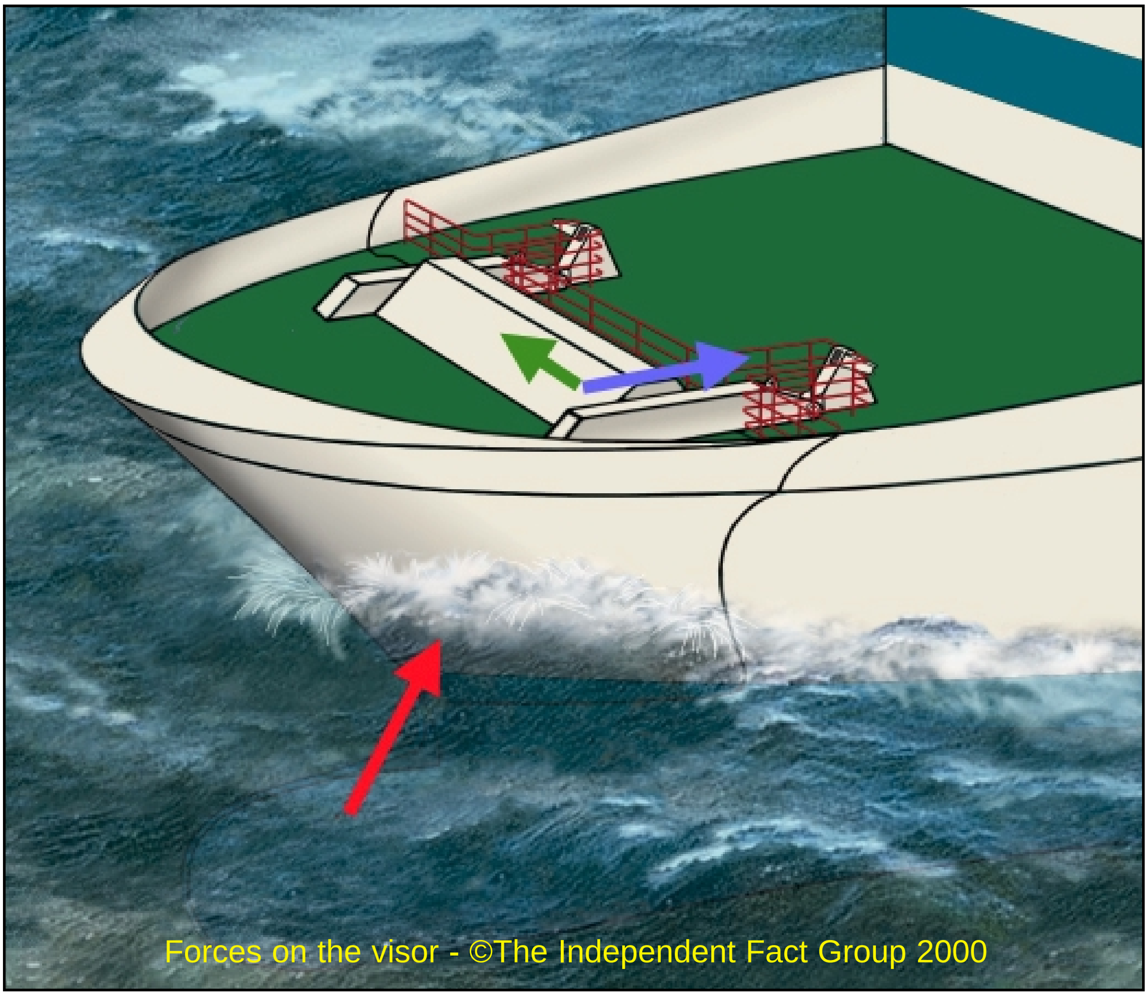
The Independent Fact Group

Impossible Visor Scenario

The Commission:

“The load needed to overcome the strengths of the bow visor attachments is thus sensitive to the shape of the visor, which has not been investigated”

”The many uncertainties involved make detailed calculations of this development meaningless”



Forces on the visor - ©The Independent Fact Group 2000

The Independent Fact Group

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STATEMENT REPORT

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The Fact Group's aims and objectives:

The Independent Fact Group was formed in early 1999 to clear up the many question marks about the MV Estonia disaster, in a structured and methodical manner. There has been considerable speculation concerning the efforts of the Joint Accident Investigation Commission (JAIC) and the political, legal and media treatment of the accident and its tragic consequences.

The aim is to give those in authority an opportunity, based on the facts of the case, to decide to review this matter, with a view to further action. Our efforts also enable the media and the general public to decide on the basis of the objective information which is available concerning the accident, and the conclusions to be drawn from a technical and civic perspective.

The overall objective is the setting up of a new investigation of the accident which can describe the course of the accident in detail, and its causes, with subsequent assessment of the moral and legal responsibilities, where this is feasible.

We are motivated by the belief that a properly conducted investigation will contribute to maritime safety and by our concern for Sweden's reputation as a nation which upholds safety at sea and the rule of law.

Methodology:

In the course of this task, we have assumed that the solution of a problem is never better than the validity of the basic assumptions. As a result, we have stipulated some methodological principles, of which the following are the most fundamental:

1. All scenarios must be considered to be true until the contrary is proved.
2. All observations, assumptions or statements on which a scenario is based must be considered false until the contrary is proved.

We have defined a number of criteria for concluding that an observation, assumption or statement may be considered to be true or false, and processes and routines for the route to be taken in clarifying an observation, assumption or statement. These criteria involve technical, empirical, statistical and/or semantic requirements which, if they are relevant must all be met if the observation, assumption or statement is to be classified as an objective fact.

The materials we have worked with are primarily the documents, audio recordings and films in the Swedish Accident Investigation Commission's Estonia archive, together with supplementary information from other public sources and, in addition documentation from the Meyer shipyard and its independent commission.

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Summary

In this report, the Independent Fact Group shows that JAIC's scenario regarding the loss of the visor, described in the final report was impossible.

As a direct result of a faulty conclusion when the Commission stated that "The many uncertainties involved make detailed calculations of this development meaningless", the Commission came to a wrong and impossible conclusion regarding the loss of the visor. The Commission did not take into consideration or study the preventive effect that a massive transverse deck beam would have if the visor broke loose. Ironically the Commission did, however, correctly assume that the transverse deck beam in fact was "the heaviest structural element preventing the visor from moving forward".

This report shows that, by a few "detailed calculations", it is proved that it was technically impossible for the visor to move forward as concluded by the Commission. First and foremost, the forces in a forward direction presented by the Commission are a confusion of reaction forces and resultants from the wave impacts. The Commission used the reaction forces in order to obtain forces strong enough to break the visor loose. Secondly, the forces to cut through the transverse deck beam could never have been achieved even if the lowest and most favourable theoretical values for the strength of the beam were used.

The Independent Fact Group shows both that it was impossible that the visor was lost in the way the Commission concluded, and as a result of this, that the ramp could never have been forced open by the visor.

The Independent Fact Group does not, however, draw any conclusions in this report as to how the visor was lost or what created the forces involved in such a scenario. We prove only that the Commission, by sloppy work and contradictory conclusions, has described a technically impossible scenario as their most central and important evidence regarding the MV Estonia disaster.

We leave it to a coming new independent investigation group to draw the correct conclusion as to how the visor was lost, and maybe most important, when it was lost and what consequences it led to.

To summarise this report in a few sentences: The JAIC final report's most important evidence was based on the assumption that the visor cut its way through a massive deck beam on two sides in four cuts. This conclusion has been presented in spite of the fact that the necessary forward forces did not exist. Whether this scenario was possible or not, has not been checked by any technical calculations whatsoever by the Commission. The scenario has now been proved wrong and therefore the complete final report musto be disqualified by this new evidence.

Definitions of certain language marks used in this report:

Text presented from the JAIC final report and its supplements is quoted as printed.

Our comments, explanations or clarifications, within quotes, are presented within square brackets [ ].

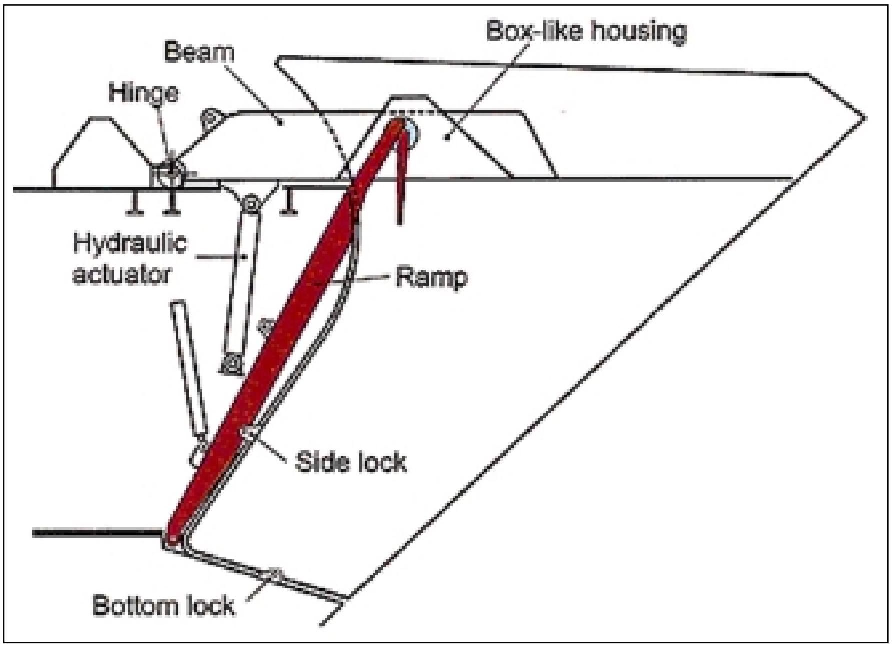
Text in quotes that has no relevance for the issue at hand has been left out and is indicated by a number of dots ".....".

We have underlined certain sentences and words, to mark their importance.

General visor description and arrangements

The visor was attached to the ship by hinges and hydraulic actuators situated close to each other in the aft part of the two ”visor arms” (shown as ”Beam” in JAIC figure 3.5 below). It was possible to lock the visor to the ship after closing by five devices. When closing the visor it was guided to the right position by three locating horns. The horns were also constructed to absorb any side loads from the waves. The locks were two hydraulic side locks and one hydraulic bottom lock (also called Atlantic lock). There were also two manual side locks.

In the picture below (JAIC Figure 3.5), the general arrangement of the bow with the visor, the hinges for the visor and the hydraulic actuators for lifting / opening the visor are shown. The visor was constructed with a ”box-like housing” for the top part of the ramp.



JAIC figure 3.5

When the ramp was closed, the visor enclosed the top part of the ramp.

The ramp was locked with six locking devices. On each side there were two hydraulic locking devices (pins) and one hydraulic locking hook, the latter also for pulling the ramp tight back when locking it.

However these locks are not shown in the JAIC figure 3.5.

JAIC Final report, 3.3.2:

”....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 three locking devices kept the visor down in its closed position and the locating horns absorbed any side loads that might develop.”

The Fact Group commentary:

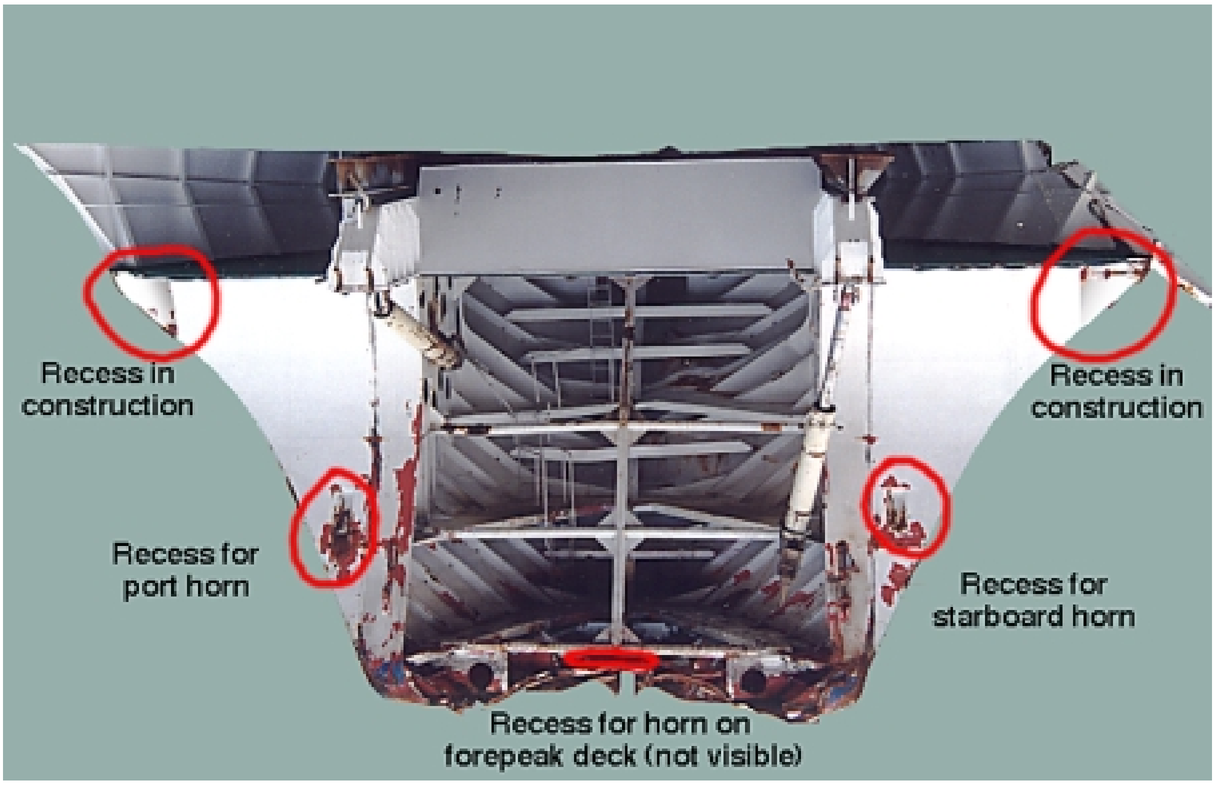
The Commission here stated that ”any side loads that might develop” are absorbed by the locating horns. After this correct statement they totally forgot all about the locating horns. They did not take in to consideration the load capacity of the horns and most important, the discharging effect of the wave impact loads on the visor locking devices.

The Locating horns

The visor construction was such that, in addition to the three locating horns mentioned by the Commission, there are two upper recesses in the visor bulkhead where the visor engaged with the forward bulkhead in the closed position. This means that if the visor had come loose as a result of any side load, the upper part of the visor with the recess in the bulkhead would also have been damaged.

In reality, none of the recesses are damaged in the side direction.

We leave it to a new commission to find out the real load on the visor locking devices after the main load was discharged by the locating horns and the upper side supports which did not break due to side loads.



Fact Group (FG) picture 1. The picture shows the visor with its bulkhead to the left and right. The circles indicate the different positions for the recesses that would have absorbed any side loads.

JAIC Final report, 3.3.2:

"....The visor including attachment devices was built of grade A mild carbon steel (yield strength minimum 235 N/mm^2, ultimate tensile strength 400-490 N/mm^2).

The deck of the visor had a box-like housing between the two beams [read visor arms for hinges], 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.

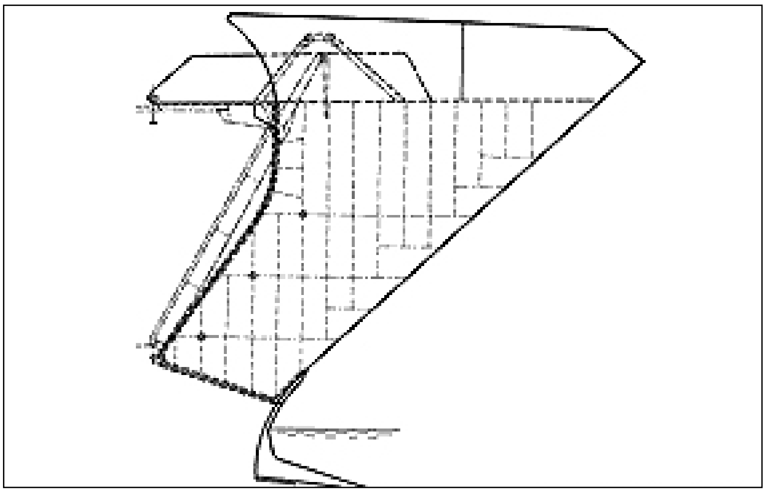
The visor pivoted around the two hinges on the upper deck during its normal opening and closing. It was secured in the closed position by three hydraulically operated locking devices at its lower part."

The Fact Group commentary:

The Commission stated that "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".

This conclusion is contradicted by the following observation. Nothing in the visor / ramp geometry would prevent the ramp from being partly opened inside the visor, which can be done without much effort. Because of this it would have been possible to close the visor even if the ramp was not properly closed and locked. Other arrangements with sensors were installed to prevent the visor from being closed if the ramp was not closed and locked properly.

It is also important to notice that the JAIC figure 3.5 and some other figures in the Commission report showing the ramp in the closed position are incorrect. The upper part of the ramp is "moved" aft so that it will meet the fore part of the upper deck. This illustrates the ramp being closer to the aft part of the visor housing for the ramp than it actually was. The most correct illustration in the final report is JAIC figure 3.6, "Bow visor general arrangement and structure".



JAIC figure 3.6 (one of three views shown here)

Figure 3.5 shown earlier will suffice for a theoretical description, and thus we have used this figure for our theoretical descriptions in comparison with the Commission's scenario.

Definitions of forces

To be able to understand and follow the Commission’s statement and conclusions we have to analyse the definitions used by the Commission regarding the forces acting on the visor.

In general terms, the Commission stated that the forces were generated by waves. Some forces from water flooding the foredeck (green water) are discussed and also forces generated from acceleration when the ship pitches in the waves.

The Commission used the definitions ”wave-induced forces” ”resultant force”, ”reaction force”, ”impact forces” and ”opening moment”.

1. The ”wave-induced forces” were forces that acted on the visor when the waves hit the visor.

2. The ”resultant force” was a force summarised from different forces like those from waves that hit different parts of the visor and / or other forces from ”green water” etc.

3. The ”reaction force”; elementary mechanics (Newton's 3:rd law) describe that every force (active force or a resultant from such a force) has a reaction force acting in the opposite direction. This force is named ”reaction force”. It means that the forces created by waves hitting the visor, are ”balanced” by ”reaction forces” of the same strength. If not balanced, the visor would have crushed the aft positioned bulk-head with the ramp.

4. The ”impact forces” were used by the Commission to describe the forces that were generated to enable the hydraulic lugs to cut through the transverse deck beam. The forces were generated by ”wave impacts” causing aft-forward movement of the visor.

It is very important to note that instead of using the ”resultant force” the Commission used the ”reaction force” to prove what force initially broke the visor attachments. Please see JAIC figure 15.4. Note also that the Commission used ”beam” instead of ”visor arm”, see JAIC figure 3.5.

5. The ”opening moment” is a force that acts around a ”given point”, for example a hinge. The moment is calculated by the force in the impact point multiplied by the distance to the ”given point”. In other words a force of 10 N acting on a distance of two metres to a given point creates a moment of 20 Nm around the given point.

Background - visor attachment strength

The forward force needed to break the hinges was more than 400 tons on each side according to the Commission. The minimum material cross section area on each side was 25 x 60 mm times 4 = 6000 mm^2. The welded bushings had a total welding length of 1560 mm with an area of 7800 mm^2. With 300 N/mm^2, that is only 70 % of the real value in breaking strength, each hinge would break at a force of 4.2 MN or approximately 420 tons.(JAIC Supplement 511, 4.6 - 7 MN).

The two upper locking hooks had an area of 1875 mm^2 each. With 300 N/mm^2 in breaking strength each hook would break at a force of 0.56 MN or approximately 56 tons.

In a letter from the German Group of Experts (SHK Estonia archive B 125, 27 october 1995) to the Commission, they said that ”In our opinion the below stated facts are undisputed” regarding the breaking strength of the upper locking hooks, that each hook had a failure load of 40 tons.

The visor side locks could take a load of more than 100 tons each.(JAIC Supplement 511, starboard side lock 1.59 MN, port side lock 1.19 MN).

The Atlantic bottom lock could take a load of approximately 200 tons (tested by JAIC Supplement 511, 2.04 MN).

The hydraulic actuators could take an outward (upward) load of more than their lifting capability of 150 tons each.

The base for the actuators would together hold for 800 tons according to the Commission.(JAIC Supplement 511, 8 MN, reduced there to 4-2 MN due to cracks and brittleness).

The foredeck of 8 mm plating would take 2.4 tons per side to cut open if it was cut in a professional cutting machine (4 sides and approximately a length of 1000 mm in each cut).

With due respect, the Commission has estimated, calculated or tested some of the above mentioned attachments breaking strength. <u>But the most important item, the deck beam, has only been identified</u> as ”the transverse deck beam, which was the heaviest structural element preventing the visor from moving forward”.

The bottom part of the deck beam (160 x 22 mm) alone could take a load of approximately 140 tons on each side (starboard / port) before breaking.

Background - visor scenario according to the Commission

The scenario of the visor failure and opening of the ramp is, in substance, described by the Commission as follows:

1. The visor locking attachment on the port side broke.
2. The port side hinges to the visor; or the bottom lock of the visor; or both broke.
3. The starboard locking attachment of the visor and the starboard hinge broke.
4. The visor fell forward now held only by the hydraulic actuators and due to 2 - 5 forward-aft impacts the visor hydraulic lugs cut through the transverse deck beam (on two sides with 4 cuts altogether).
5. After cutting through the deck beam the lugs cut another 360 mm deck plating and thereafter the visor housing hit the ramp and pulled forward, breaking its 6 locking devices.
6. Sometime thereafter the two hydraulic actuators were ripped away from their mounting platforms in the deck, and the visor fell into the sea.

The Commission scenario can be described in three steps.

A. The visor broke loose.
B. The visor cut through the deck beam and deck plating.
C. The visor released itself from the ship, ripping the ramp open in the process.

Forces on the visor according to JAIC - The visor broke loose

This section describes the JAIC conclusions regarding forces on the visor, where the failure pattern of all the attachments indicates an overload caused by forward-upward motion of the visor, despite the fact that there were no forward forces acting on the visor. We have here chosen to reflect only those parts of the text that will be of interest for this report.

JAIC Final report 12.3

The Commission's estimated maximum wave loads on the bow visor for the accident conditions are summarised in Table 12.5 below.

Load type	Load direction	Maximum value during 30 min.	
		Range of 90% confidence	Most probable
Visor forces:			
X force (longitudinal)	aft	2.7 - 6.3 MN	3.6 MN
Y force (side)	starboard	0.6 - 2.5 MN	1.0 MN
Z force (vertical)	upward	2.7 - 6.2 MN	3.6 MN
Deck hinge moments:			
X moment	upward on port side	0.6 - 7.4 MNm	1.7 MNm
Y moment	opening around hinges	4.0 - 20.0 MNm	7.5 MNm
Z moment	fwd. on port side	0.5 - 2.5 MNm	1.0 MNm

JAIC Table 12.5 Summary of estimated maximum wave loads for the accident conditions. Oblique bow sea, Hs 4,0 - 4,1 m.

The Fact Group commentary:

The Commission failed to calculate the forces that acted on the visor. Instead they estimated the maximum wave loads for the accident conditions. But they did not come to a conclusion as to how this relatively small forward momentum force, generated by the wave loads, broke the visor hinges and visor locks.

JAIC Final report 13.5:

”.... Hydrostatic pressure from trapped water inside the visor would create a resultant force directed about 45 degrees forward and down. The pressure and the resultant force would be amplified by the vertical accelerations of the bow. However, the possible amount of trapped water could not have created tension reaction forces in the attachments sufficiently high to make any of them fail. As an example, 3 m of water inside the visor would create a hydrostatic resultant force of only about 0.5 MN.

.... Green water on deck could be critical due to the unfavourable lever arm to the aft-positioned visor hinges. About one metre of water on the deck would double the weight of the visor, but several times this height would be needed to break the attachments.”

The Fact Group commentary:

The Commission concluded that resultant forces from trapped water in the visor and from ”green water” were not sufficiently high to make any of the attachments fail.

JAIC Final report 15.2:

”On the basis of numerical simulations and model tests (see 12.1 - 12.3) the Commission has concluded that the most probable maximum resultant force on the visor, developing in a significant wave height of about 4 m and after the vessel had changed course at the waypoint, was between 4 and 9 MN. Divided into force components, this equals simultaneous upward and aft forces of 3 to 6 MN and a starboard transverse force of 0.5 to 2.5 MN. The resultant maximum moments about the hinge points were 4 to 20 MNm opening moment, 0.5 to 7.5 MNm twisting moment and 0.5 to 2.5 MNm yawing moment.”

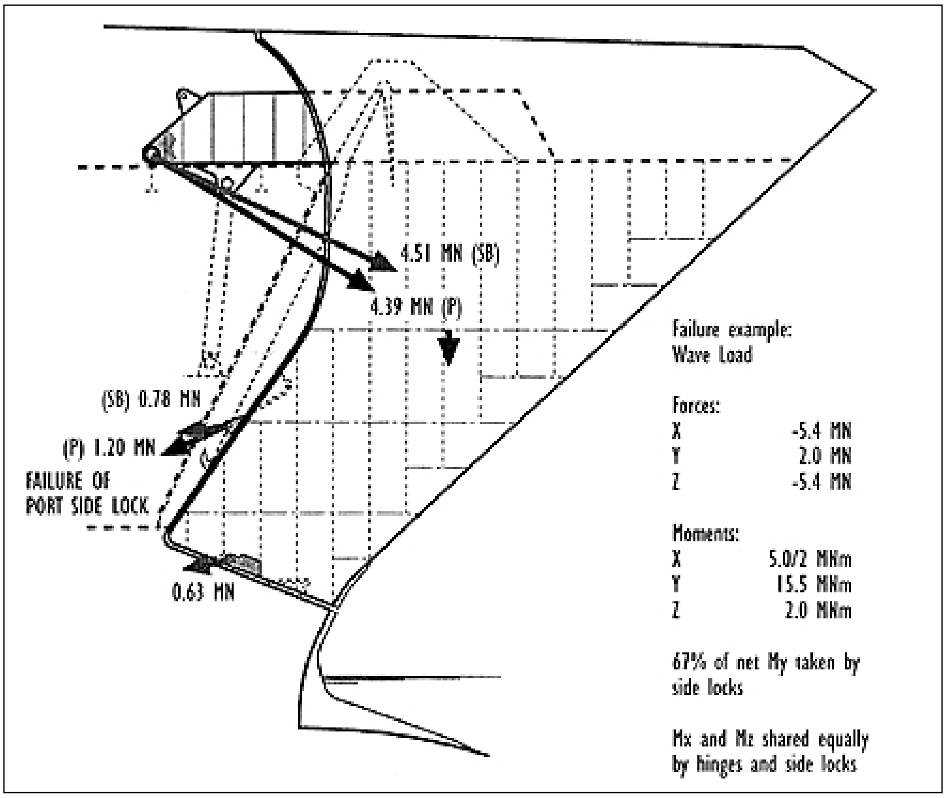
The Fact Group commentary:

The Commission concluded that the maximum resultant force, divided into force components, created upward and aft forces, not forward forces.

Force in a aft direction induced by the waves could not end up in a ”resultant force” in a forward direction. (See ”The Fact Group graphic analysis of forces on the visor” page 13).

JAIC Final report 15.10

"....Figure 15.4 illustrates an example of a possible reaction force distribution over the attachments when the port side lock fails. The load on the hinges, though large, is acting in an uncritical direction while the bottom lock and the starboard side lock are loaded only to about half of the critical level."



JAIC figure 15.4 "Example of reaction force distribution resulting in port side lock failure."

The Fact Group commentary:

The Commission failed to calculate the forces that acted on the visor. Instead of using the "resultant force" they used the "reaction force" to prove what force initially broke the visor attachments. They wrongly concluded that the "reaction force" resulted in the port side visor lock failure. Their general conclusion from the supplement (below) also shows that it was based on "may", "could", "seems" and is therefore nothing more than estimates.

JAIC Supplement 511 (MV Estonia. Visor Damage and Visor Attachment Strength Investigations at VTT):

3.7 General conclusion

"The above calculation [not shown here] indicates that breaking the side lock at 1.2 MN local reaction (equalling its strength as arrived at below) occurs at a wave load level which may be insufficient to break the next attachment. The side lock may thus break without another attachment failing. This would support the damage pattern that occurred to MV ESTONIA's sister ship DIANA II in January 1993 in the form of partial attachment failure. This involved side lock fracture and hinge damage. The shape of the bottom locking fore peak deck lugs of DIANA II was more robust indicating a stronger design (up to the limit of the visor lug of about 1.8 MN) than that of MV ESTONIA."

"A recurring judgement about an attachment breaking sequence of the MV ESTONIA accident is, however, not possible. For a direct head wave the bottom lock could reach its breakpoint of 1.5 MN at an estimated bow force of somewhat higher than the values given above before the side lockings became critically loaded. The outcome of simplistic locking system load sharing analysis yields the possible effect of moving the bow load centre more forwards (an increasingly more forwards protruding bow design) implying an increasing effect of the transverse load to increase attachment reactions and thus to weaken the system strength. The load needed to overcome the strengths of the bow visor attachments is thus sensitive to the shape of the visor, which has not been investigated. This sensitivity intimately follows from the way the moment arm of the transverse load Fy is in position along the normal through the bow load centre to the attachment plane. This seems to be the effect of the visors shape and attachment configuration - particularly the aft positioned hinges in relation to the lockings."

3.8 Visor detachment scenarios

"Visor detachment depends on the individual reactions in relations to the strength levels of the attachment sites. The above presented estimation has suggested that for 300 bow waves a minimum resultant bow force of 7 MN (lifting component around 5 MN corresponding to design load level) may be sufficient to raise the pulling load on the port side lock up to 1.2 MN with some cautiously chosen wave action centre. According to work presented below this would be enough to break the side lock in the local load direction found to apply. The loads at the port hinge and the Atlantic lock are still below their breaking capacities. The weakness of the port side lock compared to the starboard side lock has been recognised. The least bow load seems to be needed to cause the port side lock to break first, followed by break of the next attachment - the hinge or the bottom lock - at a somewhat increased level of bow load. It has not been possible to define in great accuracy the strength of the hinges, but approximate evaluation indicates that a hinge may be at risk if the local transverse shearing load reaction component directed down and forwards reaches up to about 4.6 MN. Hinge failure may thus happen second if a total bow load higher than the values given above were combined with a lower (than average) opening moment, which would be insufficient to break the bottom lock next. A combination of a higher bow load and a lower opening moment at a higher water pressure and less deep ingress of the ship (causing less opening moment) could raise the local load at the wave side hinge to the critical level before the lockings. In direct head sea a higher load is needed and then the bottom lock could be at risk first. A low bow load combined with a high opening moment would result in the port side lock becoming critical first, followed by, the bottom lock."

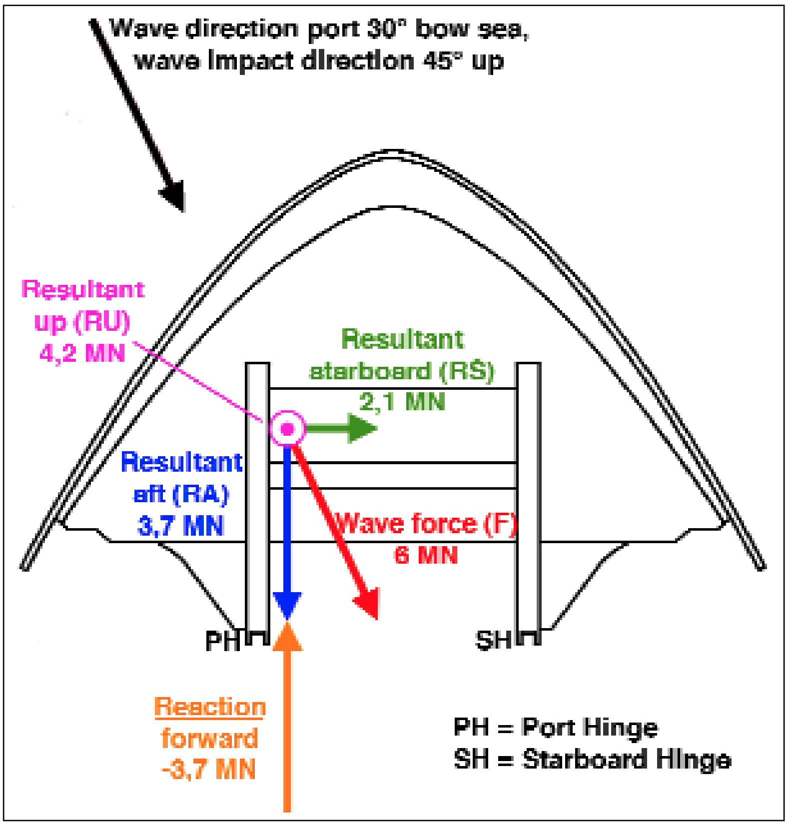
The Fact Group commentary:

Elementary mechanics, (Newton's 3:rd law) states that every force has a "reaction force" acting in the opposite direction of the applied force. Here it means that wave induced forces are "balanced" by "reaction forces" of the same magnitude in the opposite direction. In this case the reaction forces prevented the visor from continuing in the same direction as the wave forces acted, up and backwards toward the bulk-head. But in JAIC Figure 15.4 and 15.5 and the Supplement 511, it becomes clear that the Commission incorrectly concluded that "reaction forces" acted in a forward direction and thereby broke the port side locking of the visor.

We also find that the Commission in writing stated that "The load needed to overcome the strengths of the bow visor attachments is thus sensitive to the shape of the visor, which has not been investigated". So in plain language, they have not been able to calculate the load needed to break the visor attachments, nor have they defined the "the strength of the hinges".

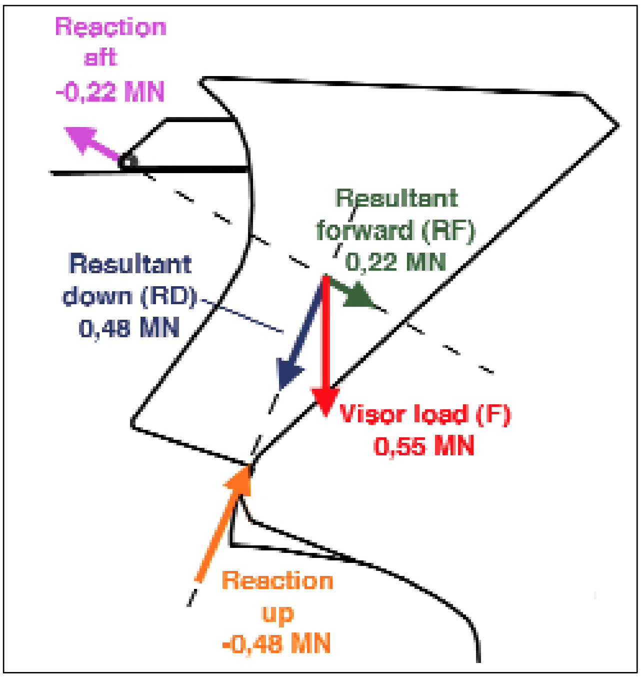
The Fact Group graphic analysis of forces on the visor

The visor is shown from above, with a wave induced force of 6 MN in bow sea 30 degrees on the port side. The centre of the wave induced force was hitting the visor 4,5 metres over the normal water line in calm water, with an upward impact direction of 45 degrees. The resultants aft, starboard and up are shown in FG 2 below. The reaction force (forward) on the resultant RA 3,7 MN is shown.



FG 2. Forces induced from bow sea.

No forward force was created from waves (unless the visor bounced back from the bulkhead). The rubber seal between the visor and the bulkhead had a total length of approximately 12 metres that could be compressed and could generate a bouncing effect. The stiffness of the seal was progressive. To compress the seal 10 mm would require a force of 10 000 N/m. To compress the seal 15 mm would call for 25 000 N/m (JAIC supplement 511). However the bouncing would only generate forces equivalent to a fraction of the visor weight as the "free motion margin" was only at maximum about 10 to 20 millimetres.



FG 3. Visor load force.

The visor seen from the starboard side. Theoretical force distribution between forward and down resultants. The visor was mainly resting on the forepeak deck. After the visor broke loose the forward resultant from the visor load was around 20 tons, but decreased to much less due to the hydraulic actuators holding the visor back.

Failure sequence of bow visor and ramp

This section describes what the Commission considered was the most likely sequence of events when the visor had broke loose, leading to the total loss of the visor and opening of the ramp. We have here chosen to reflect those parts of the text that will be of interest for this report only.

JAIC Final report 13.5:

"....The maximum opening moment to which the visor was exposed after the ship had turned at the last waypoint is estimated to have been between 4 and 20 MNm and the maximum resultant force between 4 and 9 MN. Such high loads and opening moments occurred randomly. The resultant load and the opening moment may have exceeded the lower limit of the range a number of times within half an hour under the prevailing conditions. Levels above the upper limit of the range have a low probability of occurring but cannot be excluded. The vast majority of wave impacts created no opening moment at all.

....Subsequent wave impacts caused the visor to move backwards and forwards in combination with some vertical movements, resulting in various impact damage to the bulkhead and the hinge beams [read visor arms for hinges]. Impact marks indicate violent transverse movements, and upward movements of about 1.4 m. The damage is described in detail in Chapter 8. As estimated from impact marks on the aft edges of the visor hinge beams [read visor arms for hinges], the number of heavy aftward blows was at least two and probably less than five. The vertical wave force exceeded the weight of the visor on average once a minute under the prevailing conditions. The dynamics of this aft-forward movement of the visor generated sufficient impact forces to enable the hinge beam lugs to cut through the transverse deck beam, which was the heaviest structural element preventing the visor from moving forward.

....It was when the deck beam, and thereafter about 360 mm of the deck plating, had been cut through that the visor housing came in contact with the top of the ramp, primarily on the port side as the sea loads had caused the visor to twist somewhat to starboard. Probably in one single movement, the visor pulled the ramp forward so that its locking devices and hydraulic actuators failed. The ramp was then free to fall forward towards the uppermost cross-bar of the visor. Subsequently the visor actuator lugs cut the rest of the deck and the front bulkhead plating until the visor was free to tumble forwards and overboard.

....Great force was needed only twice during this final part of the failure sequence, when the deck beam was cut through and when the ramp was forced open.

....The many uncertainties involved make detailed calculations of this development meaningless. However, calculations under simplified assumptions verify that the course of events described is fully possible."

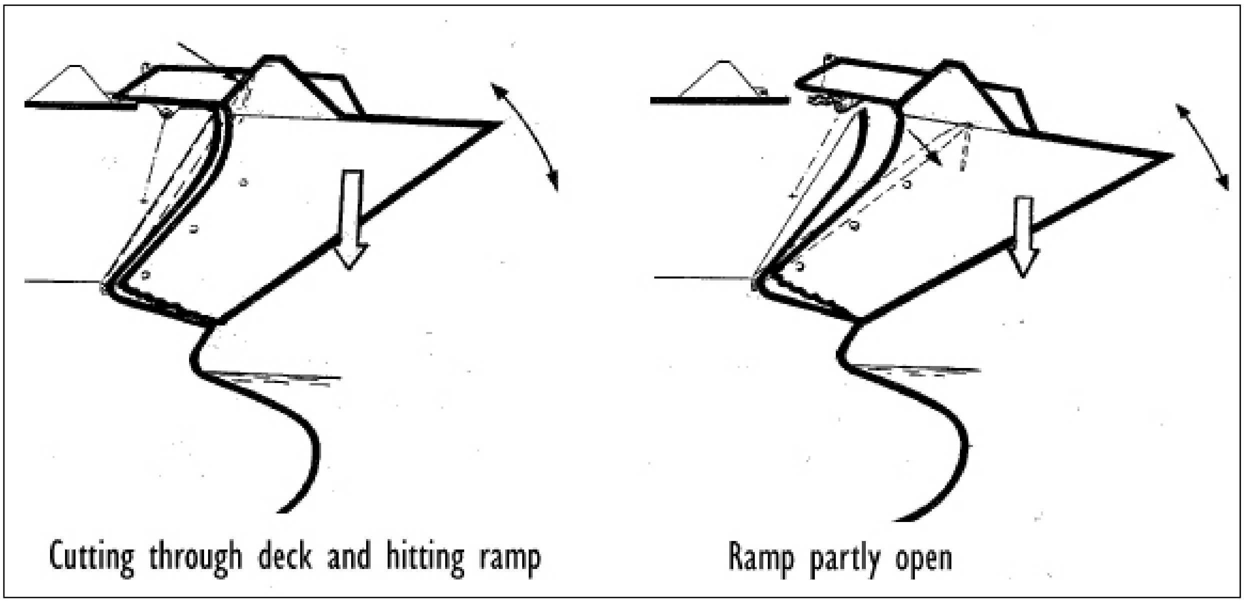
The Fact Group commentary:

The Commission estimated a ”resultant force between 4 and 9 MN” and stated that ”Such high loads and opening moments occurred randomly”. Back to the definitions, a ”resultant force” is the summarised force from one or more than one force acting on an object, also showing the direction of the summarised force. From JAIC 15.2 (above) it is clear that the Commission concluded that the resultant forces ”equals simultaneous upward and aft forces of 3 to 6 MN”.

First the Commission said that it was ”the hinge beam lugs” that cut through the transverse deck beam. The hinge beam lugs (holding the hinges) could never have been in contact with the transverse deck beam, it was absolutely impossible. But the hydraulic actuator lugs on the underside of the ”hinge beam” (or more correctly ”the visor arms”) may have been in contact with the transverse deck beam.

A bit further down, the Commission has concluded that the visor hydraulic actuator lugs first cut through the traverse deck beam ”which was the heaviest structural element preventing the visor from moving forward”, and thereafter the visor pulled the ramp forward so that its locking devices and hydraulic actuators failed.

The scenario is also described in JAIC figure 13.6 shown below.



JAIC figure 13.6 (two of six drawings shown here)

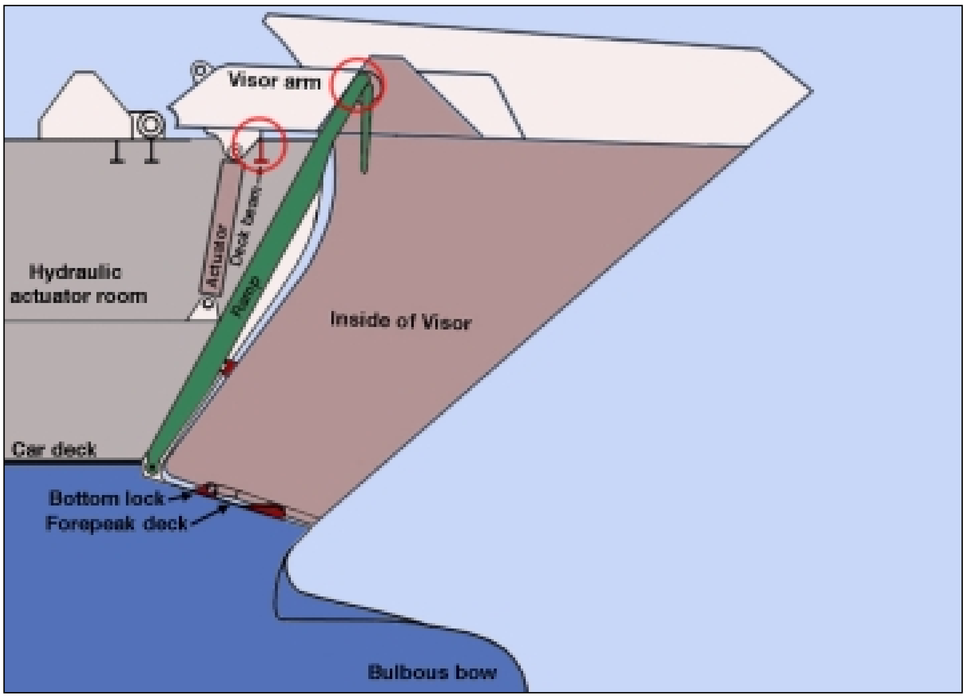
What the Commission did not do was the most important of all, namely to check by some detailed calculations if this scenario was possible or not. But instead they found this ”meaningless”. Three important questions can and will be answered by some detailed calculations;

1. How ”heavy” or strong was this deck beam?
2. Was it possible for the visor actuator lugs to cut through it?
3. Was it correct that the visor first had to cut through the deck beam, and thereafter cut through 360 mm of the deck plating to come in contact with the top of the ramp?

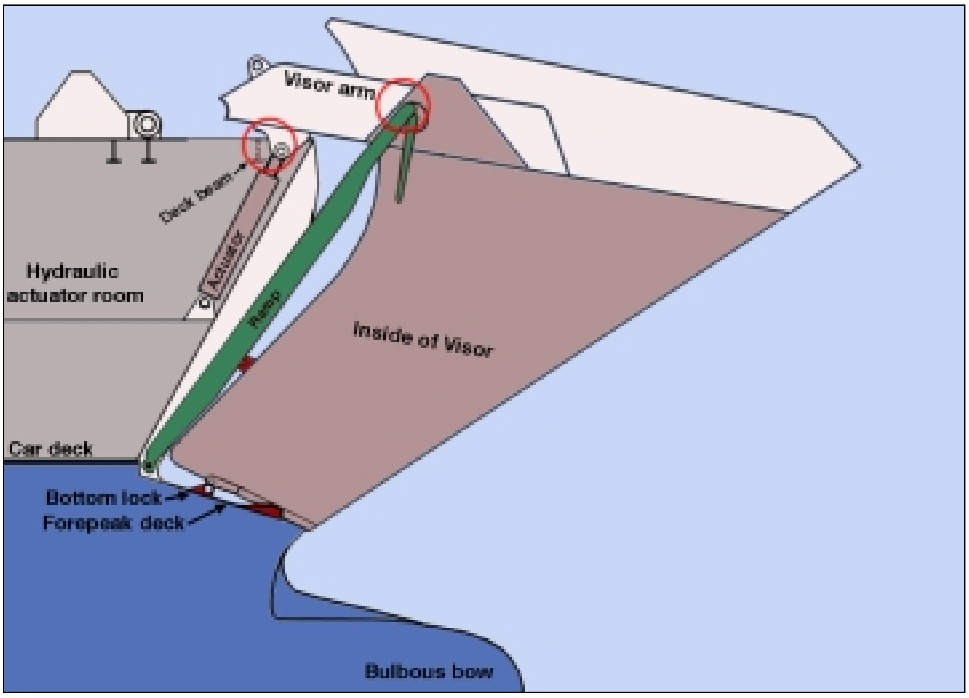
It is important to note that the deck beam is not shown in JAIC figure 13.6 above, though it was found to be the ”heaviest structural element preventing the visor from moving forward”.

Investigated cutting scenario

The scenario we are checking is limited to the short time when the hydraulic lugs are said to have cut their way through the deck beam. If cutting through the deck beam is proven impossible by the forces involved, the entire JAIC scenario is wrong. Moreover, in that case it also prove that the ramp could not have been ripped open by the visor. The scenario is described in the following figures:



FG 4. The hinges on the visor arms broke and also the side lockings of the visor. The visor fell forward and the hydraulic lugs under the visor arms hit the deck beam (see also FG picture 6, A hitting B).

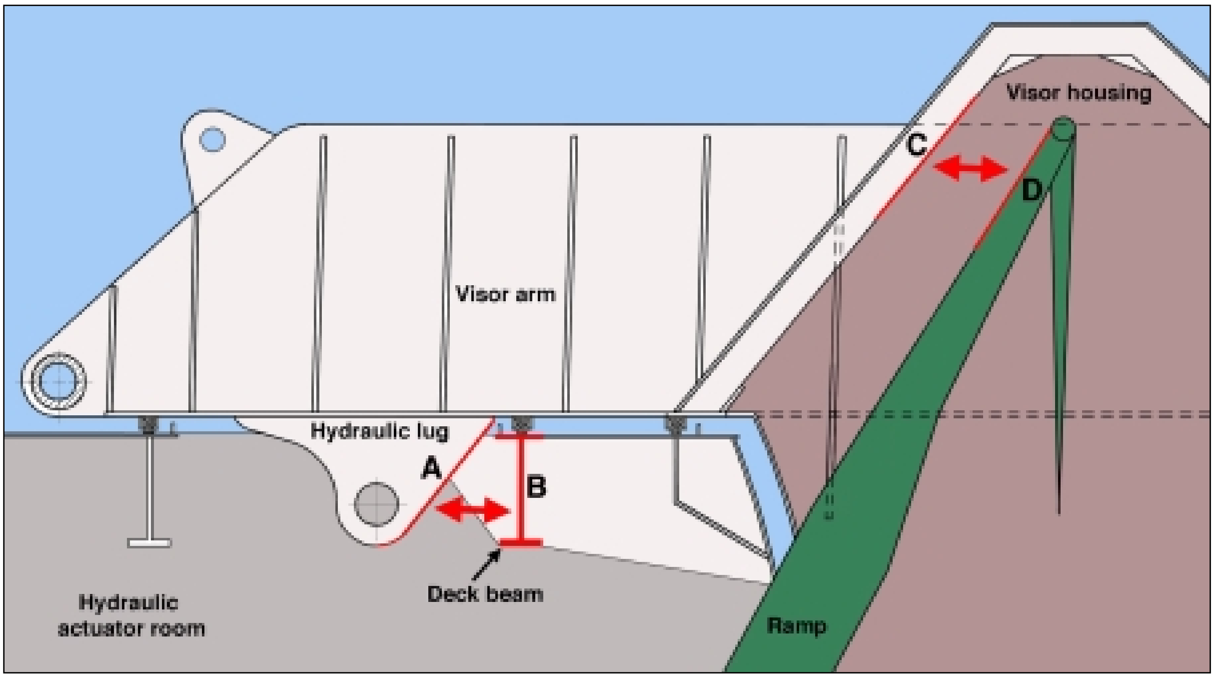


FG 5. The hydraulic lugs cut through the deck beam, and at the same time the visor housing hit the ramp and ripped it open (see also FG picture 6, C hitting D).

The Fact Group calculations, cutting through the deck beam

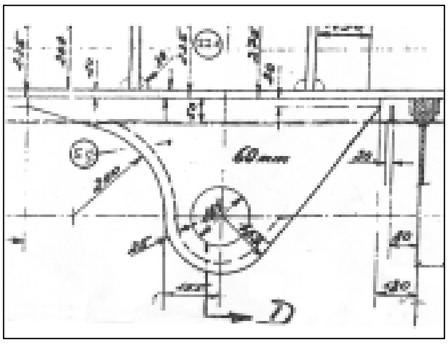
The deck beam construction.

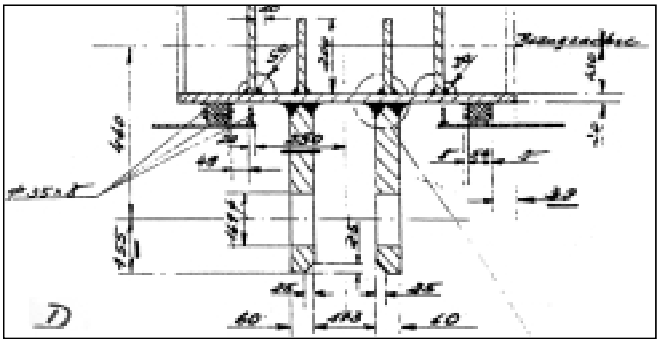
The deck beam was welded on the underside of the 8 mm thick foredeck. It was constructed like an ”upside down T”. The vertical plate was 400 mm high and 9 mm thick. The underside was 160 mm broad and 22 mm thick, welded to the vertical 9 mm plate.



FG 6. The picture shows the complete arrangement excluding the hydraulic actuator that was fastened to the hydraulic lug.

To be able to calculate the necessary force for cutting through the deck beam, we also have to look at the actuator lugs that are said to have cut through the beam. The ”cutting edges”(A above and the red edge) on the two lugs (in this example the port side) were 60 mm wide, and the forward edge of the lugs was 455 mm high. The distance between the pair of lugs on the port side was 173 mm. The cutting angle relative to the deck beam was 38 degrees.



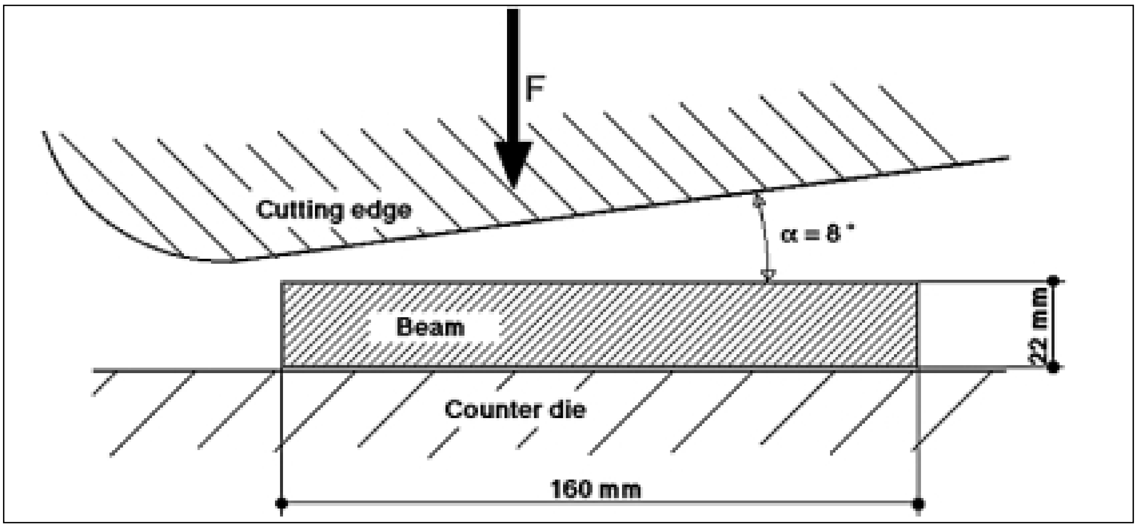


FG 7 and 8. The pictures show the dimension of the hydraulic lug seen from a side view and from aft. They are part of the Meyer Schiffswerft drawing of 2.6.1980.

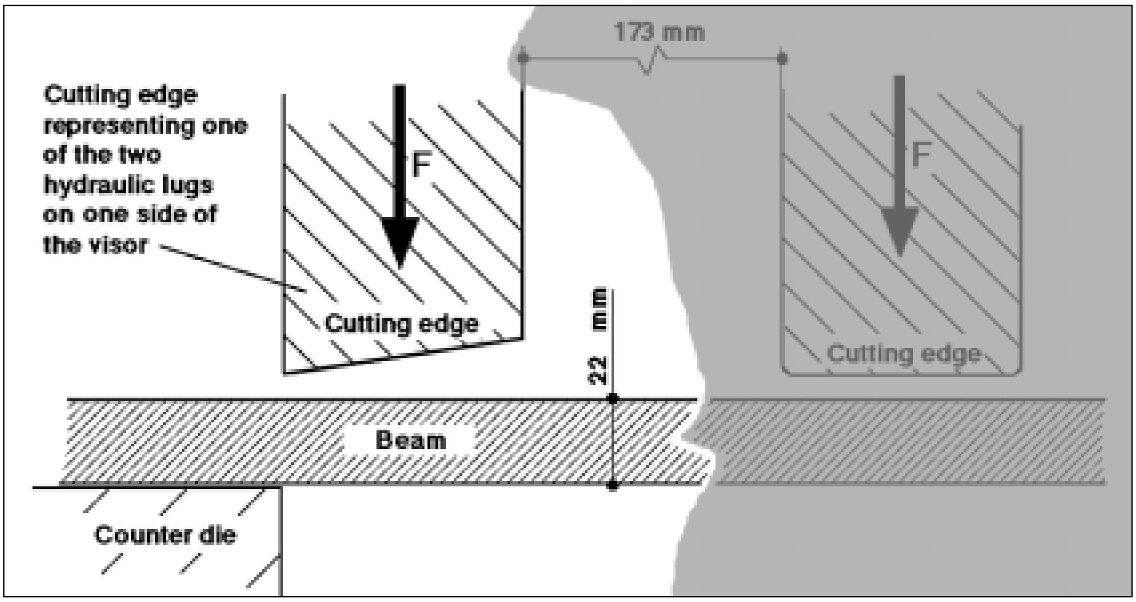
Breaking down the example - was it possible to cut through the deck beam?

When calculating we break down the example to obtain the most favourable situation in which we are certain of being able to estimate the lowest demand possible to be able to cut through a construction like this. This is done in some examples below.

Example 1. Only cutting through the lower part of the beam, cross section 160 mm x 22 mm. In this example, we calculate the necessary force if the beam was cut in a professional cutting machine. This will ensure that we can estimate the lowest demand necessary to cut through the beam. Figures 9 and 10 show the cutting principle from the side and from the front. The cutting edge has the same dimensions as the hydraulic lug on the visor, but in this example it has a hardened edge. Our example only takes into account one of four necessary simultaneous cuts.



FG 9. The lower part of the deck beam seen from the side as in FG 6. The cutting edge represent the hydraulic lug, but the angle is changed to a relevant cutting angle, 8 degrees. **F** is the force we aim to find.



FG 10. The lower part of the deck beam seen from the front. In the grey area we show the other side of the hydraulic lug pair, that in reality also had to cut through the beam in the same ”cut”. Two hydraulic lugs on each side had to make a total of 4 cuts. Moreover, in real life, there was no counter die.

Calculation Cutting, Example 1.1

Seen as a scenario in which only the bottom part of the deck beam is to be cut in a cutting machine, we get the following:

Thickness of beam S = 22 mm
Cross section A = 3520 mm^2
Cutting angle $\propto$ = 8°

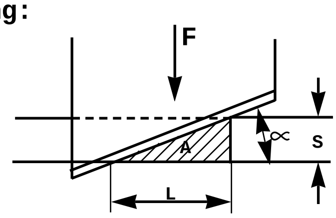
Shearing strength τ_{BS} = 400 N/mm^2 (340-470 N/mm^2 mild carbon steel St 37)

$$\text{Force } F = \tau_{BS} \times \frac{S^2}{2 \times \tan \propto}$$

$$\text{Force } F = 400 \times \frac{22^2}{2 \times \tan 8} \Rightarrow 400 \times \frac{484}{0{,}2811}$$

Force F = 688722 N = **70,2 tons** (1721 mm^2 cross section cutting area)

Formula cutting:



When cutting, the area cut at each moment is triangular (A). The area is $A = \frac{L \times S}{2}$

But as $L = \frac{S}{\tan \propto}$ it gives $A = \frac{S^2}{2 \times \tan \propto}$

where **S** is the thickness of the steel and $\propto$ is the cutting angle.

This giving $F = \tau_{BS} = \frac{S^2}{2 \times \tan \propto}$

Example 1.2

Same scenario as 1.1 but the cutting angle $\propto$ is increased to 10° respectively 12°

For $\propto$ = 10°, F = 548986 N = **56,0 tons** (1372 mm^2 cross section cutting area)

For $\propto$ = 12°, F = 455412 N = **46,4 tons** (1138 mm^2 cross section cutting area)

The Fact Group commentary:

A scenario in which the cutting angle $\propto$ = 38°, as it may have been in reality was not possible due to the following reasons: **A**. The beam would have bent forward when hit by the hydraulic lugs as there was no counter die holding the beam back. The cutting angle would therefore have been decreased to a minimum. **B**. If the cutting angle was higher than 12° there would have been a substantial risk of the cutting edge slipping in relation to the beam instead of cutting through it.

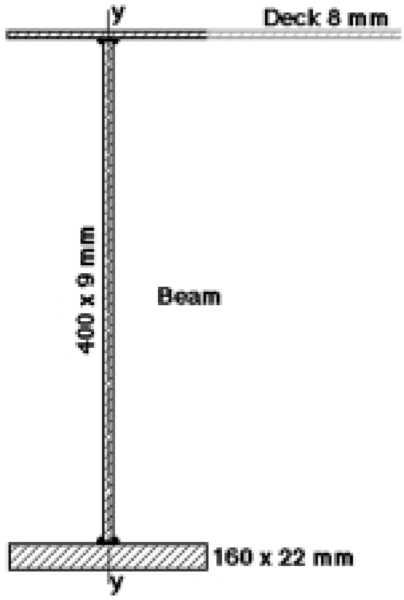
If the deck beam was cut by the lugs, there would have been two cuts done at the same time on <u>each side of the visor</u>. Both sides of the visor must have cut through the deck beam in the same time, and four cuts would have been simultaneous.

And also, if the complete deck beam was cut, the cross section area in each cut would have been doubled, increased by 9 x 400 mm = 3600 mm^2 which was the cross section area of the central vertical part of the deck beam. The cross section area of the deck plating that also had to be cut is still uncounted for.

Finally, the hydraulic lugs had no ”edges” made for cutting. The edges / lugs that were said to have cut through the deck beam are of normal mild steel as is the rest of the construction. In the following pictures, the lugs with the ”cutting edges” are shown. The edges have not been cutting through any beam as there are no contact marks from ”cutting”. It should also be noted that paint is still attached to the ”cutting surface”.

Calculation Bending, Example 2

The bending effect on the deck beam. The beam can be calculated as constructed of three parts, the bottom plate, the vertical plate, and the upper plate (a part of the foredeck).



FG 11. Deck beam cross section

Total cross section area A:
A = 2,2 x 16+0,9 x 40+0,8 x 16 = 84 cm^2(8400 mm^2)

Moment of inertia $\mathbf{I_y}$:

$$I_y = \frac{1}{12} \times (B1 \times H1^3 + B2 \times H2^3 + B3 \times H3^3) \Rightarrow$$

$$I_y = \frac{1}{12} \times (2{,}2 \times 16^3 + 40 \times 0{,}9^3 + 0{,}8 \times 16^3) \Rightarrow$$

$$I_y = \frac{1}{12} \times 12317 = \mathbf{1026\ cm^4}$$

Flexural resistance $\mathbf{W_y}$:

$$W_y = \frac{1}{6} \times (B1 \times H1 + B2 \times H2 + B3 \times H3) \Rightarrow$$

$$W_y = \frac{1}{6xH} \times 12317 \Rightarrow \frac{1}{6x16} \times 12317 = \mathbf{128{,}3\ cm^3}$$

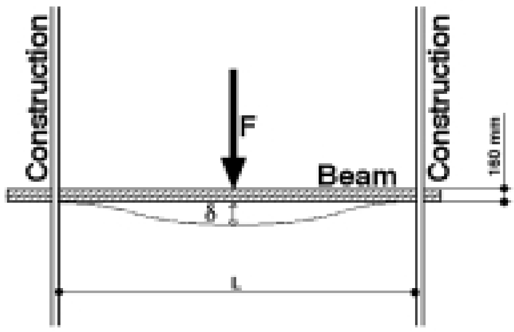
Maximum bending forward in mm:

The beam was welded to the construction on both sides, **L** was approx. 500 mm.

Coefficient of elasticity **E** = 210000 kN/mm^2
Force **F** = 455412 N (lowest theoretical force from example 1.2)

$$\delta_{max} = \frac{F \times L^3}{3 \times E \times I} \Rightarrow$$

$$\delta_{max} = \frac{455412 \times 500^3}{3 \times 210000 \times 10260000} = \mathbf{8{,}80\ mm}$$



FG 12. Deck beam view from above.

Shear stress when **F** acts in one ”cross cut section”:

F = 455412 N
A = 8400 mm^2

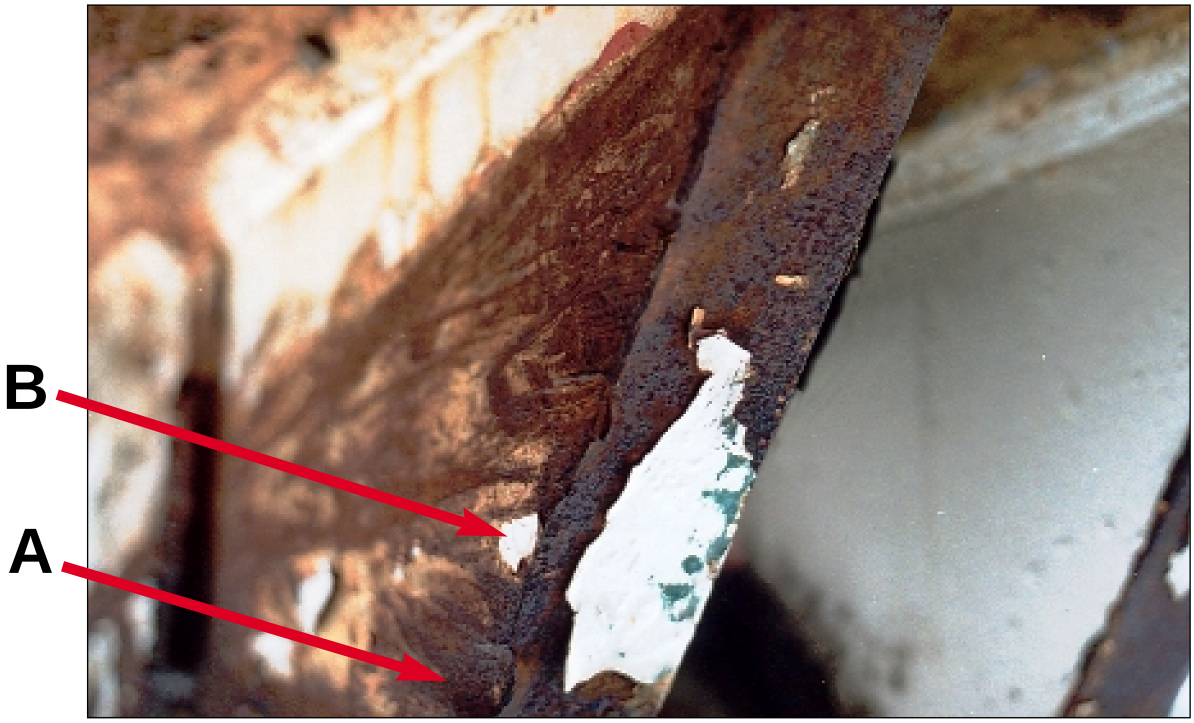
$$\tau_s = \frac{F}{A} \Rightarrow \frac{455412}{8400} = 54{,}2\ N/mm^2$$

This should be compared to the **Shearing strength,** which was over 400 N/mm^2

New picture evidence

In fact, as seen in picture FG 11 below, the edge that is said to have cut through the deck beam is razor sharp and cannot have cut through any metal. Furthermore, the damage on the side of the hydraulic lug, scratches and plastic deformation, was made in a side and forward direction. That is in the opposite direction that would have been the case if the lug had cut through the deck beam.

The picture below shows the status of the visor port hydraulic lug as it is today, five years after the catastrophe. The hydraulic lugs are mounted in pairs on each side, and this picture shows the port inner lug.



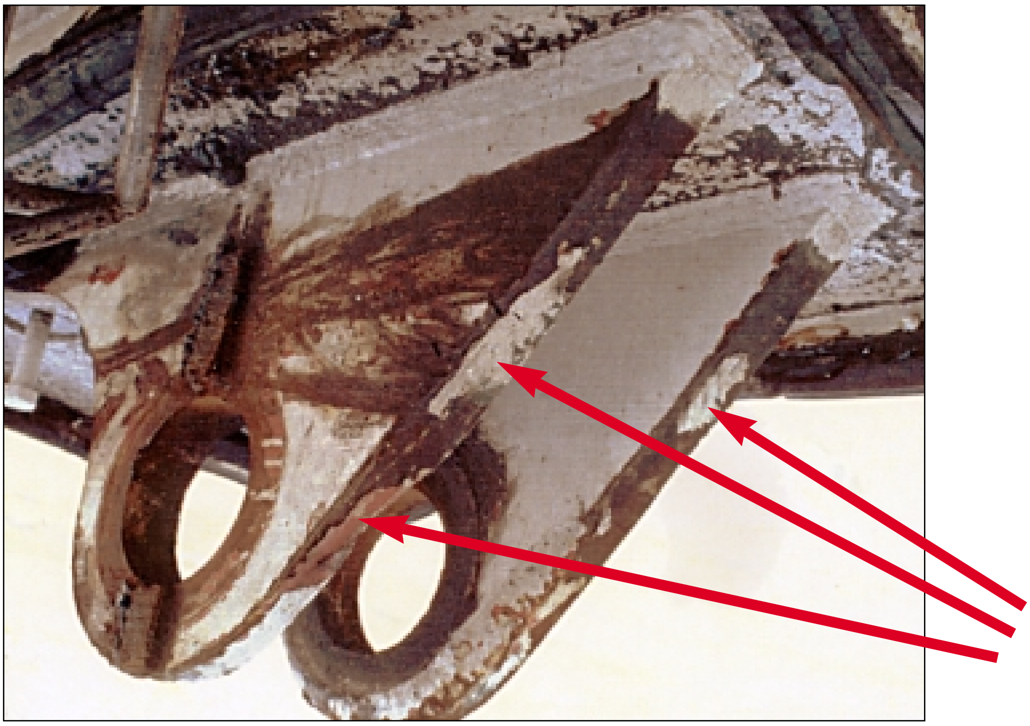
FG 13. The port hydraulic lug. Note the plastic deformation shown by arrow A made in the direction of the arrow, and the sharp edge shown by arrow B. Note also that there is paint on the very edge of the lug also shown by arrow B. (This picture can be compared with the German Expert Group picture E9 on the next page, where the complete lug is shown.)

Impossible visor scenario

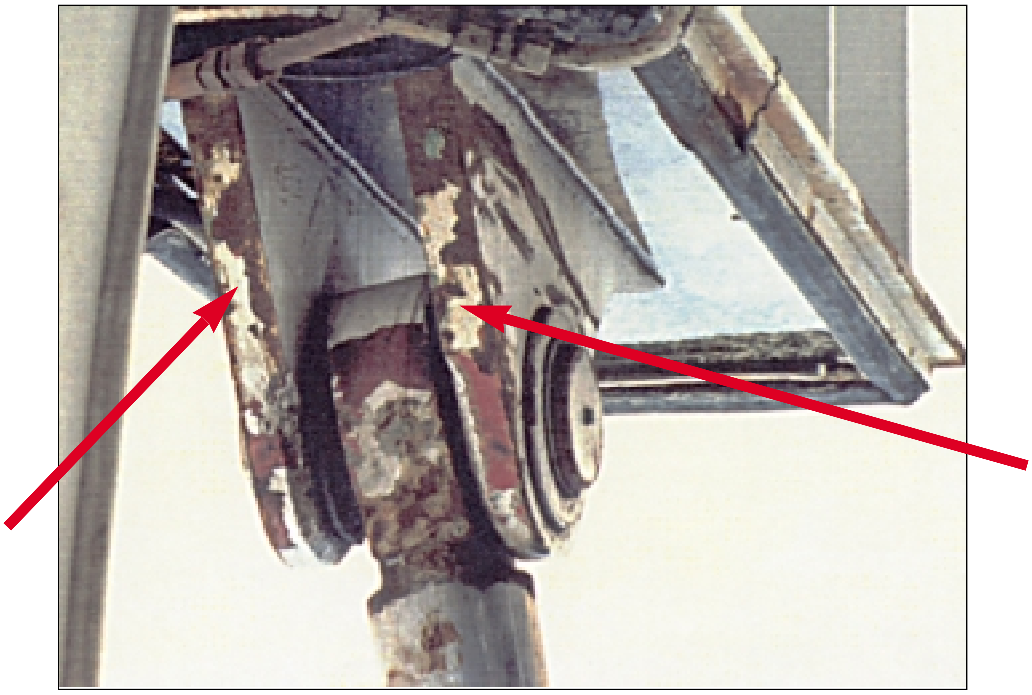
The visual and physical evidence presented here absolutely proves that this hydraulic lug never cut its way through the deck beam, and thereafter two metres through the upper foredeck and the front bulkhead. Therefore the Commission’s entire visor scenario is disqualified as impossible and a new commission must be appointed as stated by UN resolution IMO A 849, 2.0.

Pictures of the hydraulic actuator lugs

The following two pictures are from the German Expert Group. The pictures have been edited to show the lugs in detail.

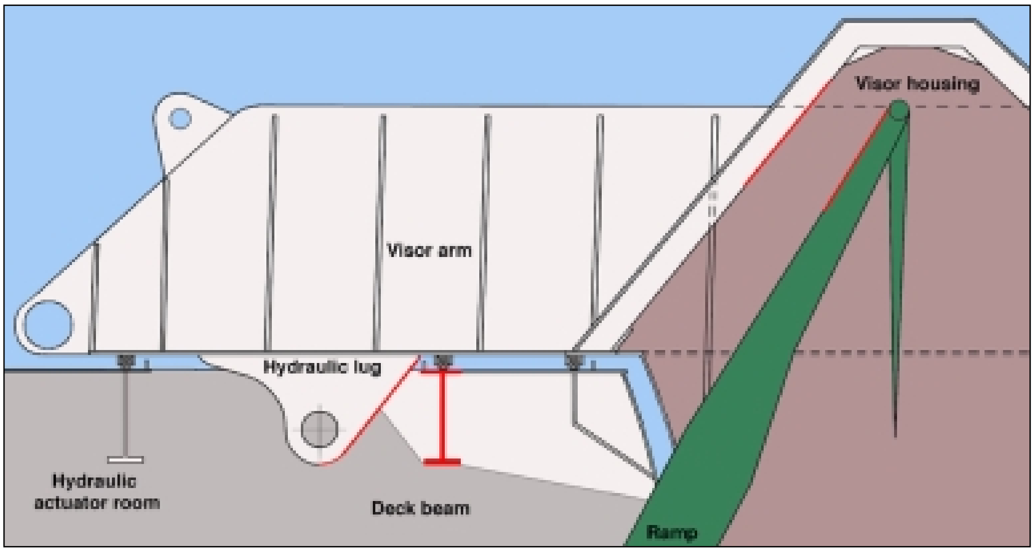


German Expert Group picture E9, No. 17 A. Lugs for dismounted port hydraulic actuator. On the lug to the left in the picture, the Commission adapted a vertical plate by welding and later cut this plate away. Note all the paint left on the surface that should have been in contact with the deck beam while cutting (arrows).

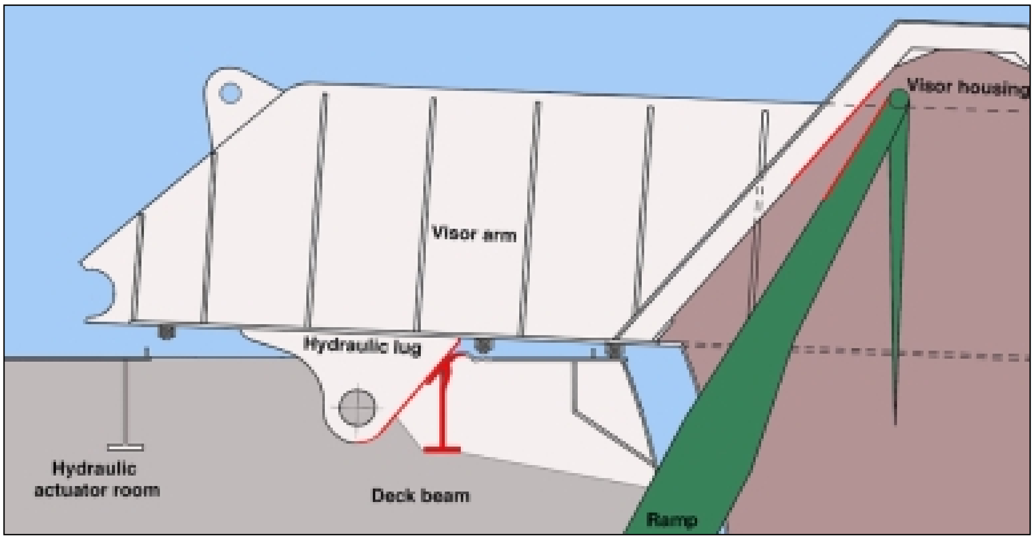


German Expert Group picture D8, No. 15 A. Lugs for starboard actuator.

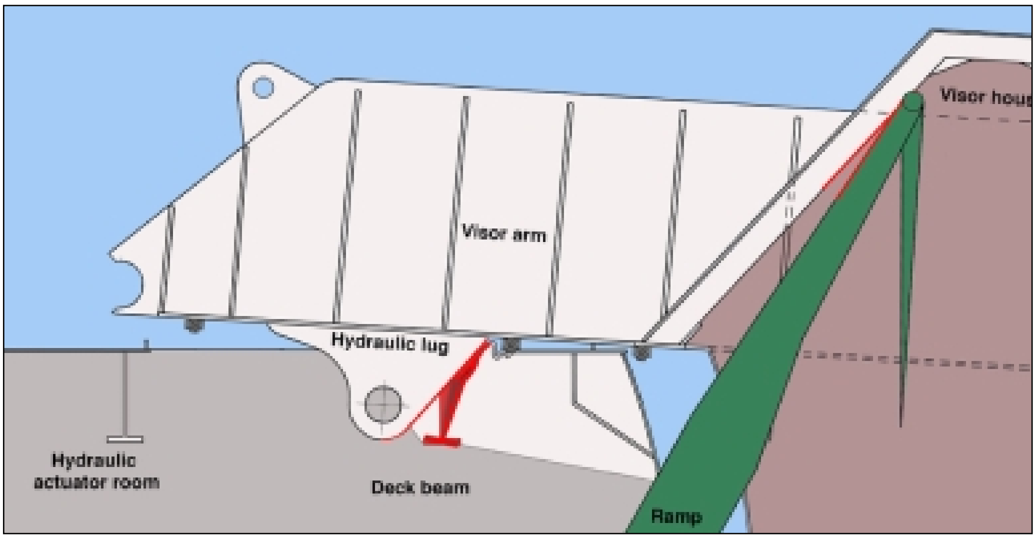
The Fact Group conclusion - pictures showing the visor scenario:



FG 14. Visor and ramp in correct position. Visor arm hinges and hydraulic actuator are not shown.



FG 15. The hinges broke and the visor fell forward and hit the deck beam that was bent and deformed but not cut.



FG 16. The visor hit the upper part of the ramp and caused only slight damage. The deck beam and ramp prevented the visor falling any further.

The Fact Group conclusion - text:

Our examples shows that even if the cutting was performed in machinery conditions, the theoretical minimum forward force must have been approximately 4 x 46.4 tons = 185.6 tons. This must be compared with the weight of the visor which is said to be approximately 56 tons.

If the hydraulic lugs had cut through the deck beam, the beam would have been bent, causing damage to the foredeck and the construction in general. The force needed to break through the beam would therefore rise to close to the ultimate tensile stress, the necessary force of 8400 mm^2 x 400 N/mm^2 = 3360000 N or 343 tons, and this is only on one side. No damage can be seen on the foredeck (railings in the deckplating following the ”cuts”, with a distance of approximately 100 - 150 mm, are perfectly intact), and no damage can be seen on the beam where it appears in the ”ramp tunnel” into the car deck (which is just 100 millimetres away from the cuts).

Our calculations regarding ”cutting through the deck beam” prove that it was impossible for the hydraulic actuator lugs or the actuators to cut through the deck beam. This is due to the lack of sufficient forward forces induced from waves. The maximum forward force created by green water and / or acceleration due to vertical movements in the ship, together with the forward resultant from the weight of the visor, was not more than 10 - 20 % of the visor weight. The impossible scenario is also proven by the simple fact that the paint is still on the hydraulic lugs. The ”cutting edges” on the visor hydraulic lugs are not damaged by any cutting as they would have been if they had cut through the deck beam. This proves that the hydraulic lugs never cut through the deck beam.

We have not taken into consideration that the forward force also had to break the ramp locking devices, as stated by the Commission. Our report shows that the visor housing would have hit the upper part of the ramp at the same time as the visor hydraulic lugs would have hit the deck beam. Each locking device could take a force of around 20 - 40 tons. In other words this force would have held the visor back, with the same strength also preventing the lugs from cutting through the beam. The reason why we have not taken the ramp locking devices into consideration is simply because the ramp locking devices were not ripped open as the Commission said, and we therefore do not know exactly how the ramp was locked, properly or not. There were also other elements that held the visor back, for example the hydraulic actuators (approximately 150 tons each).

The final conclusion is that if or when the visor broke loose for some reason initially, it never can have fallen forward, and that therefore the visor never can have ripped the ramp open.

Thus we have found the answers to the three questions on page 15, they are;
1. The deck beam is strong enough.
2. No, it was not possible for the visor actuator lugs to cut through the beam.
3. No, it was not correct, the visor would have hit the beam and the ramp simultaneously.

There are a number of possible scenarios that may have caused the visor to break loose from its attachments, leaving it hanging / standing loose on the little forepeak deck in front of the ramp. However, at that point it would still substantially have been held in position by the hydraulic actuators connected to the deck in the actuator rooms.

The video recordings from the wreck show a number of clean cuts of the deck beam, the foredeck and the front bulkhead. We leave it to a new independent commission to investigate what caused this damage. Maybe it was caused by the same activities that cut the two ramp railings away inside the cardeck when the ship already rested on the bottom. This activity took place in spite of the fact that the Commission stated that the divers never entered the cardeck. However, video recordings from the wreck clearly show divers working inside the cardeck.

Sources

- JAIC (Joint Accident Investigation Commission);
  Final report on the capsizing of the Ro-ro passenger vessel MV ESTONIA on 28 September 1994 in the Baltic Sea

- Supplement to the Final Report

The Swedish Board of Accident Investigation archive:

Paper	Date	archive No.
Letter from the German Group of Experts	1995.11.02	B 125
Video recordings		B 40 b - B 40 c

Other:

Information from the German Group of Experts and their reports.
Photographs from the German Group of Experts E9, No. 17 A - D8, No. 15 A

Books:

Elementär Mekanik by Fridolf Medé and Edward V. Tent
Hållfasthetslära by Fridolf Medé and Rune Lindh

DEDICATION

We dedicate this report to all those that lost their lives at sea as a result of a ship's lack of seaworthiness.

If MV Estonia had been seaworthy, many of the more than 850 persons who lost their lives would have had a chance to survive.

Stockholm, 1 January 2000

For the Independent Fact Group

Björn Stenberg Johan Ridderstolpe