ANALYSIS OF THE CAPSIZE AND LOSS OF A 12000 DWT BULK CARRIER

Rumen Kishev, Bulgarian Ship Hydrodynamics Centre, r.kishev@bshc.bg
Vladimir Rakitin, Bulgarian Ship Hydrodynamics Centre, v.rakitin@bshc.bg
Silvia Kirilova, Bulgarian Ship Hydrodynamics Centre, s.kirilova@bshc.bg

ABSTRACT

In early 2004, a 12000 DWT bulk carrier suffered heavy storm weather when sailing in South-West Black Sea and has been reported to capsize and sunk shortly afterwards. Numerous lives have been lost.

In the paper, analysis is made of the circumstances of the accident and consequent loss of stability and sinking. Official data and documentation on ship technical status as well as weather conditions en route have been solely utilized as supplied by the National Investigation Agency.

Theoretical and experimental investigations on the vessel's operational stability, damage stability and seakeeping have been implemented and the most probable scenario of the accident has been drawn.

Keywords: *Stability, Capsize, Seakeeping*

1. INTRODUCTION

1.1. Background

The history of accident, recreated after witness testimonies, documents and recorded conversations of the ship officer's staff with the port officials, describes the event as follows:

Early morning on the day of disaster the vessel left Ukrainian port Yuzhny for Gebze (Turkey), loaded with 11750 t coal, in spite of the storm warning for the next three days. The wind and seas in the area were Nord-Nordwest, with increasing severity. At the approaching of Bosforus the vessel has been warned by the port authorities, that the channel is closed due to the bad weather and the master ordered change of course at adverse angle to waves and low speed. Later on, he has been given instructions to assume course to Bosforus. At a position about 10 miles from the shore the master reported, that the vessel is intensively taking water in Hold № 1. A few minutes later the ship capsized and sank, according witnesses from a ship heading close behind and confirmed by the traffic operators in the port of Istanbul.

1.2. Site — Black Sea, about 8 -10 nm in front of Bosforus:

Figure 1. Location of the two ships at the time of the accident.

1.3. Reported Loading

According the cargo plan submitted by the ship master and approved by the port authorities, the vessel has been loaded with 11751,7 t coal, distributed over cargo holds as follows:

Hold № 1 – 1800,0 t
Hold № 2 – 3200,0 t
Hold № 3 – 3325,0 t
Hold № 4 – 3426.7 t

At this, the logged drafts and trim have been:

Draft astern:	8,375 m
Draft afore:	8,188 m
Trim to stern:	0,200 m

1.4. Heading

By testimony of the witness ship's master, at the time of the accident the subject vessel sailed in following seas with a course angle of about 20° with reference to wind and wave propagation direction.

1.5. Wind speed

As reported by the shore weather control center, the wind speed at the time of the accident has been about 55 – 57 km/h, with blows up to 75 – 80 km/h, direction Nord.

1.6. Wave height

By testimony of the witness ship's crew, the sea severity has been 6-7 Beaufort, which corresponds to significant wave height of about 6 m and average period of 9 sec. This conforms with wind speed data reported above.

1.7. Ship condition before capsizing

By testimony of the witness ship's crew, immediately before capsize and sinking the subject vessel sailed at 5-6 knots with visible heel of 8-10 deg to starboard and about 1 deg trim to bow.

2. ANALYSIS OF LOADING CONDITION

The vagueness of initial information on loading concerned as cargo itself as well as the lightship weight.

2.1. Lightship

The lightship weight had changed with years of operation and numerous modifications of hull structure which have been not properly documented and approved. In particular, some years ago the tweendeck had been cut off, later two of the deck cranes had been removed also.

For conformity with existing ship documentation, lightship weight has been assumed to be 3773 t, as declared by the latest cargo plan approved by Yuzhny port authorities, even if the weight assessment during the investigation shows a most probable value of 3657 t.

2.2. Cargo weight and distribution

Loading data given in 1.3 correspond to the cargo plan submitted by the ship master before the last departure and approved by the port authorities. In its analysis, however, several inaccuracies have been found out, namely:

- The declared cargo quantities for the four cargo holds do not correspond to their capacity, as shown below:

Hold №	1	2	3	4
Capacity m³	2827	4701	4710	4642
Declared load, t	1800.00	3200.00	3325.00	3426.67
Max allowable load at SF=1.45 m³/t	1949.6	3242.1	3248.3	3201.4
Comment	under loaded	within norms	within norms	over loaded

- Declared values for Holds № 1 – 3 are rounded numbers, while for Hold № 4 they are given with accuracy up to the third digit, which gives grounds to conclude, that the stability calculations in the cargo plan had been "attuned" to match the draft readings. An additional argument for that is the unusually high correction constant of 195 t virtually situated in the superstructure, which has no physical explanation and does not exist in earlier stability calculations.
- The free surface corrections for service tanks had been estimated incorrectly.

For the sake of this investigation, several possible loading cases have been thus formulated:

Loading case	Description	Weight displ, t	Draft fore, m	Draft aft, m
CH1	According last submitted cargo plan	15671.0	8.28	8.32
CH2	Added 500 t water poured in Hold № 1	16171.0	9.18	7.88
CH3	Another 350 t water added in the forepeak	16521.0	9.99	7.52

The last two cases have been lately considered with and without existence of free surface in the holds, having in mind, that initially poured-in water will be absorbed by coal, but after saturation of the mixture to a liquid state a free surface will appear.

3. SEAKEEPING ASSESSMENT

The seakeeping qualities of the vessel have been analyzed by linear strip theory. Serial calculations have been made on ship motion parameters, motion related phenomena and added resistance at various speeds of advance and various headings.

The results obtained show that motion parameters are within expected limits, the differences between three loading conditions being minor. However, at adverse headings (as was the case of forced storming after closing of the strait), the deck wetness intensity is very high – even at speed reduced down to 6 kn at Bf6 (H1/3 = 6 m), the number of deck wetness occurrence for loading case CH1 is about Ndw = 50, while good marine practice allows 30. This means that the bow part and the hatch cover of Hold № 1 in particular had been subjected to intensive loading by overwhelming waves. For loading cases CH2 and CH3 this intensity increases 1.5 – 2 times, due to effective freeboard decrease after flooding of the bow compartments.

The added power in Bf6 conditions restricts attainable speed down to 8 kn, which is close to the value reported by the witnesses.

Figure 2. Illustration of intensive deck wetness at head seas.

4. WAVE LOADS ON HULL STRUCTURE

The vertical shearing forces and bending moments in waves have been calculated by strip theory, integrating wave loads along the ship length and adding those in still water.

The allowable limits have been estimated according the IACS Unified Requirements [2].

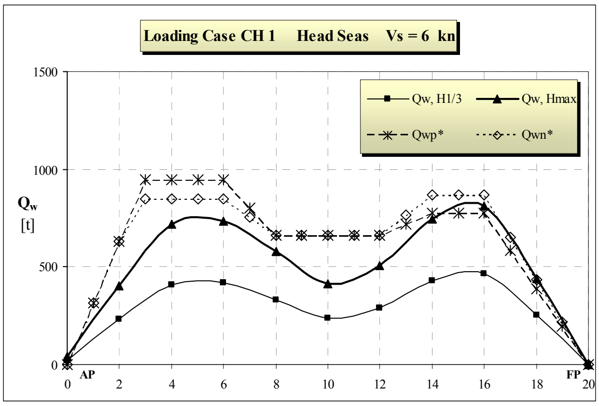
Below, results of the shearing forces calculations are illustrated for the CH1 loading condition. In the figures,

Q_w, $H_{1/3}$ - Vertical shearing force acting in the cross section at passing along of a wave with height equal to $H_{1/3} = 6.0$ m

Q_w, H_{max} - Vertical shearing force acting in the cross section at passing along of a wave with height equal to $H_{max} = 1.75\ H_{1/3}$

Q_{wp}* - Allowable positive shearing force

Q_{wn}* - Allowable negative shearing force



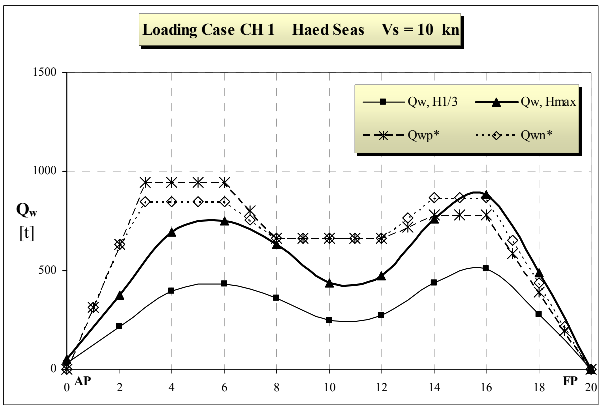


Figure 3. Shearing forces along the ship length as compared to the IACS allowable values.

It is well seen, that in head seas the resulting shear forces at the bow, in vicinity of Hold № 1, exceed the maximum allowable values in case of chancing over a wave larger than the statistically average one. It means that at the time of taking adverse course to waves in heavy storm, the occurrence of structural damage at the bow or dislocation of the hatchcover was highly probable.

5. STRUCTURE STRENGTH ASSESSMENT

The overall strength calculations followed the vessel operational lifetime and structural modifications, as follows:

- The vessel has been built in 1975.
- In 1996, the tweendeck structure has been cut off in all four cargo holds.
- In 2002, ultrasonic thickness measurement has been implemented and significant wear (corrosion) has been observed on structural members and plating. Thickness reduction has been done within GL (IACS) recommended limits.
- The same year, partial repairs have been implemented, replacing sections of main deck and double bottom with plates thinner than the recommended reduction.

Following this succession, four structural conditions have been considered, as follows:

K1 – ship structural state right after delivery;

K2 – ship structural state after tweendeck cut off;

K3 – ship structural state with reduced thicknesses of structural members and plating;

K4 – ship structural state at the time of the last voyage.

The strength estimation for the case K4 in particular shows that the reduction of cross section inertia amounts to 14%, and this of the section modulus – to 19%. At this, the absolute value of the section modulus becomes less than the allowable limit according IACS Unified Requirements [2]. This practically means that the ship does not possess even small reserve of strength to be able to withstand severe wave loads in harsh environment.

The reduction of inertia and section modulus leads also to increasing of deformations from overall bending in waves or during loading-discharge operations and can provoke cracks, plastic deformations or destruction. Increased deflections, together with the direct action of the green water on deck, often is the reason for dislodging of hatchcovers and consequent water penetration, as it had been frequently observed on bulk carriers.

6. ASSESSMENT OF STABILITY IN FOLLOWING SEAS

The assessment of vessel stability when advancing in following seas has been implemented according the recommendations of the Resolution MSC/Circ.707. A diagram of safe operation regimes has been drawn, distinguishing three zones of danger, as follows:

- Zone of significant reduction or loss of stability, when the wave crest passes along the middle;
- Zone of the main roll resonance, when the wave encounter period becomes close to the roll natural period;
- Zone of parametric resonance, when the wave encounter period becomes close to the half of the roll natural period;

The diagrams for the safe operation in following seas for the three loading conditions are shown in Figs. 4 – 6. It can be seen that when sailing with heel and trim and taking into account the newly formed free surfaces in the partially flooded cargo holds, the vessel falls into an unfavorable zone which endangers her operational stability. More specifically, at significant wave heights over 5 m, after the instance of water penetrating the holds and forming free surface the ship becomes unstable.

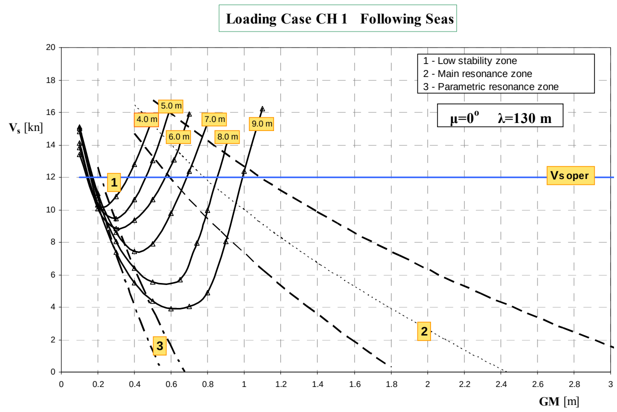


Figure 4. Diagram of endangered stability in following seas for the intact ship.

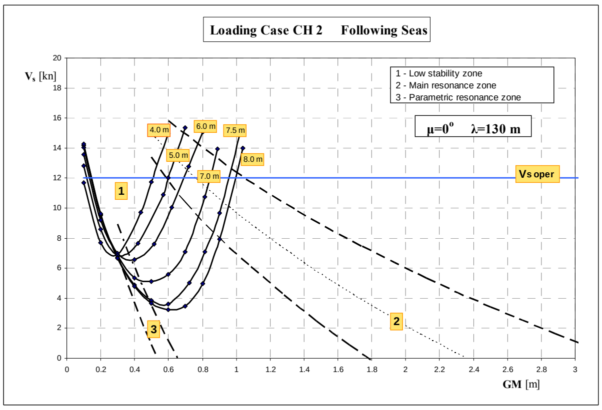


Figure 5. Diagram of endangered stability in following seas for the damaged ship – Hold № 1 flooded, static heel 9°, 1.30 m trim to bow.

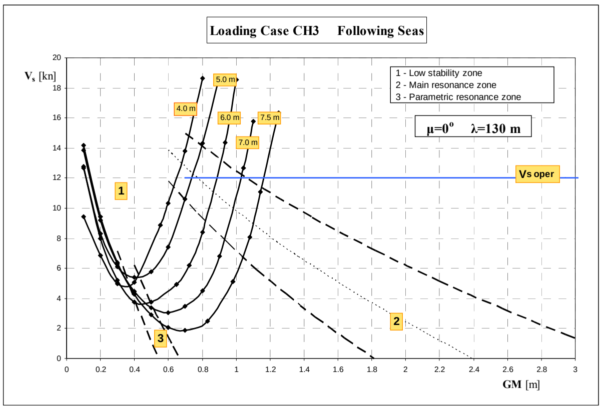


Figure 6. Diagram of endangered stability in following seas for the damaged ship – Hold № 1 and forepeak flooded, static heel 9°, 2.45 m trim to bow.

7. MODEL TESTS ON CAPSIZING IN FOLLOWING SEAS

Conclusions drawn by the numerical assessment have been verified by specially tailored model tests. Various scenarios have been realized and examined.

7.1. Model preparation

The model has been manufactured in 1:38 scale using drawings submitted by the original shipbuilder. The freeboard, superstructure and large deck equipment have been exactly modeled. The model has been intended for free-running tests, with watertight compartments for on-board instrumentation. The cargo holds and the forepeak have been made waterproof by epoxy coating.

The model has been dynamically balanced along the three inertial axes.

7.2. Tests on intact ship

The tests on the intact ship, corresponding to loading condition CH1, have been carried out at various headings and speed of advance, as follows:

- Advancing in head seas at speed 10 and 6 kn
- Change of course at low speed in beam seas
- Advancing in following seas at speed 10 and 6 kn
- Black-out (stop engine) in following seas

In all tested cases, the model kept its good stability. In head seas, however, intensive deck wetness has been observed even at low speeds of advance. It could be a reason for excess loading on hatchcovers and air-vents as well as for jammer’s loosing, the probable cause for water ingress into bow compartments at a later stage of accident progressing.

7.3 Tests on damaged ship

Both loading cases corresponding to the damaged ship conditions CH2 and CH3 have been inspected in following seas (0° and 20°), speeds of advance 10 and 6 kn, black-out condition. Damage has been imitated by various rates of hatchcover № 1 opening.

From the model responses observed it could be concluded that even at considerable heel and trim in extreme seas the ship retains positive stability until the moment of hatchcover loose. The crucial circumstance for the accident happened to be the water ingress in bow compartments, which sharply reduces stability due to the newly formed free surface. In that condition, passing of an extremely high wave forces the ship to ride-on, restoring forces rapidly decrease and the ship capsize.

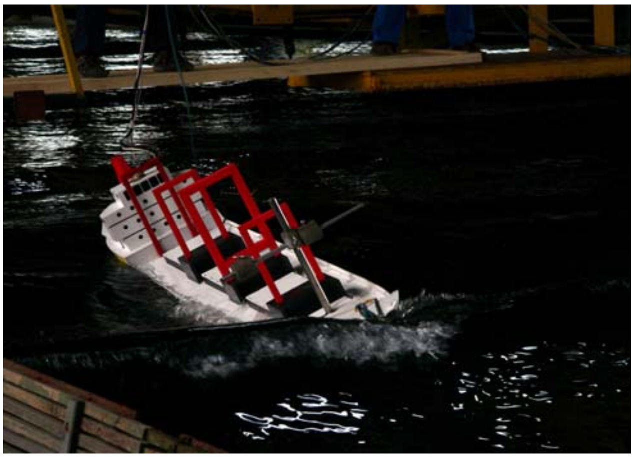


Figure 7a. Final phase of surf-riding – large wave is passing along the ship, water is pouring into an opening in the hold.

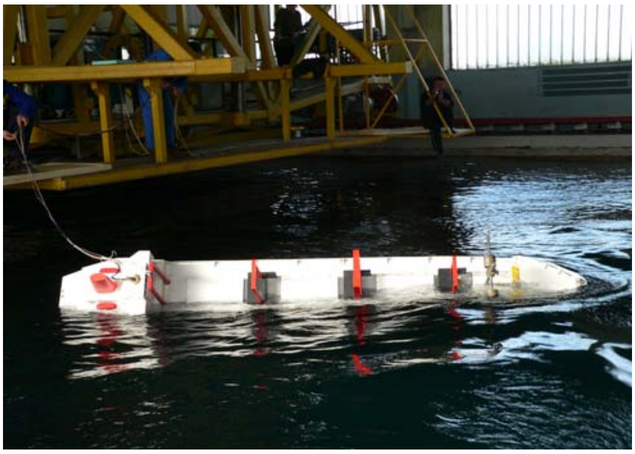


Figure 7b. Ship losses stability.

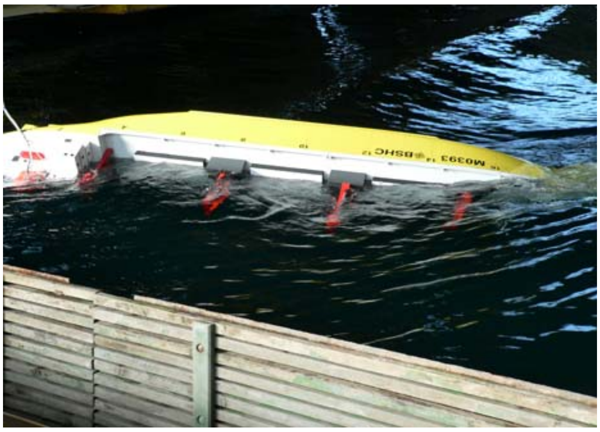


Figure 7c. Ship capsizes.

8. MODEL TESTS ON THE "FALLING LEAF" EFFECT

During initial reconnaissance of the ship wreck by a ROV, the hatchcover of Hold № 1 has been found lying on the ground in vicinity of the main body, while other hatchcovers have been found intact. Having in mind the water depth at the site, it was considered possible to find a relation between the distance to the wreck, the moment of disengagement and the manner of hatchcover falling into water, considering the "falling leaf" effect.

The investigation has been carried out with a flexible hatchcover model, imitating the geometry as well as weight in water. Three possible cases have been tested, as follows:

- Horizontal slip of the hatchcover with the edge leading ahead;
- Horizontal slip of the hatchcover parallel to the board line;
- Vertical entry into water.

The process of hatchcover submergence has been registered on video and excursions from the initial position read every second (model scale). Surprisingly good reproducibility of tests has been observed. Sample results are shown in Fig. 8.

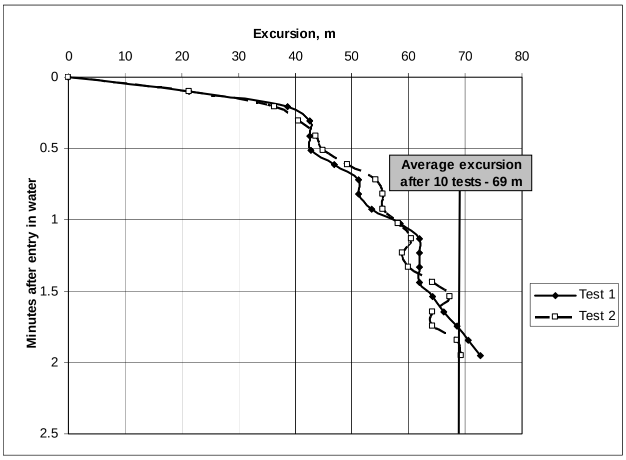


Figure 8. Falling trajectory of the hatchcover of Hold № 1 in case of entering into water with the edge ahead.

Based on the test results it can be stated that the hatchcover's fastening dogs have been loosed in advance, maybe by green water chancing on deck during storm ride, and the shock of collision with the ground at the moment of sinking provoked final disengagement.

9. CONCLUSIONS: MOST PROBABLE SCENARIO OF THE ACCIDENT

From the analysis performed it can be concluded, that the reason for the ship capsizing is the simultaneous occurrence of four unfavorable circumstances, namely:

- Extremely rough storm conditions;

- Closing of the strait and related forced changes in course and speed as well as the lack of asylum haven;
- Water chancing in bow compartments due to dislodging of hatchcover or air-vents and related reduction of initial stability;
- Instant loss of stability due to forced raiding on an extremely large following wave.

Taking into account these circumstances, the most probable scenario of the accident can be narrated as follows:

The initial course of ship is advancing with about 10 kn in following seas from North to South. After receiving the information of strait closing the ship changes course to adverse at low speed. About this time she starts to take water in Hold № 1 and/or the forepeak, due to one of the following reasons:

- Breaking of air-vents by waves overcoming the bow;
- Dislocation of hatchcover of Hold № 1 due to significant bending or torsion of structure under extreme wave action and loosing of fastenings;
- Splitting of a local crack by the above reasons.

(The exact reason of loosing hold watertightness could be specified after detailed diver inspection).

At course change combined with heavy rolling, cargo shifting or sliding over wet coal layer initially formed at the bottom caused static heel. At lack of asylum haven nearby, the ship assumes her initial course in following seas with increased speed up to 10 kn with the intention to reach and pass the Bosforus under emergency conditions. The continuous water ingress, already for certain through the dislodged hatchcover, increases the heel and trim, free surface is formed in both cargo hold and forepeak, the metacentric height reduces sharply. At an instant when an extreme wave of length comparable to the ship's length passes along, the stability arm becomes negative and the ship capsizes. Further, the water penetrates the nearby compartments due to local structural damages, the ship losses floatability and sinks.

10. REFERENCES

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