New Research into the MV Estonia Disaster

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ABSTRACT

Since March 2006 the HSVA-Consortium, that is, the HSVA and the Technical University of Hamburg-Harburg (TUHH) together with the company TraffGo HT, which is specialized in evacuation simulation software, is investigating the MV Estonia accident for the Swedish Governmental Agency for Innovation Systems (VINNOVA). Some first preliminary results of the on-going investigation are presented. These results are mainly based on the motion simulation of the damaged ship in seaway carried out in the HSVA with the program ROLLS, including the simulation of the water sloshing on the vehicle deck. The results give an improved picture of the early phases of the accident.

KEYWORDS

MV Estonia, Ship Motion Simulation; Water on Deck; Shallow-Water-Equations; Capsizing; Evacuation Simulation.

INTRODUCTION

The MV Estonia sank on September 28, 1994 in the Baltic Sea on its way from Tallinn to Stockholm. According to official documents at least 852 human lives were lost in this accident, which makes it one of the worst in the European maritime history. The Joint Accident Investigation Commission (JAIC) published its report few years after the accident in 1997. This report gives a picture of the accident, which understandably is not complete and appears also partly controversial. The discussion on the MV Estonia has not calmed down after all these years and perhaps as a consequence the Swedish Government authorized a new study in 2005. Since March 2006 two consortia, the SSPA-Consortium and the HSVA-Consortium with their partners are separately investigating the sinking sequence of the MV Estonia. This paper gives information on the methods used in the on-going HSVA investigation and on some first preliminary results.

It is believed that in the framework of the relatively limited research budget the best contribution to the already existing studies could be delivered using as advanced simulation techniques as possible, both for the capsizing and sinking of the vessel and for the evacuation of the passengers and crew.

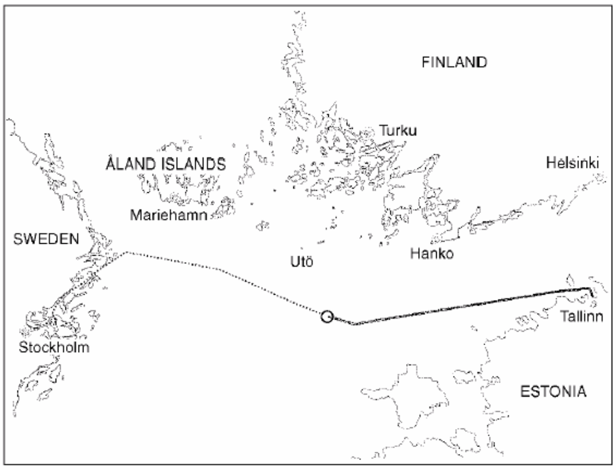

Fig. 1: The route and accident site of the MV Estonia (JAIC, 1997).

Since the beginning of the investigation by JAIC various organizations have carried out hydrostatic analyses of the capsizing and the consequent sinking of the vessel. The later hydrostatic analyses did not provide results essentially deviating from the earlier ones. Therefore in the HSVA investigation simulation of the ship motions together with the flooding of the vehicle deck will be carried out. Here the inflow to and outflow from the vehicle deck are crucial. The models used in the past for describing this detail have not always been very advanced. In this study new ways to model the inflow-outflow will be applied.

analysis will turn out to be considerable. This may help to develop the guidelines further. The evacuation analysis is still far from complete and is not reported further here.

The HSVA-consortium research is strongly based on survivors' testimonies (SPF, FAIB), physical facts, and numerical analysis. The very early survivors' statements have been given somewhat more emphasis than the later ones. However, some later interviews carried out by the interest groups working on MV Estonia have given some additional information often supporting our conclusions based on the early testimonies. A new time sequence of the course of the accident in form of ship's list as a function of time was established purely on the basis of the survivors' testimonies by the TUHH, the second partner in the HSVA–Consortium. This sequence of the ship's list is one of the crucial facts to be reproduced with the motion simulation of the damaged ship. Figure 2 shows the new time sequence of the capsizing of the MV Estonia together with the list development reported by the JAIC. There is a clear difference between these two time-histories. The HSVA

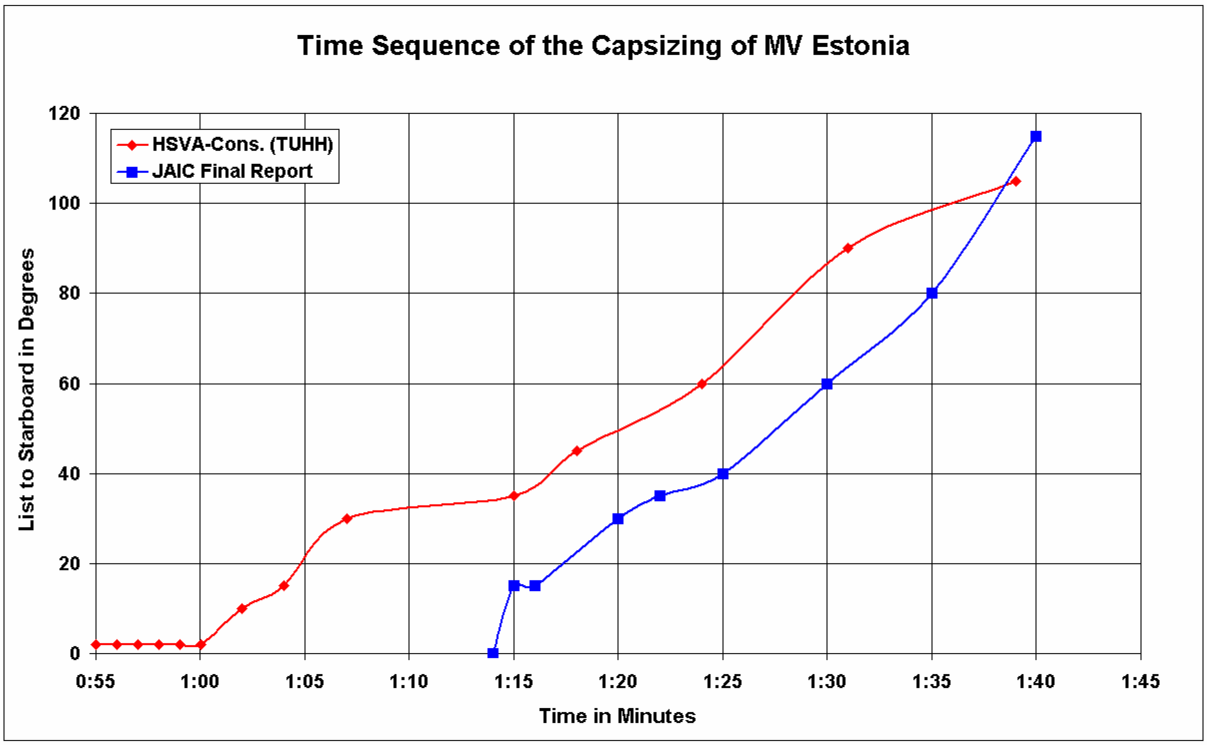

Fig. 2: Development of list to starboard during the MV Estonia accident.

On the other hand an evacuation analysis will help to establish as complete picture of the MV Estonia accident as possible. In our analysis with evacuation software AENEAS, which has the capability to account for the ship motions, the actual crew and passenger population of the MV Estonia at the time of the accident is modeled. First evacuation analyses with the real MV Estonia population and the newly estimated ship's list as a function of time were carried out. For purpose of comparison also evacuation analyses according to the IMO guidelines will be carried out. It is expected that the differences between the Estonia evacuation and the IMO advanced evacuation consortium believes that the actual accident started earlier, around 01:00, and not at 01:14 as stated by JAIC. The values of list in the TUHH-curve are based on subjective observations made by the survivors. It is possible that the actual values of list were at certain points somewhat lower than those felt and reported by the survivors.

THE ACCIDENT

Track of the Vessel

Figure 3 reproduced from the JAIC Final Report (1997) shows the MV Estonia's track during the last hour. The red circles and the ellipse mark areas where the visor, an unknown object and various loose items lay on the seabed, based on sonar measurements carried out in October 1994 (Nuorteva, 1995). These are hard facts in the Estonia investigation: The vessel must have passed very near these points. physical facts related to the behavior of the damaged vessel in the seaway of the night to September 28, 1994.

Start of the Accident

The accident can be considered to have started around 01:00, when many survivors heard and felt two to three heavy blows from the bow, after which a scraping sound apparently coming from under the vessel was heard by several survivors. After this the vessel experienced 2-3 deep sudden heels to starboard. The vessel straightened a little, but a considerable list remained.

Disconnection of the Bow Visor

It is known that the visor must have dropped in quite an early phase of the accident and according to JAIC pulled the ramp completely open. These conclusion have, however, been put into question by various interest groups

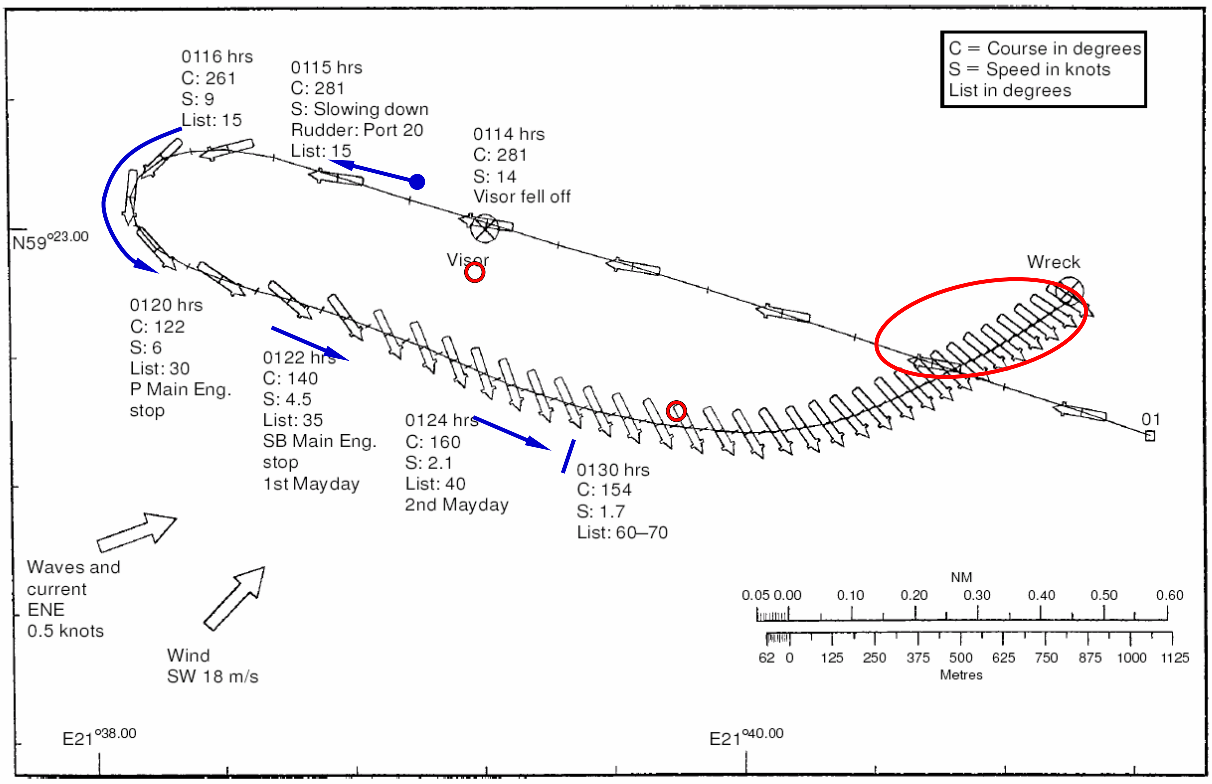

Fig. 3: MV Estonia's track during the last hour, as composed by the Navigation Simulator at the Maritime Academy in Kalmar, Sweden (JAIC, 1997).

The blue arrows in the figure show the part of the track, which is subject to be defined with the help of the survivors' testimonies and working on MV Estonia. The bridge of the MV Estonia was constructed so that it was not possible to see the bow visor. Even if the officers on the bridge could not see the visor itself, as shown in Figure 4, they may have seen that the spray flying upwards, when the bow hit a new wave was very different, because the visor had dropped. Also the feel of the ship at each wave impact must have changed, because the vessel without the visor had now a very blunt bow shape above the waterline. It is, however, very likely that the officers on the bridge at that moment did not realize that the visor, due to built-in interlocking, may have also pulled the ramp open.

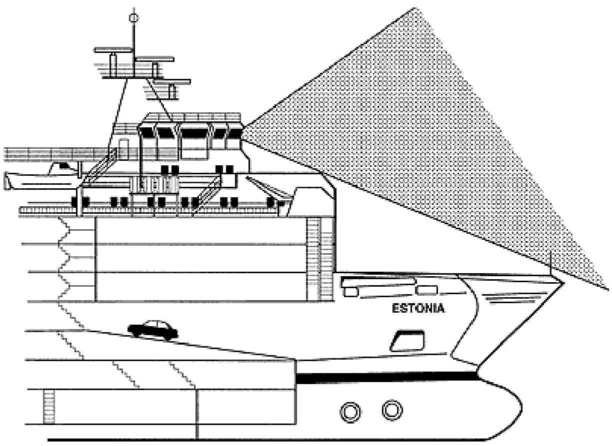

Fig. 4: Approximate field of vision from the bridge (JAIC, 1997).

It is likely that the visor dropped quite soon after the first sudden heel, if not already earlier: The crew member C42[1] (interview 29.09.94 in Tallinn) was in his cabin around 01:00 reading a book. Suddenly the vessel listed to the starboard side so heavily that objects fell down from the cabin table. C42 dressed rapidly and went out of the cabin. In the corridor he met the first and second engineers (C46 and C38). One of them said “the visor went off” or “the visor was pushed up, it would be good if we would get the vessel to shore”. He got the impression that the locks holding the ramp had loosened and through there water came in. So already few minutes after 01:00 some members of the crew knew that the visor had dropped or opened, and that the ramp was leaking.

If the visor disconnected from the vessel advancing 15 kn, it of course had in the beginning approximately the same horizontal velocity as the ship. When the visor hit the water surface its velocity slowed down drastically. In this situation it is very likely that the advancing ship hit the visor.

Thus it is only natural that the visor has a deep dent obviously caused by the bulb of the advancing ship. As a results of such collision the visor would be pushed away by the relatively narrow bulb, in this case to the port side, where the MV Estonia underwater hull shows some minor damages. A visor pushed beside by the narrow bulb is still ahead of the ship hull advancing 14-15 kn. Further contacts between the visor and the advancing ship hull are very likely to have taken place. Thus the scraping noise, heard by some survivors as noise coming from underneath their cabins on Deck 1, was probably caused by the ship running over the visor, which could not sink fast enough to avoid contact with the advancing ship.

In order to throw some light on these early phases of the accident the following cases were investigated with the program HSVA Rolls. A description of the program can be found in (Valanto, 2006).

NUMERICAL SIMULATION

Scenario 0a: Visor and Ramp both 1 m open

The MV Estonia runs on the course 287° in a sea state having a significant wave height of 4.2 m and modal period of 8.0 s. The waves come at 45° from the port bow quarter. The visor is loose in its position: There is a 1 m high horizontal gap between the visor and the ship shell just below the visor. The ramp has been pulled 1 m open at its upper end. This scenario is plausible as an initial scenario.

The triangular shaped openings between the ramp and its frame on both sides of the ramp were modeled in the motion computations of the damaged ship with the program Rolls. The effect of the somewhat opened visor on the inflow rate was estimated, in absence of other sources, with the experimental results by SSPA

[1] The code refers to the confidential list Witness Key.xls shared by the two consortia.

(2007). These suggest that the inflow rate would be reduced by 70 percent in comparison with the situation without the visor.

Simulation result: In this scenario the inflow rate of about 10-20 m³/min is relatively small from the point of view of the ship stability. However, also this amount certainly appears considerable for an observer on the vehicle deck or somebody observing this via a TV-monitor, like the crew in the Engine Control Room (ECR) did.

The water accumulates slowly on the vehicle deck; in ca. 26 min the list of the ship reaches 10°. The list increases gradually as the water volume on the vehicle deck increases. If no corrective action were taken, the ship would be in danger to capsize after more than 3 hours.

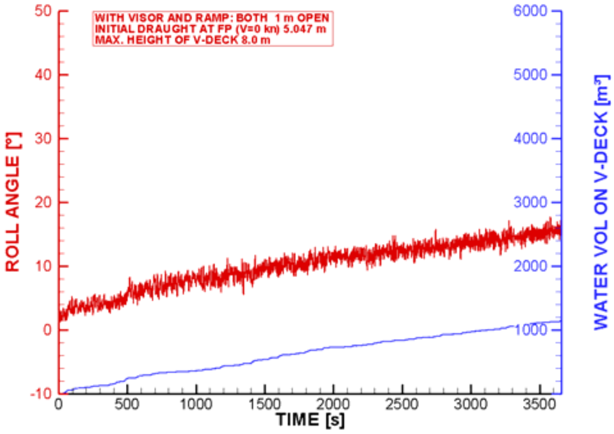

Fig. 5: Roll angle and water volume on the vehicle deck when both the visor and ramp are about 1 m open.

This scenario may have taken place before the ramp opened, but not for very long, as the gradually increasing list, e.g. 7° after 10 min, would have been noticed sooner or later by the crew. The simulation does not indicate any sudden heeling or other sudden ship motions.

- ⇨ The flooding rate in this scenario is too slow for it to be the final scenario for the flooding of the vehicle deck.
- ⇨ The scenario can be true for the very initial phase of the accident, but not for very long, as the slowly increasing list would have been observed by the crew.

Scenario 0b: Without Visor, Ramp 1 m open

The MV Estonia runs on the course 287° in a sea state having a significant wave height of 4.2 m and modal period of 8.0 s. The visor has dropped away. The ramp has been pulled open 1 m at its upper end. This scenario is not plausible according to JAIC, as there is nothing which can hold the ramp in this partially open position. It is, however, favored by some interest groups working on the Estonia case, perhaps because the ramp at the wreck resting on the seabed is approximately in this position.

Simulation result: In this scenario the inflow rate of about 70-80 m³/min is considerable from the point of view of the ship stability and certainly appears massive for an observer on the vehicle deck or on a TV-monitor. In addition in this case the airflow at the open gaps beside the ramp consisting of the ship speed and a component of the wind outside may have speeded the finer water spray coming in up to about 20 m/s or more.

The water accumulates on the vehicle deck; in ca. 7 min the list of the ship reaches 10°. The list increases monotonously as the water volume on the vehicle deck increases. If no action were taken, the ship would be in danger to capsize in about 40 minutes. Due to the gradually increasing list the situation would have been noticed by the crew relatively soon. Even after a considerable list there would have been enough time to take action against the water inflow on to the vehicle deck. The simulation does not indicate any sudden heeling or other sudden ship motions.

This scenario is difficult from the point of view of the ramp position. The wave forces the ramp would encounter in this inclined position would be considerable, thus no weak support can hold the ramp in this partially open position. The ramp weights about 12.5 tons. It is, however, light enough to be moved by the waves the ship encountered in the night of the accident.

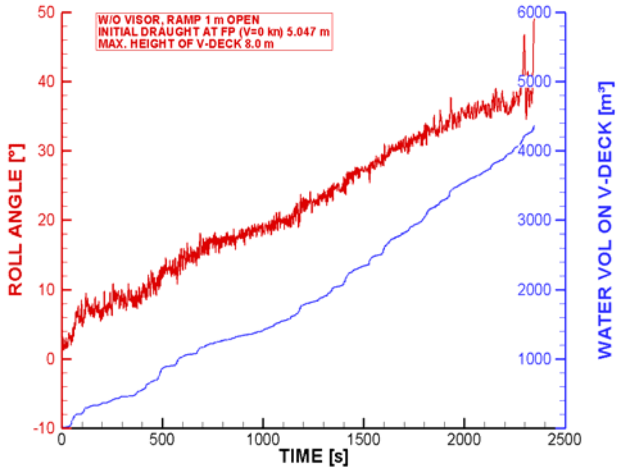

Fig. 6: Roll angle and water volume on the vehicle deck without visor when the ramp is about 1 m open.

- ⇨ The flooding rate is perhaps somewhat too slow for this scenario to be the final scenario for the flooding of the vehicle deck.
- ⇨ The inflow to the vehicle deck could hardly remain unnoticed by the crew. In this scenario the ship gets a list of 14-15° in 10 min. After this observation the crew would still have had sufficient time to take action against the inflow.
- ⇨ This scenario does not fit to the known technical facts reported by the JAIC.

Scenario 1: Without Visor, Ramp fully Open

The MV Estonia runs on the course 287° in a sea state having a significant wave height of 4.2 m and modal period of 8.0 s. <u>The visor has dropped away. The ramp has been pulled fully open.</u> This scenario is the accident scenario according to JAIC.

<u>Simulation result</u>: In this scenario the computed inflow rates vary between 300-700 m³/min, which are of course relatively high also from the point of view of the ship stability. This scenario is very likely to have taken place, but not for very long, as the increasing list, over 10° in three to four minutes would certainly have been noticed by the crew. If no corrective were be taken, the ship would be in severe danger to capsize in little more than 10-20 minutes, which did not happen. The likely further progressive flooding of the vessel leading to sinking is at the moment not considered.

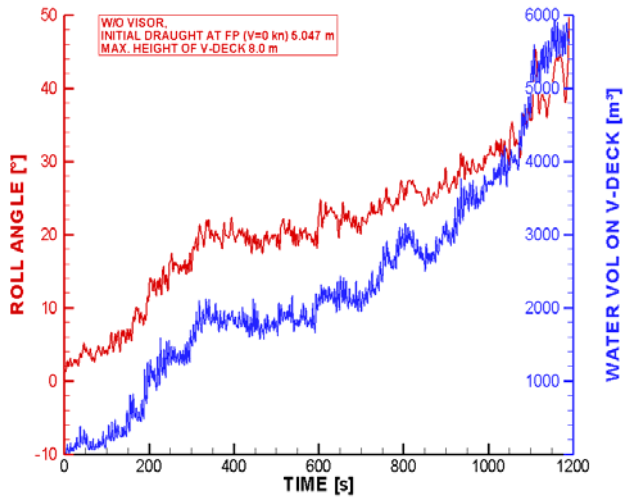

Fig. 7: Roll angle and water volume on the vehicle deck without visor when the ramp is fully open.

Notice that the curve in Figure 7 describing the water volume on the vehicle deck has a somewhat rougher look than the earlier curves shown in Figures 5-6: This is due to the open bow ramp, which allows more water sloshing in and out of the vehicle deck than in the earlier cases with the bow ramp only about 1 m open.

- ⇨ The flooding rate is suitable for this scenario to be the final scenario for the flooding of the vehicle deck.
- ⇨ The inflow to the vehicle would certainly be noticed by the crew. In this scenario the ship gets a list of over 10° in 3-4 minutes. If the crew in this scenario would not rapidly slow down or turn the ship, it would capsize. This scenario can be considered in general to fit with most testimonies by survivors and to known technical facts.

Discussion

The JAIC Final Report assumes that the waves hit the visor and made it to break loose. The visor was banging against the ship structures, and after a while it fell off pulling the ramp completely open. Through the open ramp enormous amount of water flowed on to the vehicle deck and the ship heeled. This scenario is plausible also in view of the preliminary simulation results above provided that the following two questions can be answered:

(1) What caused the sudden heel described by many survivors? The survivors` testimonies appear to indicate that one first heard strange “metallic” noises from the bow (two to three heavy blows), second some scraping noises appearing to come from underneath the ship hull, and third one experienced sudden, violent heeling to starboard. Some survivors explain that they expected the ship to straighten and to roll back towards the other side, but this never happened. After the sudden heel to starboard the ship straightened somewhat, but a significant list remained.

(2) How can the JAIC scenario be combined with the statements of the three crew members, who reported they saw water spraying on both sides the closed bow ramp after the ship already had a significant list?

THE SUDDEN HEEL

Introduction

A negative intact stability, e.g. due to water on the vehicle deck, would cause the ship to have two positions of stable equilibrium, that is, the ship would be stable, when inclined with the angle of loll to either side. The rolling motion between these two positions of equilibrium, with the associated overshooting of the roll angle can of course cause a sudden heeling experienced by the passengers and crew onboard. In case of MV Estonia, which had a small initial list to starboard and then heeled further to starboard, this possibility does not appear to be the explanation for the sudden heeling.

If the sudden heel had been caused by a wave an intact ship would have straightened afterwards. Thus the assumption of a large wave alone causing the big heel does not appear to be very likely.

If the heeling had been related to water accumulating on the vehicle deck, a more gradual increase in the list would have been likely. A somewhat distant possibility is that the ship encountered, just after the ramp was pulled open, some very large waves, which very rapidly brought considerable amount of water on to the vehicle deck. Even then the sudden list would most likely not have been as impressive as reported. This is a possible, but perhaps an unlikely scenario.

Finally there is the possibility that the sudden heel was not a consequence of wave forces or of massive ingress of water, but a consequence of the ship starting to turn to port initiated by the officers on the bridge. To the present author this appears to be a plausible hypothesis for the sudden heeling motion and will be investigated below.

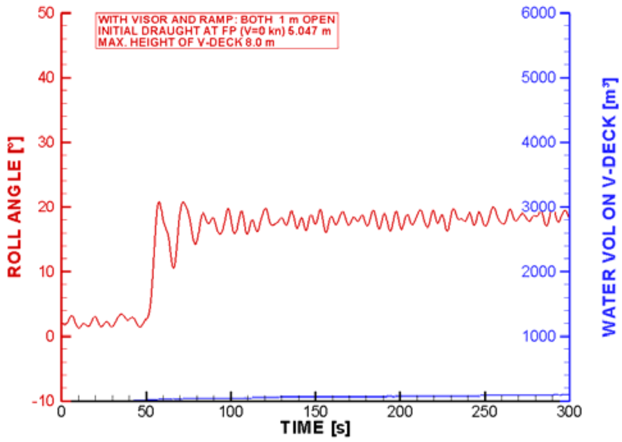

Fig. 8: Case (a): Roll angle and water volume on the vehicle deck, when both the visor and ramp are about 1 m open, start of turn at t=50 s.

In their testimonies the survivors P28 and P30 describe a turn to port. The P28 also describes how the ship heeled so heavily to starboard that furniture inside started to move. The person P28 also fell on the deck due to a sudden heeling motion (Schager, 2006). A HSVA technician on the full-scale trials of the MV Viking Sally, that is, later MV Estonia, experienced something quite similar. He was on the upper deck, when the ship started a Zigzag-maneuver: He remembers he had difficulties to stay on his feet and he heard how objects were falling down from tables and shelves, because of the sudden heeling due to the start of the turn.

Turn to Port

The location of the visor, the debris dropped from the ship listing heavily and the position and orientation of the wreck quite strongly hint that the ship made a turn to port, before it capsized and sank. See Figure 3 for illustration of the vessel's track. In addition the second officer E1 on watch onboard the MV Mariella tracking MV Estonia that night saw in the corner of his eye on the radar screen the track of a hasty, sharp turn to port made by MV Estonia (FAIB, 1994).

It is also very plausible to assume that the officers on the bridge of the MV Estonia decided to make a turn to port. They may not have been fully aware of what was wrong with the ship, but they certainly knew that something had changed. Strange noises from the bow had been reported to the bridge. They may have known that they had water on the vehicle deck. If they were in contact with crew members in the engine control room, at worst these could have told that plenty of water sprayed onto the vehicle deck on both sides of the closed ramp. Even if the officers on the bridge had assumed that the visor had broken or dropped away, they could at this situation not have the knowledge that the falling visor could pull the ramp fully open. A turn to port would bring the wind and the waves to the starboard side. This would have a straightening effect on the ship's list. In this light the turn to port appears a plausible measure to try to improve the situation of the ship.

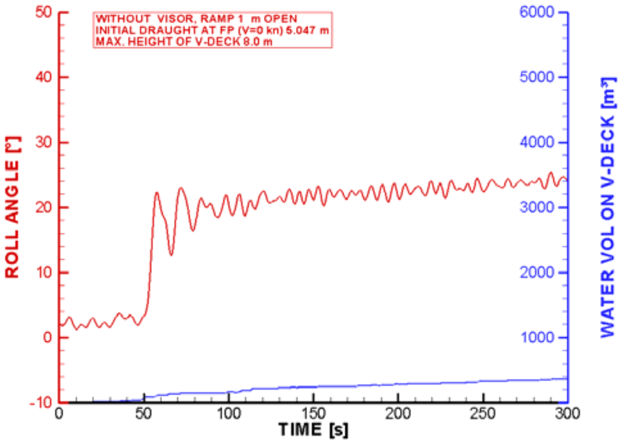

Fig. 9: Case (b): Roll angle and water volume on the vehicle deck, without visor, with the ramp about 1 m open, start of turn at t=50 s.

It is well known that when a ship starts a sudden turn to port, an overshooting of the heeling angle to starboard takes place. This overshooting can in certain conditions be quite significant, e.g. objects can slide on tables and drop down. There is, however, very little information available of how large this overshooting angle can be, on a ship in seaway, when there is water on the vehicle deck.

The water on the deck accumulates to the starboard side due to the sudden heeling and also due to the centrifugal acceleration caused by the turning of the ship. Thus the officers on the bridge may have themselves been surprised of the magnitude of the heeling that now followed.

It is perhaps not absolutely sure whether the ship ramp opened before or after the ship started its turning maneuver. Therefore the sudden heeling motion due to the sharp turn to port was simulated in three basic situations:

a) The ship with both the loose visor and the bow ramp 1 m open.

b) The ship without visor and the bow ramp 1 m open.

c) The ship without visor and the bow ramp completely open.

In all cases the ship speed amounts to 15 kn, the steady turning diameter of the ship's turn is 2.9 ship lengths (L_{pp}) (JAIC Supp. 523, 1996; SSPA, 2007). The full centrifugal acceleration due to the turn is reached in 14 seconds from the start of the turn. In the beginning a large oscillation (overshoot) to the outer side of the turn takes place. After a while the static heel balances the centrifugal acceleration acting on the ship. This situation lasts as long as the ship turns. Thus the heeling angle is not returning to zero. This was also noticed by some of the survivors in their testimonies, even if they did not know the reason for the sudden heeling.

In the case (a) the simulations provide a step of 18-19° in the heeling angle curve, the heel angle reaches 20° and remains high, as shown in Figure 8. The transient roll oscillations after the step dampen rapidly. The water inflow on to the vehicle deck is not strongly influenced by the increased heel of the vessel, and the ship list remains practically constant. The water volume on the vehicle deck is in this particular case small. The situation has an almost quasistatic character and does not appear to correspond as well with the survivors' testimonies as the case (c) below.

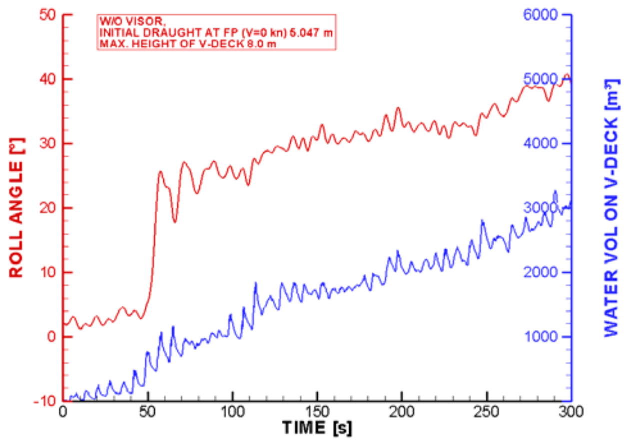

Fig. 11: Case (c): Roll angle and water volume on the vehicle deck, without visor, ramp fully open, start of turn at t=50 s. Second realization of random waves.

Case (b): If the simulation for the case (a) is carried out without the visor, the curves look in the beginning very similar, with the exception that the additional heeling increases the inflow onto the vehicle deck and the ship would be in danger to capsize in less than 20 minutes. For this reason, even if problematic from the point of view of the ramp position, this scenario cannot be left out of further consideration as the main scenario.

In the case (c) the step is a little higher (19°-22°) leading to a momentary heeling angle of up to 26°. The water sloshing on the vehicle deck is likely to contribute to the magnitude of the sudden heeling motion. In this case the inflow through the completely open bow increases due to the sudden heel. Figures 10 and 11 illustrate the case with two different random wave realizations used in the simulations.

The actual magnitude of the sudden heeling motion depends on the ship's actual position in the waves, ship speed, rate of turning, height of the center of gravity and also how rapidly the ship starts to turn. Further the amount of water on the vehicle deck and its motion can influence the situation. For these reasons the three cases in Figures 8 to 11 should be taken only as examples.

It should be taken into account that the survivors' estimates of the felt heeling angle getting up to 45-50° may be too high. Person P28 explained further that after the initial overshooting he could see a metal plate stick out of the hull (the stabilizer fin) on the port side. This implies a heeling angle of at least ca. 15°-18°, which is not far from the few examples shown above in Figures 8-11. The following conclusions can be drawn based on the simulations carried out.

- ⇨ A sharp turn to port gives a plausible explanation to the sudden heeling motion of the ship reported by the survivors.
- ⇨ The amount of water on the vehicle deck, as shown in Figures 8-11, appears to contribute to the magnitude of the sudden heeling motion.

Water on the Vehicle Deck - Water onto Deck 1

Many survivors coming up from their cabins on Deck 1 reported water either on the Deck 1, or on the way up in the staircases, when they were passing Deck 2, that is, the vehicle deck. One of the important questions in the case of the MV Estonia is, how did the water come on to Deck 1, the next deck below the vehicle deck? This question is crucial from the point of view of the damage scenario. Either the water came from the vehicle deck as JAIC has suggested, or it came from somewhere deeper down, as suggested e.g. by Holtappels and Hummel (GGE, 1999). The survivors from the Deck 1 reported encounters with relative small amounts of water on their way out of their cabins just after the sudden heel, that is, when the ship still had a relatively moderate list.

Hydrostatic considerations indicate that a relatively high list is needed before the water reaches the openings in the central casing and can flow down on to Deck 1. This would take place quite late in the course of the accident, thus the persons from Deck 1 would hardly have had time to escape. The numerical simulation of the motion of the ship and of the water on the vehicle deck gives a more refined picture than the hydrostatic analysis.

The numerical computations show how the water flows in from the open ramp to both sides of the central casing on the vehicle deck. The simulations show wilder sloshing motion in the longitudinal direction, when the ramp is fully open compared with those cases, when it is only about 1 m open.

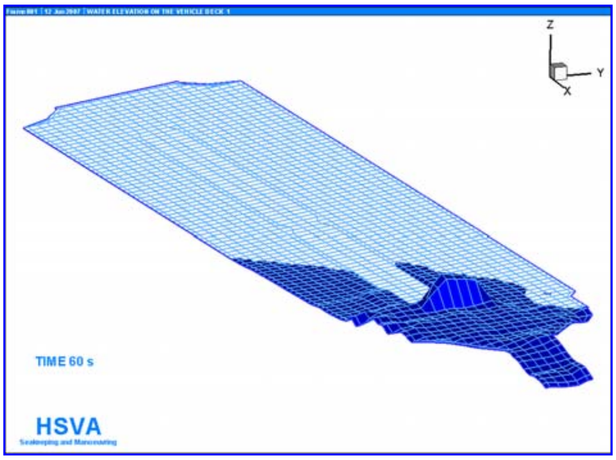

Fig. 12: Waves on the vehicle deck coming through the fully open ramp slosh against front face of the central casing and splash water high up.

See the incoming wave hitting the front face of the central casing in Figure 12. The numerical grid on the vehicle deck is coarse, and the shallow-water-equations used in the computations are an idealization of the reality. Thus this small detail cannot be described very accurately by the numerical model, but in reality the wave at the front face of the central casing would have splashed water high up making the video camera fixed on this front face wet, as described by three crew members in the Engine Control Room (ECR). It is likely that this can take place only when the ramp is open.

As the vessel is rolling and pitching in the waves, the water sloshes around on the vehicle deck. Some water may splash into the staircases of the central casing and flow down onto Deck 1 below. The flooding of the vehicle deck starts from the bow, as also shown in Figures 12-14. Thus it is more likely that in the early phases of the accident water would flow into the front compartments on the Deck 1 than those further aft. This is also supported by the testimonies of those who survived from the Deck 1, as shown in Figures 15-16. Depending on the case as early as 3-4 minutes after the start of the accident some water can flow down to Deck 1 through the front staircases in the central casing.

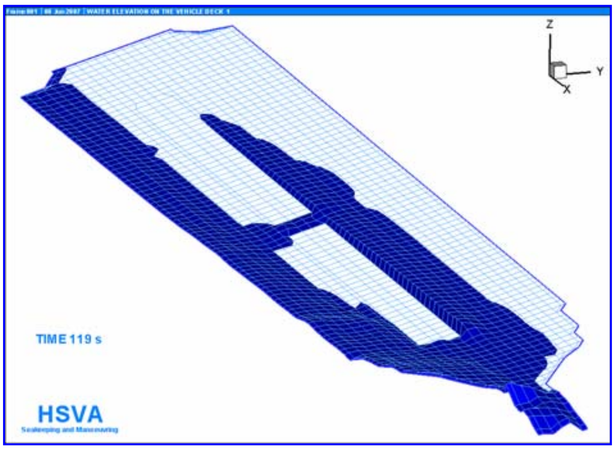

Fig. 13: Waves slosh water onto the vehicle deck through the fully open ramp. The flooding starts from the bow. Before the turn starts the heeling angle is relatively small.

In the ECR motorman C7 was looking into a monitor showing the camera view towards the pilot door located in front at the starboard side of the ship. He reported water sloshing in this area between the cars and reaching up to the level of the cars, that is, 40-50 cm high (Kurm, 2007). In the simulations the water sloshing on the vehicle deck almost always floods this area. Thus the simulated results are in full harmony with the statement by C7.

The GGE Enclosure 12.4.4.161 (Holtappels and Hummel, 1999) contains an interview with retired pilot Bo Söderman concerning his observations of water on deck of the MV Estonia on 26 December 1993, that is, on another earlier trip. Pilot Söderman says “In my opinion there was 5-10 cm water over the whole area of the vessel’s car deck. The water was splashing about 1 m high against the bulkhead with the stairways (centre casing).”

This statement directly supports the computed results of the water sloshing on the vehicle deck and splashing high against the central casing walls.

A further interesting point is added when one looks what happens on the vehicle deck, if the vessel makes a turn. When the vessel starts the turn to port, it heels suddenly to starboard, and the water on the port side of the vehicle deck flows towards the central casing, where the water level rises and in addition the water sloshes high against the port side central casing

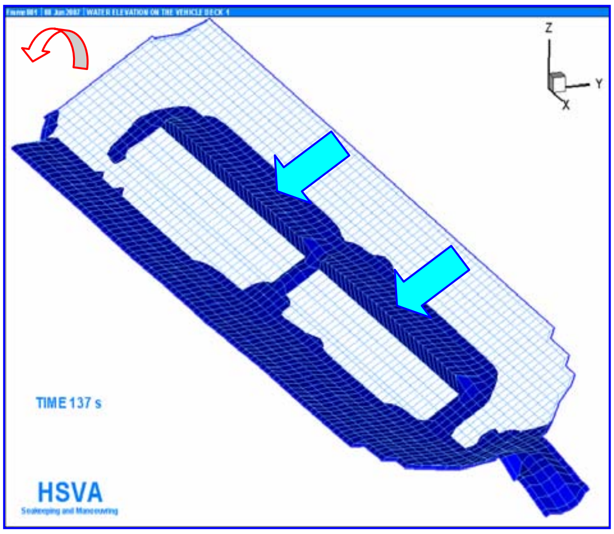

Fig. 14: When the turn has started at 120 s. the ship heels suddenly, the water on the vehicle deck rushes to starboard and the water level rises momentarily high on the port side wall of the central casing as it flows towards the lower starboard side.

wall and can easily flow into the staircases and from there down on to Deck 1 below. Figure 14 illustrates this moment. Many of the cabins of those survivors, who reported water on Deck 1 are located directly starboard of the staircases, that is, “downhill”, exactly where water would flow in a ship having a significant starboard list. See Figure 16.

- ⇨ Water flows in from the opening at the bow to ***both sides*** of the central casing on the vehicle deck. Thus in this case this dynamic distribution of water is more even than a hydro-static distribution would be. Therefore values of list estimated hydrostatically for a given amount of water on the vehicle deck are in this case likely to be somewhat too high.
- ⇨ If the ramp was open, it is likely that incoming waves hit the front face of the central casing splashing water high towards the camera fixed on this face possibly making the camera wet, as described by the crew members in ECR.
- ⇨ The flooding of the vehicle deck started from the bow. As the ship was rolling and pitching in the waves, it is likely that some water splashed or flooded into the staircases in the central casing and flowed further down in to the front compartments on Deck 1.

The sudden heeling motion caused a momentary high water level on the port side of the central casing. This most likely contributed to water being able to flow down to the front compartments on Deck 1. This matches well

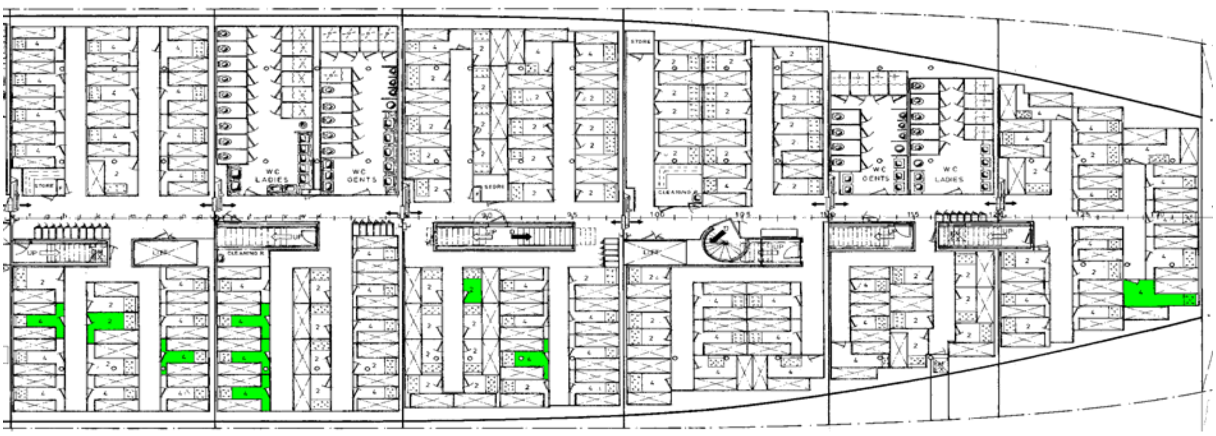

Fig. 15: Location of survivors, who reported water on Deck 2 (Vehicle deck) above, but not on Deck 1

with the testimonies of the survivors, who came up from Deck 1 just after the sudden heel and encountered water on the way up.

TESTIMONIES FROM CREW MEMBERS

It would be important to know exactly what the crew members saw and what they reported about the situation on the vehicle deck. Unfortunately the statements are to certain extent controversial with each other, and sometimes also controversial with physical facts. Therefore any selection of the statements will unavoidably be somewhat subjective. Thus also other interpretations than the one below are possible.

According to the interview on 03.10.94 at the security police in Tallinn, at 00:45 AB Seaman on watch (C16) was on the vehicle deck just in front of ramp and heard a crash from behind the ramp. C16 stated further that everything was fine on the vehicle deck at that time.

After the accident in the hospital the crew member C15 overheard a discussion according to which AB Seaman on watch C16 had been on the vehicle deck and said into walkie-talkie that there was lots of water on vehicle deck and that they should abandon the ship. This interview took place on 30.09.94 in Bromma.

Another crew member C6 has confirmed the information from C15.

The AB Seaman on watch (C16) obviously never returned to the vehicle deck later on, thus it can be assumed that he made this call with the walkie-talkie around 00:45.

The three crew members in the ECR (motorman C7, system engineer C33, and 3rd engineer C36) reported seeing water coming in on the monitor showing the ramp. In the first interview the motorman C7 said:

At 00:46 there was a narrow stream of water or a jet at the right hand side of the bow ramp. Little after the moment when the sudden heeling took place C7 came into ECR and the 3rd engineer said to him: “The situation is serious (or bad), while the ramp has become broken.” According to the Swedish translation of this first interview on 29.09.1994 in Turku the motorman C7 saw large waves on the vehicle deck. After a new interview with C7 this statement has been corrected by Kurm (2007) as follows:

First, C7 did not see water in the camera viewing the ramp, but in the camera, which was looking over to starboard from the centre of the ship. It was a camera below the ceiling directed towards the pilot door; and the floor

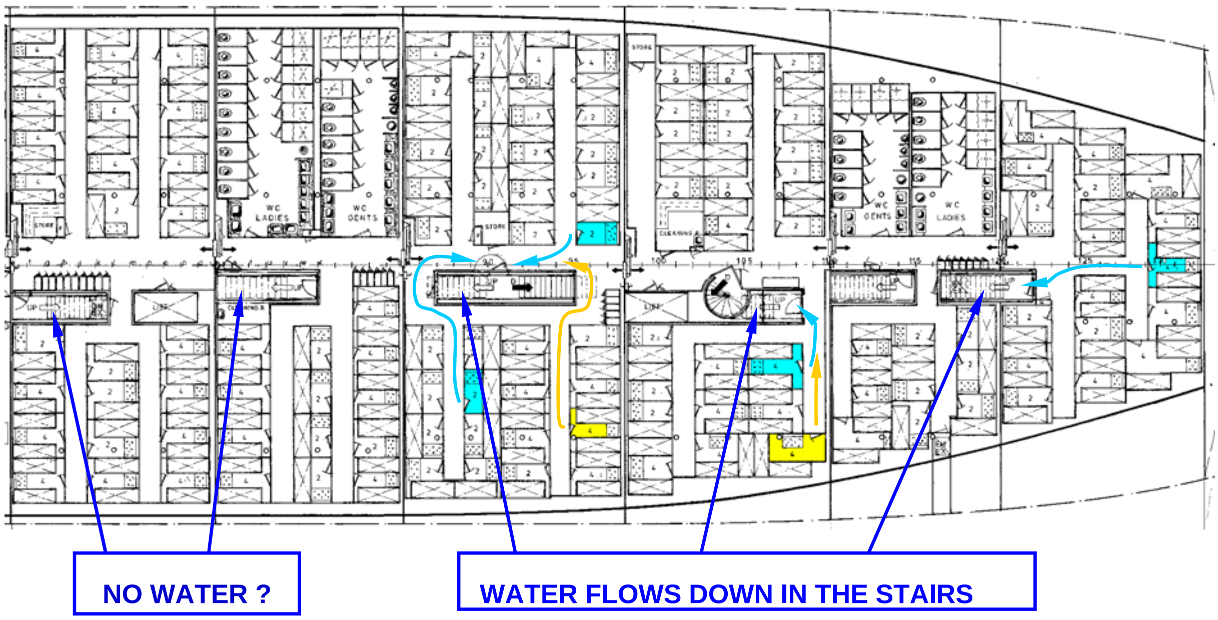

Fig. 16: Location of survivors, who reported water on Deck 1, and their likely escape routes,

could only be seen in the narrow passage that had been left between the cars so that the pilot could pass through. It was not possible to see the floor in the camera looking at the ramp, which the 3rd engineer and the system engineer were looking at. All three men confirmed this (Kurm, 2007).

Second, C7 has never talked about the waves of water reaching up to the cars. He saw that "water had gathered at the side of the deck, reaching up to the lights of cars in the outermost row … and as the ship was rolling, it was flowing from one end to another." Thus, there was about 40 to 50 cm of water on the starboard side, and the ship already had list, how else water could have gathered on the starboard side of the ship (Kurm, 2007).

The 3rd engineer testified on 3.10.94 in Tallinn: I saw on the monitor after the impacts that large quantities of water were being pressed in through the sides of the ramp and under the ramp. There were no seals at the ramp itself, or at its sides.

The 3rd engineer C36 said on 31.03.95 at Landvetter Airport: After the blows I saw in the monitor showing the ramp that water was penetrating between ramp and hull at such a high pressure that the camera was hit. I realized that the vessel rolled 3° to starboard and 1.5° to port and the next time much more to starboard and upright and then a very heavy heel to starboard. Then I heard the voice of AB Seaman on watch (C16) on the walkie-talkie that water was coming in.

The mentioned video camera was probably situated below the level of the fourth deck, that is, about 4.0 - 4.5 m above the vehicle deck, on the front face of the center casing, about 25 meters from the ramp. C36 testified further about the amount of water that came in on both sides of the ramp: As if one would throw water in with buckets. So it was not some individual drops.

In general the three crew members were speaking of lots of water coming in at the sides of the ramp. Let us interpret the statement of C36 literally: A bucket has a capacity of around 10 liters. Let us assume that as much as 5 buckets of water came in per second. This makes 3 m³ in one minute. This amount is so small that the ship is really not in danger. However, according to the motorman, the 3rd engineer had said that the situation was bad, as the ramp was broken.

The AB Seaman on watch (C16) had understood this obviously already earlier around 00:45 when he said into the walkie-talkie that there was lots of water on vehicle deck and that they should abandon the ship. After this C16 went on to the bridge, where the captain was concerned that the ship would be late. Later C16 was ordered to go down to the vehicle deck to check the situation again. He was at the information desk on Deck 5, when the sudden heel occurred. He claims he tried to reach the vehicle deck. He reached the Deck 4, but he could not get further down because passengers fleeing from below clogged the narrower stairs leading down from Deck 4. Thus he did not go down on to the vehicle deck anymore and he is still alive today. It can be only added that after the accident divers found over 35 victims in the lobby on Deck 4 (JAIC, 1997), which is located just one floor below the information desk, at which C16 had been standing. Also all three crew members in ECR managed to escape. All four were safe in life rafts already at 01:24-01:30, that is, very much at the same time as the officers on the bridge sent their MAYDAY, about 40-45 minutes after the call of the AB Seaman on watch (C16) on the walkie-talkie.

According to the their testimonies the three crew members saw water only on the monitor screens in the ECR. They have not reported being on the vehicle deck themselves. The AB Seaman on watch C16 himself has never reported seeing water on the vehicle deck. Yet they all understood to abandon the ship sufficiently early. Their testimonies may not give a complete picture of what the crew members knew, what they did and when this took place.

Discussion

If we believe in the JAIC scenario, we still have the problem with the open ramp assumed in the JAIC scenario and the closed, but broken ramp observed by the three members of the crew. Here are some alternatives to explain the dilemma.

(1) The crew members saw the ramp just before it was pulled open by the visor. They may also have left the engine control room somewhat earlier than they have reported.

(2) How could the video camera on the center casing observing the ramp be sprayed with water? One answer to this question could be that the speed of the finer spray coming from the opening at the bow could perhaps just reach the camera and make it wet. Second answer is perhaps better: If the ramp was open, waves coming in at almost full ship speed could have sloshed against the front face of the central casing splashing some water high up to the video camera located at height 4.0 - 4.5 m above the vehicle deck. It was not possible to see the floor in the camera looking at the ramp (Kurm, 2007). Thus the crew members in the ECR were not able to see whether any water was sloshing on the deck between the ramp and the front face of the center casing, but they could certainly see if the camera was splashed with water.

    If the camera was sprayed with water, how could the crew in ECR see clearly the ramp and the spray on both sides of it on the monitor connected to this camera? There were lights on the vehicle deck. The ramp had a dark color. Outside it was dark. Could it be possible that the ramp was open, and that the crew members saw just a dark opening, where always earlier the ramp had been?

(3) They all observed correctly and told the truth, and the ship sank with the ramp only slightly open, that is, in the position of only about 1-1.4 m open, which at the moment does not appear to be mechanically possible. This would imply changes in the JAIC scenario.

CONCLUSIONS

Based on the survivors' testimonies the following conclusion can be drawn:

⇨ The accident can be considered to have started, as reported by the TUHH, already around 01:00 and not at 01:14 as stated by the JAIC.

The investigation with the motion simulation of the damaged ship including the sloshing of water on the vehicle deck gives plausible explanations in following issues:

⇨ When water was sloshing on the vehicle deck, limited amounts of water could flow down on to Deck 1 trough the front staircases in the central casing already at early phases of the accident.

⇨ In view of the water being able to flow from the vehicle deck down to the Deck 1 at the early phases of the accident, the assumption of damage deeper down on the hull as a cause for the water on Deck 1 appears superfluous.

⇨ The sudden heel was probably caused by the start of the turn of the vessel initiated by the officers on the bridge.

⇨ The main flooding of the vehicle deck probably took place, after the visor had dropped, either trough the completely open bow ramp or through the bow ramp at least about 1 m open, when the ship was turning.

⇨ The scenario of the visor and ramp being loose, let's say both about 1 m open, is not likely to be the main flooding scenario for the vehicle deck. The inflow rate appears to be too small for this. This implies that the visor dropped off relatively early and did not hang on the vessel until the ship heeled to near or over 90°.

The HSVA investigation is going on, thus all results presented are preliminary.

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