineer, the chief officer, the chief purser and the third officer.

The master was the overall commander of the operations. The chief engineer was the fire chief, commanding the two fire groups and the engine control group. The chief officer was responsible for sta-

bility calculations and was also the deputy fire chief. He commanded the port and starboard lifeboat groups, the first aid group and the helicopter groups. The chief purser was responsible for evacuation, the evacuation groups reporting to him through forward and aft zone leaders. The third officer's main responsibility was to record times of events and to take notes.

According to the emergency plan and the safety manual, the chief officer – not the radio officer – was responsible for external radio traffic. The reason for this is believed to be that the safety organisation for the *ESTONIA* was partly copied from organisation plans made for vessels not carrying a radio officer. The Commission has not been able to elucidate whether this order was applied in practice.

Various checklists were included in the equipment of the command group. Among these were checklists for collision, grounding, leakage and evacuation.

Fire groups no. 1 and no. 2 were led by the second engineer and the third engineer respectively. They were alerted by the coded alarm signal "Mr Skylight" and by the general fire alarm given by the alarm bells. A number given after "Mr Skylight" indicated the fire station where the group should meet. The call "Mr Skylight" followed by the Estonian words for "damage control" indicated that the damage control group should bring equipment for damage control and without further instructions start their work. Fire group 1 was trained and equipped mainly for fighting fires in the accommodation, and fire group 2 was focused on fires on the car deck and in the engine room. Fire group 2 was also trained in the use of chemical protection equipment.

The engine control group was led by the first engineer, and the only other member was the motorman on duty. The group was alerted by the "Mr Skylight" alarms, and by lifeboat and fire alarms. The muster station for the engine control group was the engine control room, and the prime task was to relieve the engineer on duty and take over responsibility for the running of the engine plant.

The lifeboat groups were alerted by the call "Mr Skylight" and by the general alarms. The muster stations were for the port lifeboat group number 2 lifeboat and for the starboard lifeboat group number 1 lifeboat. The main responsibility for the lifeboat groups was to ready lifeboats and liferafts for launching, and to prepare the ladders for use. Organising passengers on boat deck and distributing lifejackets were also duties included in the directions for these groups. Each group was under the command of a second officer and consisted of four other members. Four of these, two in each group, belonged to the deck crew and the other two were from the catering crew. The members of the lifeboat groups were all assigned positions in the lifeboat or liferaft crews.

The first aid group was led by the ship's doctor, and consisted of 11 members. The group was alerted by the call "Mr Skylight 727", and the meeting place was the ship's hospital. The meeting place could be somewhere else, and in this case a suffix was added to the alarm call, indicating the meeting place. The main duties of the first aid group were to take care of injured and/or deceased persons, give first aid and prepare them for transport ashore or to other vessels. In an emergency situation which included "abandon ship", the first aid group was also responsible for moving the injured to lifeboats.

The helicopter group was not intended to work in "abandon ship" or other situations when the entire safety organisation was mobilised. The group was therefore made up of persons with suitable skills from other groups in the emergency organisation such as the lifeboat groups and the fire groups. The ten-member helicopter group was led by the second officer and its duties were to prepare the vessel for helicopter landing.

For restricted evacuation and for closing off specific areas, there was a control group. The seven-member group was led by the security assistant. This group was alerted by a "Mr Skylight" alarm, and assembled at the cashier's office on deck

5. The duties of the group included restricted evacuations, searching of restricted areas, blocking off of areas where other groups were working, and assisting the first aid group. The control group was disbanded by the lifeboat alarm, the members then taking other duties in the evacuating groups.

Total evacuation of the vessel was the responsibility of 11 evacuation groups, led by the forward and aft zone leaders. The forward zone leader was in charge of groups 1, 2 and 3 and responsible for evacuation through the forward staircase. The aft zone leader was in charge of the other eight groups, and responsible for evacuation through the aft staircase. The evacuation groups were mustered by the lifeboat alarm or by "Mr Skylight". Each group had a specified area to evacuate, from the muster station within, or in the vicinity of, that area. The evacuation groups were as far as possible composed of persons normally working in the area they were to evacuate, to ensure local knowledge thereof.

Each lifeboat had seven crew members with defined duties during launch-

ing and on board.

All liferaft stations had one station leader, and there was one raft leader for each liferaft.

Every crew member was assigned his/her own unique alarm number upon commencing service on board. This alarm number indicated his/her duties and position in the safety organisation.

4.4.4 Training and drills

The various groups in the safety organisation drilled according to the vessel's exercise schedule. The drills were led by the group leader, who also made a report of the content of the drill and of any group members absence. This report was submitted to the responsible officer in the command group.

The fire groups, the engine control group and the boat groups were scheduled for training every two weeks, and the first aid group and the evacuation groups were to exercise once every month.

Lifeboats on the port side were launched into the water every three

months, and those on the starboard side once a year. Under normal operation the vessel always had her starboard side alongside the dock. The starboard lifeboats were, however, lowered every three months.

Of the current crew, 142 had undergone a one-week IMO-approved safety training course on a training vessel, and were certified as proficient with survival craft.

When the ESTONIA commenced her traffic between Tallinn and Stockholm, an operative control was carried out on board by the Swedish Maritime Administration. The control included implementation of the entire safety organisation and a check on the skills of the crew in conducting their duties according to the plan.

In January 1994 the ESTONIA also participated in a major fire exercise. The purpose of this exercise was to train co-operation between helicopter-landed, shore-based, fire-fighters and the vessel's safety organisation.

CHAPTER 5

THE CIRCUMSTANCES OF THE VOYAGE

5.1

Timetable and route

The ESTONIA operated on the route between Tallinn and Stockholm. She left Tallinn every second night at 1900 hrs and arrived in Stockholm the next morning at 0900 hrs local time. She left Stockholm the same day at 1730 hrs local time and was back in Tallinn the next morning at 0900 hrs. As the vessel was in port a great part of the day a late arrival did not affect the next departure.

In Tallinn the ship had her starboard side to the berth and the cargo was handled via the forward ramp. In Stockholm the ship docked in Frihamnen, and there also she had her starboard side to the berth. All ro-ro cargo handling in Stockholm took place via the aft ramps.

Normal passage through the Stockholm Archipelago was via Sandhamn, but when the weather conditions were considered unfavourable, the passage was via Söderarm.

The total distance between Tallinn and Stockholm via Sandhamn is 225 nautical miles and via Söderarm 228 nautical miles. To keep the schedule, the required average speed in unrestricted waters between Tallinn and Stockholm was 16.5 knots via Sandhamn and 17.0 knots via Söderarm. The normal time for entering the Stockholm Archipelago by the Sandhamn passage was 0515 hrs at the Revenggrundet lighthouse, and by the Söderarm passage 0425 hrs at the Söderarm lighthouse.

The voyages were very regular and, according to the log book at Stockholm Pilot station, the passing times at the Söderarm lighthouse did not vary more than about 15 minutes.

5.2

Status of the vessel on departure

On departure from Tallinn on 27 September the ESTONIA was seaworthy and properly manned. There were no outstanding items either from the authori-

ties or from the classification society's surveys. The maintenance standard of the vessel was good as witnessed by various instances.

During the last day in Tallinn the vessel was used in a training programme for Estonian Maritime Administration surveyors in the conducting of a Port State Control in compliance with the Paris Memorandum of Understanding on Port State Control (see about Paris MOU in 9.1). The trainees made a thorough Port State Control inspection of the ESTONIA and were supervised and instructed by two senior inspectors from the Swedish Maritime Administration. The exercise was documented in protocol, set up in a form according to the Paris MOU. A copy of this protocol is included in the Supplement.

The Swedish inspectors leading the exercise have been interrogated by the Commission and have stated that the vessel was in good condition and very well maintained. They found no deficiencies that would have caused detention or other serious remark, if the inspection had been a regular Port State Control. However, some deficiencies were noted, such as that the rubber seals for the bow visor were worn, had tear marks in some places, and were in need of replacement, and watertight hatch covers on the car deck were open and in a condition indicating that at least one was not normally closed. It was also stated during the interrogation that the Swedish inspectors had experienced "lack of respect for issues related to load line matters" in their contact with officers met during the exercise.

5.3

The departure condition

The vessel had on departure from Tallinn a loading condition that was normal for the route. The car deck contained mainly cargo vehicles. The bunker and stores condition was based on the normal routine of supply during the stop in Stockholm. The trucks and trailers were identified on the cargo manifest for the voy-

age, giving information about vehicle identity, length, weight and content in general.

Due to uneven weight distribution on departure the vessel's port side heeling tank was filled.

Instructions had been given by the chief officer to secure the heavy cargo carefully due to the forecast heavy weather.

Table 5.1 Departure condition.

Deadweight		
Heavy fuel oil (IFO 180)		
tank 10	108 m ³	
tank 11	108 m ³	
daytank 36	25 m ³	
settling tank 38	20 m ³	
Total	261 m ³	250 t
Marine diesel oil		
tank 18	33 m ³	
tank 41	10 m ³	
Total	43 m ³	35 t
Gas oil		
tank 20	12 m ³	10 t
Ballast water		
tank 1	175 m ³	
tank 13+14	183 m ³	
Total	358 m ³	360 t
Fresh water		300 t
Miscellaneous liquids		50 t
Weight on the car deck		
Cargo vehicles, 40 units, 1000 t		
Passenger cars, 25 units, vans, 9 units, buses, 2 units, 100 t		
Total		1100 t
Crew and passengers		100 t
Miscellaneous		95 t
Total deadweight		2300 t
Floating Condition		
Draught mean	5.390 m	
Trim, positive by stern	0.435 m	
Displacement	11930 m ³	
Longitudinal CG from aft. perp.	63.85 m	
Vertical CG from keel	10.62 m	
Transverse metacentric height	1.17 m	

Table 5.1 gives the departure condition of the ESTONIA. Deadweight on departure has been estimated to a total of about 2300 t as detailed in Table 5.1. Quantities of oils and water have been estimated by Nordström & Thulin, based on the normal consumption rates and replenishment routines. The weight of the heavy vehicles is taken from the cargo manifest. One truck included in the custom list but not in the cargo manifest has been added to the weight given in the cargo manifest. The number of passenger cars, vans and buses is taken from the custom list. Their weight is an estimate. The hydrostatic particulars are based on calculations by the NAPA program assuming a water density of 1.01 t/m³. The transverse metacentric height of 1.17 m includes the correction due to free liquid surfaces. According to the valid stability booklet the minimum required metacentric height was 0.63 m.

5.4

Meteorological conditions

5.4.1

Weather

Forecast

Prior to departure from Tallinn the vessel had received the route-adapted weather forecast from the Swedish Meteorological and Hydrological Institute (SMHI) in accordance with the subscription arrangement. The forecast, issued on 27 September at 1311 hrs, was transmitted by fax

and acknowledged by the ESTONIA in the afternoon. It contained the information shown in Table 5.2.

In Tallinn the Harbour Authorities forwarded the weather forecasts given by the Estonian Meteorological and Hydrological Institute (EMHI) to ships in port. The forecast distributed during the morning of 27 September predicted south-westerly wind of 12–17 m/s with a wave height of 2–3 m for the Northern Baltic area. At 1230 hrs a new warning message was issued, forecasting the wind to increase to 17–20 m/s, veering to west in the morning of 28 September.

Prior to departure the vessel also had the use of weather forecasts from the Estonian and Finnish regular broadcasting stations and coastal radio stations on VHF or MF and via the NAVTEX system.

The NAVTEX message – transmitted by Stockholm Radio on the morning of 27 September – forecast the wind to be SW 10–13 m/s, increasing first to 17–22 m/s and during the night to 20–25 m/s and veering to west.

After departure, marine weather forecast for the Northern Baltic and the Gulf of Finland could have been received on VHF. The forecasts transmitted during the night of 27 September by Tallinn Radio, Helsinki Radio and Mariehamn Radio all included warnings of winds of 20 to 25 m/s from a westerly direction.

Prevailing weather

The weather situation on 27 and 28 September 1994 has been analysed by the SMHI, FMI and EMHI. The reports of

Table 5.2 Weather forecast from SMHI.

Stretch	Time LT	Mean wind speed on 10 m level (m/s)	Prob. for mean wind > 15 m/s in %	Wave height sign max (m) (m)	
Naissaar - N Osmussaar	20–22	S-SW 10–15	20	1.0–2.0	3.0
N Osmussaar - S Bogskär	22–04	SW-W 15–20	70	2.5–3.5	5.5
S Bogskär - Sandhamn	04–07	W-NW 18–25	90	3.5–2.0	5.5
Comments: Intense low near Oslo moving E-ward via southern Sea of Bothnia to southern Finland. It will cause increasing SW – later W-NW, from to night gusty wind. At dep. rain with mod vis. Later some short showers.					

the analyses are given in full in the Supplement.

According to the reports there was a severe depression covering Northern Scandinavia and the Norwegian Sea. One of the low-pressure centres intensified on 27 September and moved rapidly eastward via southern Norway and eastern Sweden to southern Finland. The depression deepened and was located over Oslo on 27 September at 1400 hrs with pressure 987 hPa. On 28 September at 0200 hrs it was over the south-eastern part of the Gulf of Bothnia with 982 hPa, and at 1400 hrs over eastern Finland with 985 hPa.

A warm front, associated with this low, together with an area of rain, moved quickly eastward during the evening of the 27th over the northern Baltic Sea. South and south-west of the low, the wind shifted from south-westerly to westerly, and then became very gusty.

The wind direction, the mean and the maximum wind speeds in m/s at the most relevant observation sites are shown in Table 5.3. The indicated maximum values are the highest mean value for any 10-minute period during the preceding three hours except for Ristna, where the maximum values are measured in gusts. Maximum wind speed in gusts was also recorded at Bogskär and was 24.6 m/s at 2246 hrs on 27 September and 27.7 m/s at 0625 hrs on 28 September.

5.4.2 Waves

Wave conditions for the night of the accident have afterwards been calculated by the Finnish, Swedish and German institutes of marine research, MTL, SMHI and DW respectively, using their own numerical models of wave growth. The most important input data to the wave calculation models were the estimates of area sea wind speed and direction for a certain time period before and after the accident. The basic wind data were provided by the national meteorological institutes.

Wave calculation models predict the

Table 5.3 Wind observations.

Day/time	Söderarm	Svenska Högarna	Bogskär	Utö	Russarö	Ristna
27/9 1700 hours	SW 09 mean 12 max.	SW 12 mean 14 max	SW 13 mean 14 max	SW 09 mean -	WSW 09 mean -	SW 08 mean 12 max
27/9 2000 hours	SW 11 mean 13 max	SSW 14 mean 16 max	S 14 mean 17 max	SSW 13 mean -	SW 08 mean -	SSW 08 mean 14 max
27/9 2300 hours	S 13 mean 17 max	SW 16 mean 18 max	SW 17 mean 18 max	SW 15 mean -	S 16 mean -	WSW 16 mean 21 max
28/9 0200 hours	SW 14 mean 15 max	W 17 mean 18 max	SW 20 mean 21 max	SW 15 mean -	SW 12 mean -	WSW 15 mean 22 max
28/9 0500 hours	W 20 mean 20 max	WNW 24 mean 24 max	W 19 mean 22 max	WSW 15 mean -	WSW 12 mean -	W 18 mean 29 max
28/9 0800 hours	WNW 17 mean 20 max	WNW 18 mean 25 max	WNW 21 mean 24 max	WNW 13 mean -	WNW 09 mean -	W 17 mean 26 max
28/9 1100 hours	WNW 12 mean 17 max	WNW 14 mean 18 max	- - -	W 15 mean -	WNW 11 mean -	W 12 mean -
For locations of the observation sites, see Figure 13.1.						

significant wave height, wave period and mean wave direction at different points of the sea area under consideration. Significant wave height is defined in the numerical models by the area under the

wave spectrum, but is very close to the statistical measure of the mean value of the highest one-third of the waves.

Table 5.4 shows the significant wave height H_s , spectrum peak or modal wave

Table 5.4 Summary of wave conditions.

Institute	Position	Time day, hrs	H_s [m]	T_p [s]	Mean dir. [deg.]
MTL, Finland	59° 25', 22° 35'	27.9, 2300	3	7	260
SMHI, Sweden	59° 25', 22° 35'	27.9, 2300	2.9	7.1	246
MTL	Accident site	28.9, 0100	4.0	7.8	260
SMHI	Accident site	28.9, 0100	4.1	8.4	214
MTL	Accident site	28.9, 0200	4.4	8.2	260
SMHI	Accident site	28.9, 0200	4.3	8.7	217
DW, Germany	Accident site	28.9, 0200	4.3	8.3	218
MTL	Accident site	28.9, 0800	5.0	8.7	270
SMHI	Accident site	28.9, 0800	5.4	9.7	236

period T_p , and the mean direction of the waves predicted by the Finnish, Swedish and German institutes of marine research before, during and after the accident.

MTL experience is that the root-mean-square error in predicted significant wave height is about 0.5 m, in wave period about 1 s, and in wave direction about 10° .

Due to the wind shift six hours before the accident, waves were at the time of the accident still duration-limited. If the wind direction had remained constant, the waves would have been fetch-limited, significant wave height could have been about 5 m and the modal period about 10 s. This gives the absolute upper limit for the significant wave height.

Numerical predictions by MTL show that significant wave height may increase significantly in shallow water due to focusing of refracted waves. The minimum water depth in the accident area as verified by the Finnish Maritime Administration was over 40 m, which means that there was no shallow-water effect on the route of the ESTONIA.

Numerous studies of wave statistics in a seaway show that during a short interval when the significant wave height may be assumed constant, the distribution of measured wave crest-to-trough heights and heights of individual wave crests and troughs follow closely the Rayleigh distribution. Table 5.5 shows probabilities of an individual wave height exceeding different levels determined by the Rayleigh distribution. Wave height is given in a non-dimensional form divided by the significant wave height.

Table 5.5 Short-term wave height exceeding probabilities.

Height/ H_s	Prob. of exceedance
1	0.14
1.5	0.01
2	0.00034
2.2	0.0001

Thus, if the significant wave height is 4 m, one wave in 100 will be higher than about 6 m. Often as a rule of thumb the maximum wave height is estimated as twice the significant height.

The calculated significant wave height of about 4 m agrees well with visual observations made on board vessels which took part in the rescue operations. Masters of these vessels have estimated that before the accident waves were not higher than 5–6 m while after the accident individual waves were up to 7–8 m high and in general the wave height was 4–6 m. The estimates of wave height by the Swedish helicopter pilots who arrived at the accident site between 0350 hrs and 0645 hrs vary more than estimates by the mariners. A majority of the pilots have given estimates between 5–6 m or 6–8 m, one pilot gave 6–9 m and another 6–10 m. One pilot reports even a single very high wave of 12 m height measured by radar.

5.4.3

Light conditions and visibility

During the night of the accident the moon was about half in the last quarter. Moonrise was at about 2150 hrs and sunrise at about 0625 hrs.

Pictures from weather radars (Figure 5.1) show that broken cloud fronts were passing over the Northern Baltic and the accident area at about the time of the accident.

The night was cloudy with an occasional clearing of the sky just before midnight. After midnight the cloud coverage gradually increased again and in the early morning the sky was cloudy.

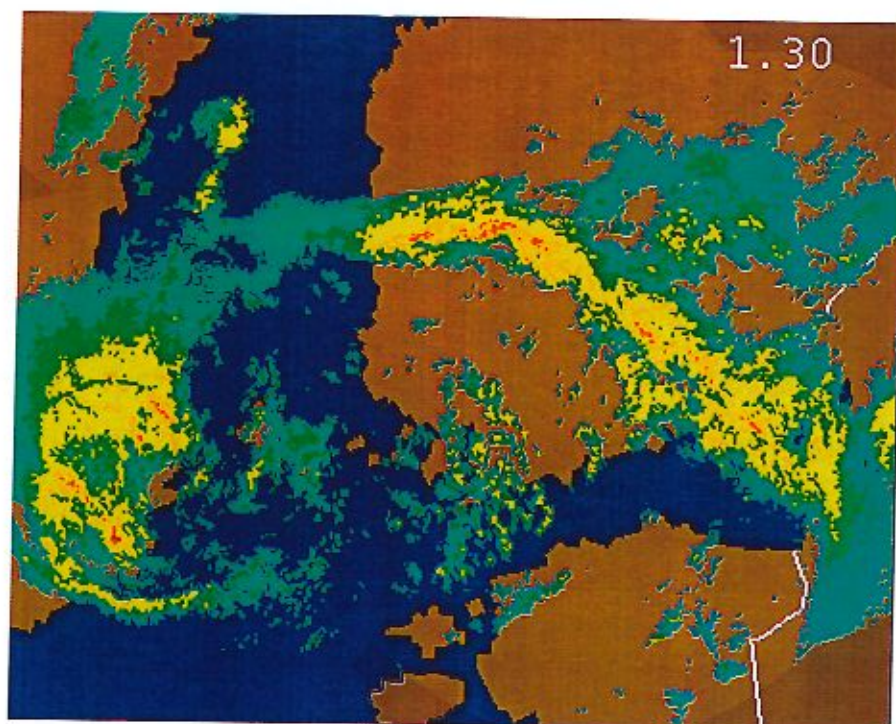
For most of the night visibility was more than ten nautical miles, but was occasionally reduced by rain showers.

5.4.4

Hydrological conditions

Currents were not measured during the night of the accident in the northern

Figure 5.1 Cloud fronts over the Northern Baltic on 28 September 1994 at 0130 hrs (Finnish Meteorological Institute).



Baltic. However, the surface current speed and direction were later estimated by both MTL and SMHI.

According to MTL the velocity of the surface current was between 0.2 and 0.6 knots in an easterly direction at the time of the accident. The velocity of the current was estimated by SMHI to be 0.5 knots in a direction between east and north east.

A surface water temperature of between 12°C and 13°C was measured in the accident area before midnight on 27 September. After midnight the temperature dropped to 10°C–11°C.

The air temperature during the night was 12°C–8°C.

5.5 Speed

There are no recordings of the speed of the ESTONIA during her voyage from the harbour in Tallinn to the time of the accident. The Commission has made an estimation of how the speed was affected by the waves, inter alia by comparing her speed with the speed of the SILJA EUROPA, another passenger ferry steering a nearly parallel course about eight nautical miles north of the track of the ESTONIA. Other available observations have also been used in the estimations. The speed of the SILJA EUROPA is taken from the DGPS recording which 30 times/minute registers the position, the time, the speed over ground, the course over ground and the heading. The data reveal how the speed was affected by the wind and waves.

The ESTONIA departed from Tallinn 15 minutes late from her normal schedule. The manoeuvre from the port to the Tallinn leading lights is estimated to have taken about 10 minutes. It must be as-

sumed that full service speed, i.e. about 19 knots, was maintained from the Tallinn breakwater to Osmussaar lighthouse, which she passed very close at 2200 hrs. Her estimated speed was still close to 19 knots and she was now a few minutes ahead of normal schedule. Between 2215 and 2245 hrs (approximate) the ESTONIA was plotted by a meeting vessel, the AMBER and according to AMBER's plot, the speed was then about 18.5 knots. The speed of the SILJA EUROPA was at this point 18.8 knots and further decreased to 17.6 knots between Russarö lighthouse and the Apollo buoy.

After passing Osmussaar lighthouse the ESTONIA lost her land shelter and the sea conditions deteriorated. Based on experience it is believed that the sea conditions were slightly worse in the area where the SILJA EUROPA was sailing.

At about 2255 hrs the Apollo buoy was abeam and the ESTONIA's speed is estimated to have been close to 17 knots.

The ESTONIA passed the Glotov buoy at about 2355 hrs and, by comparing with the SILJA EUROPA, it can be assumed that her speed was now about 15 knots. This estimate is also confirmed by the trainee second officer, who has stated that the speed was between 14 and 15 knots, as well as by the third engineer who has stated that the speed was 15 knots when he started his watch in the engine control room at midnight.

During the first thirty minutes after midnight the average speed of the SILJA EUROPA dropped by about one knot.

When the ESTONIA reached the waypoint at 59°20' N, 22°00' E between 0025 and 0030 hrs, her true course was changed from 262° to 287° and the stabilisers were extended. Her average speed was between 14 and 15 knots.

Table 5.6 The recorded speed of SILJA EUROPA.

Time, hrs	Max [kn]	Min [kn]	Aver [kn]
0030	16.4	14.8	15.4
0035	16.4	15.3	15.9
0040	16.8	15.4	16.1
0045	16.4	14.8	15.6
0050	16.2	14.7	15.6
0051	16.6	14.8	15.8
0052	15.7	14.3	15.2
0053	16.1	14.9	15.6
0054	16.0	14.2	15.0
0055	15.5	13.3	14.6
0056	15.3	13.9	14.4
0057	15.5	13.8	14.6
0058	14.9	11.6	13.9
0058	14.9	11.6	12.9
0059	13.9	11.7	12.7
0100	14.5	12.9	13.4
0105	13.6	11.9	12.9
0110	13.8	12.1	12.9
0115	13.2	10.7	12.3
0120	12.6	10.9	12.4
0125	13.6	9.6	13.3
0130	10.7	9.1	10.7

Table 5.6 gives the speed of the SILJA EUROPA and illustrates how the sea state affected her speed. At 0042 hrs the SILJA EUROPA changed course from 259° to 276°. The change of course and possibly also deteriorating sea conditions resulted in increased motion of the vessel and at 0059 hrs the officer of the watch reduced the speed to 13 knots. The position of the SILJA EUROPA at about 0100 hrs was bearing approximately 350° and distance 10 nautical miles from the ESTONIA.

In the table the Max, Min and Aver columns give the highest, the lowest and the average speeds, respectively, during one minute.

