A STUDY ON FACTORS RELATED TO THE CAPSIZING ACCIDENT OF A FISHING VESSEL "RYUHO MARU No.5"

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Abstract

An offshore trawler "Ryuho Maru No.5" capsized and foundered off Hokkaido, Japan on 11 September 2000. In this paper the factors related to the accident are evaluated.

As the main factors followings are listed;

1. hauling much amount of fish on the upper deck,
2. rough manoeuvring,
3. shift of unlashed items on board, and
4. shift of the cod end with fish over the inner bulwark.

Evaluating the effect of each factor on stability and on heeling moment, the sequence and mechanism of capsizing are clarified from the energy balance like the IMO weather criterion concept.

Moreover the effects of dominant factors are investigated through a parametric study. It is clarified that the heavy cod end on deck and the outward heeling moment due to hard turning are of prime importance because the former not only reduces the stability but also leads to excess heeling moment, and the latter keeps working along the capsizing motion.

1. INTRODUCTION

A typical Japanese offshore trawler "Ryuho Maru No.5" capsized and foundered off the Erimo Cape of Hokkaido on 11 September 2000 in moderate sea condition. The accident claimed 14 lives out of 18 crews onboard. An official inquiry committee was immediately set up in Ministry of Transport. The main tasks of the committee were to investigate the cause of the capsizing and to study measures for preventing similar accidents. In the course of the inquiry the sequence and mechanism of capsizing were clarified and the factors related to the accident were analysed and evaluated. In this paper main points of the investigation are presented.

2. OUTLINE OF THE ACCIDENT

2.1 Offshore Trawler "Ryuho Maru No.5"

"Ryuho Maru No.5" constructed in 1983 was a twin-deck stern trawler of 160 gross tons. The principal particulars of the vessel are given in Table 1 and its general arrangement is shown in Fig. 1. About 60 similar offshore trawlers to "Ryuho Maru No.5" are operating around Japan.

Table 1 Principal Particulars of "Ryuho Maru No.5"

Length (registered)	31.9m
Breadth (moulded)	7.40m
Depth (moulded)	4.65m

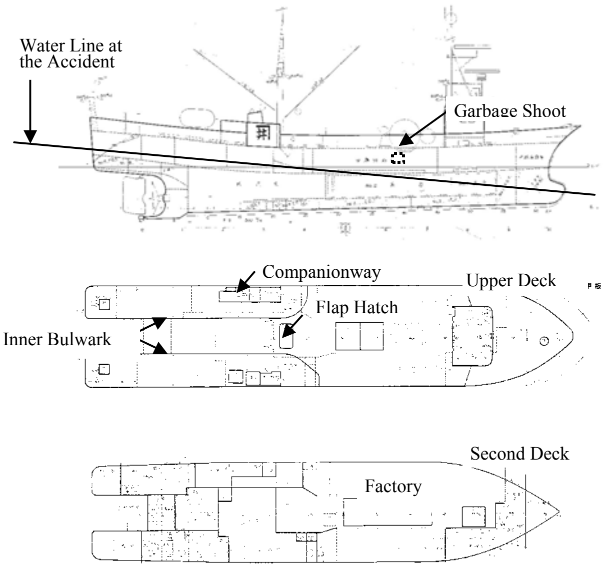
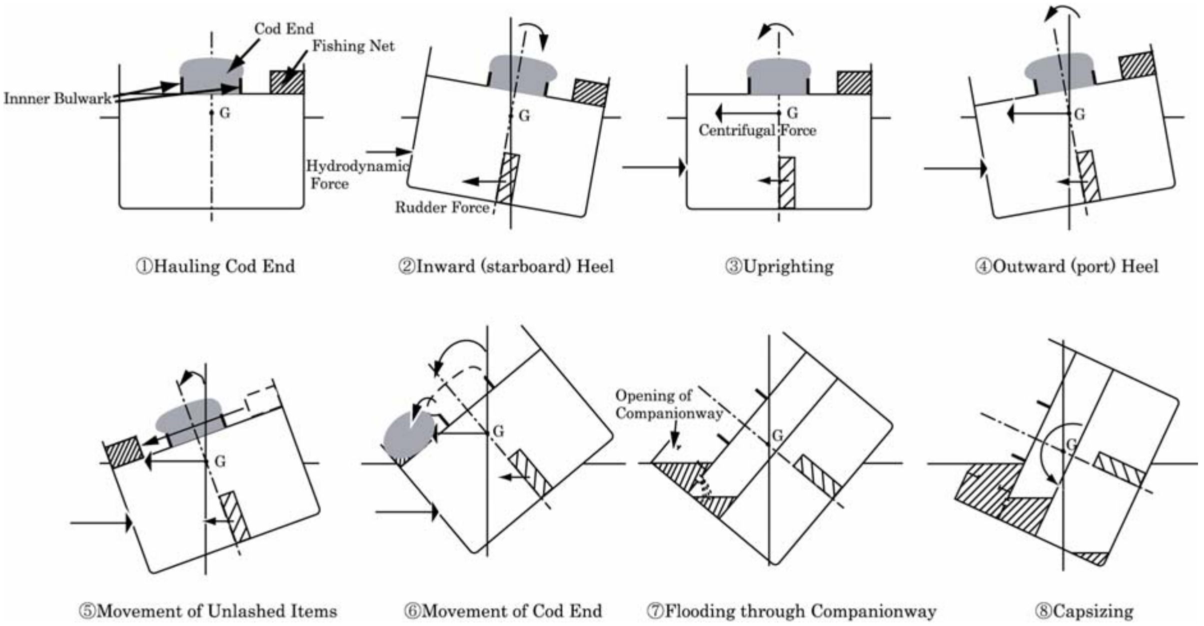


Fig. 1 General Arrangement of "Ryuho Maru No.5"

2.2 Capsizing Sequence

The accident occurred while hauling a fishing net for the first time in that day. The sequence of the events during the accident, which was based on the testimony of survivors, is summarized below (Fig. 2).

1. The fishing net (cod end) with about 50 tons of fish was hauled on to the upper deck. The heavy cod end increased the centre of gravity of the vessel and consequently its stability was reduced.
2. The skipper took hard starboard with full ahead. This caused the inward heeling moment and at first the vessel heeled to the starboard side.
3. As the turning motion developed, the outward heeling moment got larger. This outward moment restored the vessel and heeled it to the opposite (port) side.
4. The vessel heeled further because the outward heeling moment kept working.
5. As the result, unlashed items onboard, e.g. the wing net, moved to the port side. This caused the vessel to further port side heel.
6. Then the cod end moved over the inner bulwark and the resultant heel angle became very large.
7. An opening of the companionway was submerged and water started to enter inside of the hull through it.
8. Due to the accumulation of water the vessel lost its stability and capsized.



①Hauling Cod End ②Inward (starboard) Heel ③Uprighting ④Outward (port) Heel

⑤Movement of Unlashed Items ⑥Movement of Cod End ⑦Flooding through Companionway ⑧Capsizing

Fig. 2 Schematic Diagrams of Capsizing Sequence

3. FACTORS RELATED TO THE ACCIDENT

From the capsizing sequence, it was presumed that the following factors were related to the accident.

1. Hauling much amount of fish on the upper deck.
2. Rough manoeuvring.
3. Shift of unlashed items on board.
4. Shift of the cod end with fish over the inner bulwark.

The effects of these factors were estimated based on the situation clarified through a marine accident inquiry.

3.1 Stability

Table 2 shows the estimated condition of the vessel at the time of the accident, which is based on the data confirmed by the marine accident inquiry. The estimated condition before hauling the net is also given in the table.

Stability calculations were carried out with trim free condition. The free surface effect in fuel oil tanks was taken into account as the shift of the centre of gravity due to the shifting of fuel oil. Fig. 3 shows the stability curve at the time of the accident (the solid line) along with the stability curve before hauling the net (the dotted line). Fig. 3 and Table 2 show that due to “hauling much amount of fish on the upper deck” the centre of gravity of the vessel was raised and the stability was reduced so much at the time of the accident.

Table 2 Condition of “Ryuho Maru No.5” at the Accident

	With Cod End on Deck	W/o Cod End
W (t)	474.62	424.62
mid-G (m)	-3.59	-2.71
KG (m)	3.41	3.09
GM (m)	0.33	0.61
da (m)	4.17	3.70
df (m)	1.15	1.33
dm (m)	2.66	2.52

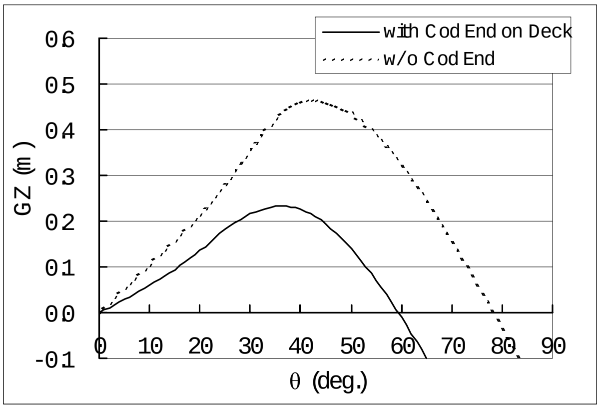


Fig. 3 Stability Curves at the Accident

3.2 Heeling moments

The presumed heeling moments acting on the vessel were related to the factors 2 to 4 mentioned at the beginning of section 3. These heeling moments were estimated as follows.

Inward and outward heeling moments due to manoeuvring

The inward heeling moment, $M1$, which acted on the vessel immediately after the manoeuvring motion began, was estimated with equation (1) [1].

$$M1 = F_N \times \cos\delta \times \left(OP - d_m/2\right) \tag{1}$$

where F_N is the rudder normal force, δ is the rudder angle, OP is the vertical distance of the centre of rudder force from the water surface, and d_m is the mean draft.

The outward heeling moment, $M2$, which became larger as the tuning motion developed, was estimated with equation (2) [1].

$$M2 = m \times V_t^2 / R \times \left(OG + d_m/2\right) \tag{2}$$

where m is the mass of the vessel, V_t is the speed of the vessel in turning motion, R is the radius of turning trajectory, OG is the vertical distance of the centre of gravity from the water surface. The values of V_t and R at the time of the accident were unknown, so the sea trial record was temporarily used.

Heeling moments due to shift of unlashed items

Based on the situation described by survivors, the following items were presumed to move during the capsizing motion (Fig. 4).

1. The reserve net on the starboard side of the upper deck.
2. The wing net on the central part of the upper deck.
3. The fish boxes with ice on the starboard side of the factory in the second deck.

Heeling moments due to these unlashed items were estimated with the weights clarified in the marine accident inquiry and the movable distances presumed based on their locations.

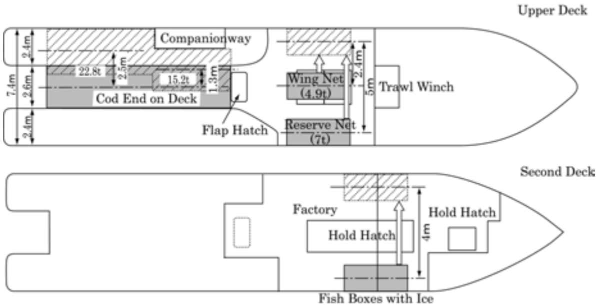


Fig. 4 Movable Items and Cod End on Deck

Heeling moment due to shift of cod end

The cod end containing 50 tons of fish was considered to be hauled on board. And it was presumed that only the part containing 38 tons of fish, which was laid between the inner bulwarks, moved over while the other part on the slipway remained. The movable distance was presumed with the same manner as for the unlashed items.

Table 3 shows the summary of the estimated heeling moments. It should be noted that the estimated heeling moment due to the shift of cod end is quit large in comparison with the other heeling moments.

Table 3 Heeling Moments at the Accident

Factors	Moment (ton-m)
1. Rough Manoeuvring	
Inward Heel	16.8
Outward Heel	35.1
2. Shift of Unlashed Items on Board	
Reserve Net	35.0
Wing Net	11.8
Boxes with Ice	3.6
3. Shift of Cod End	76.8

3.3 Critical heel angle for shift of items onboard

The shift of items onboard occurs when the heel angle exceeds the critical angle. However there was no available data about the critical angle so far. Therefore forced oscillation experiments with a part of actual fishing net and an imitated cod end were carried out. As the result the critical heel angle for the fishing net shift was estimated at 18 degrees. And for the cod end the estimated angle was 20 degrees while the information from a fishery company suggested that it would be about 45 degrees. So the critical angle for the cod-end shift was presumed to be between 20 to 45 degrees.

3.4 Investigation based on the energy balance

Outline of the energy balance calculation

In order to verify that the presumed heeling moments could cause the vessel with the estimated stability to capsize, investigation based on the capsizing sequence were carried out. As the testified time to capsize was as short as about 10 seconds, the dynamical effect should be taken into account. Therefore, based on the IMO weather criterion concept, the rolling energy toward the capsizing direction was evaluated and compared to the dynamical stability.

In the calculation the following items were treated as parameter and set at 2 different values within realistic range because it was difficult to specify the definite values at the time of the accident.

1. The initial heeling angle due to the asymmetric shape of the cod end (θ_i).
2. The speed of the vessel in turning motion (V_t).
3. The critical heel angle for the cod-end shift (θ_c).

Moreover in the calculation only the shifts of the wing net and the cod end were considered because one of the persons concerned in the accident testified that the reserve net and the boxes in the factory might be lashed.

Example of calculation

Fig. 5 shows an example of calculation. In this case the initial heeling angle (θ_i) is set at 2 degrees, the vessel speed (V_t) is set at 7.68kt, which leads to 35.1 ton-m of outward heeling moment, and the critical heeling angle for the cod end shift (θ_c) is set at 25 degrees.

The upper figure of Fig. 5 shows the stability curve (GZ1; the solid line) and the heeling moment due to the shift of the wing net and the cod end (Dn; the dotted line). The difference between GZ1 and Dn, the residual stability curve after the wing net and the cod end moves (GZ2), is shown as the folded line in the lower figure. The outward heeling moment by turning motion (Dc) is also indicated with the doted line in the same figure. From this figure it is noticed that in this case the maximum residual stability is greater than the outward heeling moment. This means that the static comparison between the heeling moments and the stability cannot explain the capsizing mechanism.

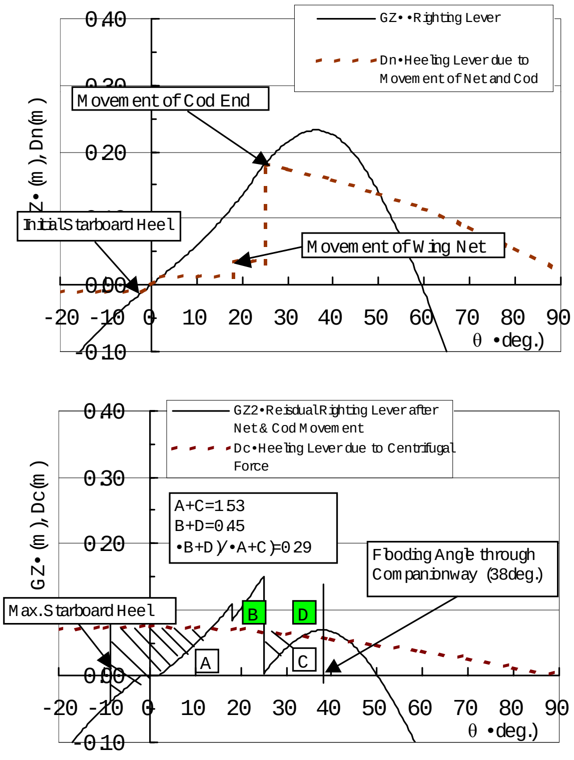


Fig. 5 Comparison between Dynamical Stability and Heeling Energy (θ_i = 2 deg., V_t = 7.68 kt, θ_c = 25 deg.)

From dynamical point of view, the rolling energy and dynamical stability were evaluated from the maximum starboard heel angle to the flooding angle through the companionway at the port side. In this case the maximum starboard heel angle is 8 degrees (2 degrees of the initial heeling angle and 6 degrees of the inward heel) while the flooding angle is 38 degrees.

In the lower figure of Fig. 5 the shaded areas A and C indicate the rolling energy toward the capsizing direction while areas B and D indicate the residual dynamical stability. So if the ratio of the residual dynamical stability to the rolling energy, (area B+D)/(area A+C), is less than 1, the vessel capsizes in such condition. In this case the ratio is 0.29, so the vessel is considered to capsize.

Calculation results

Table 4 Calculation Results

Case	θ_i (deg.)	V_t (kt)	θ_c (deg.)	Result
1	4	7.68	25	×•0.18•
2	4	7.68	35	×•0.90•
3	4	6.14	25	×•0.80•
4	4	6.14	35	○•2.02•
5	2	7.68	25	×•0.29•
6	2	7.68	35	○•1.26•
7	2	6.14	25	○•1.08•
8	2	6.14	35	○•2.95•

Note1 ○: Not capsizing, ×: Capsizing
Note2 ( ):Ratio of dynamical stability to heeling energy

As mentioned above, the calculation was carried out for the conditions where the initial heeling angle (θ_i), the speed of the vessel in turning motion (V_t), and the critical heel angle for the cod-end shift (θ_c) were set at 2 different values respectively. So the ratios of the residual dynamical stability to the rolling energy for 8 cases were evaluated. The results are shown in Table 4. Among 8 cases the vessel is judged to capsize in 4 cases. From these results, it is considered that the presumed factors could cause the vessel to capsize in the situation described by survivors, in other words these factors represent the essential part of the capsizing mechanism.

4. DISCUSSION ON FACTORS RELATED TO THE ACCIDENT

As mentioned in section 3 the investigation based on the energy balance in the capsizing sequence clarified that the combination of 4 factors, namely,

1. hauling much amount of fish on the upper deck,
2. rough manoeuvring,
3. shift of unlashed items on board, and
4. shift of the cod end with fish over the inner bulwark,

could cause the vessel to capsize. As the next step, to establish effective preventive measures for similar accident, the relation of each factor to capsize was analysed and their effects on capsizing were evaluated through a parametric study. In this paper the discussions on "hauling much amount of fish on the upper deck" and outward heel due to "rough manoeuvring" are presented.

4.1 "Hauling much amount of fish on the upper deck"

Hauling much amount of fish onboard raises the centre of gravity of the vessel and reduces the stability. And it leads to reduced freeboard and large trim by stern, therefore the flooding angle through an opening situated on the aft part of hull is also reduced.

Fig. 6 shows the stability curves of the capsized vessel with various weight of cod end on the upper deck. Table 5 shows the metacentric height (GM), the flooding angle through the companionway (θ_v), and the dynamical stability up to the flooding angle (Dst) in each condition. From Table 5 it is found that with increasing the cod end weight, these quantities are reduced so much. Especially it should be noted that the reduction rate of the dynamical stability is lager than that of the initial stability GM. The investigation [2] so far suggested that for the Japanese offshore trawlers similar to "Ryuho Maru No.5", the standard maximum weight of the cod end, which could be hauled on the upper deck safely, would be 30 tons. However even with the 30 tons of cod end, the dynamical stability is reduced by about 40% of that with no cod end onboard.

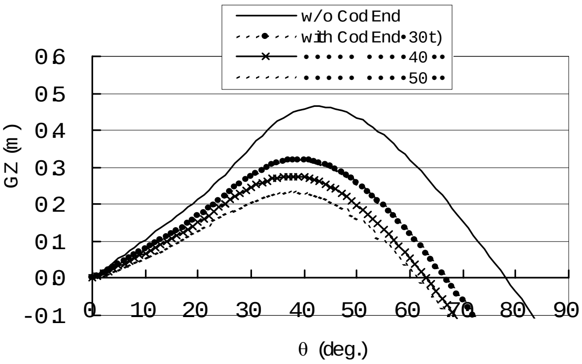


Fig. 6 Stability Curves at Various Loading Conditions

Table 5 Metacentric Height (GM), Dynamical Stability up to Flooding Angle (Dst), and Flooding Angle through Companionway(θ_v) at Various Loading Conditions

Loading Condition	GM (m)	Dst (m•rad)	θ_v (deg.)
W/o Cod End	0.613 (1.00)	0.211 (1.00)	46 (1.00)
With Cod End (30t)	0.435 (0.71)	0.128 (0.61)	41 (0.89)
With Cod End (40t)	0.384 (0.63)	0.104 (0.49)	39 (0.85)
With Cod End (50t)	0.327 (0.53)	0.087 (0.41)	38 (0.83)

Note ( ):Ratio to w/o cod end condition

Moreover, as indicated in Table 3, the heavy cod end on deck causes excess heeling moment if it moves over the inner bulwark. And the raised centre of gravity causes the lever for outward heeling moment to increase.

From above analysis it could be concluded that hauling much amount of fish on the upper deck increases the capsizing risk so much in both stability and heeling moment aspects. Therefore in order to prevent similar accidents it is essential that in case of a big catch, a cod end should not be hauled up at once.

4.2 Outward heel due to “rough manoeuvring”

As shown in Table 3, the estimated outward heeling moment caused by taking hard starboard with full ahead is 35.1 ton-m, and it is less than half of the heeling moment due to the cod end shift. However the outward heeling moment was supposed to keep working from the early stage of the accident until capsizing. Therefore it is considered that the outward heeling moment also gave large effect on the accident.

Fig. 7 shows the stability curve of the vessel at the time of the accident and the outward heeling moment caused with the vessel speed of 7.68kt. In this case the original dynamical stability is indicated by area OABCD. If the outward heeling moment keeps working from the upright condition, the dynamical stability is reduced to the one indicated by shaded area ABC. The reduction of the dynamical stability is indicated by area OACD, which corresponds to about 42% of the original stability. Moreover under action of the outward heeling moment, the energy indicated by area OEA is added to the rolling energy. Therefore the effect of the outward heeling moment on capsizing becomes even larger.

In Fig. 7 the outward heeling moment caused with the vessel speed of 6.14kt, 80% of 7.78kt, is also indicated. The outward heeling moment is proportional to the square of the vessel speed, so in this case the outward heeling moment is reduce by 36% of the one with the speed of 7.78kt. And the resultant reduction of dynamical stability gets small and becomes about 30% of the original one.
From the above analysis it could be concluded that as the outward heeling moment keeps working along capsizing motion, it gives large effect on similar type of capsizing to the “Ryuho Maru No.5” case. Therefore taking a slow turn is important to prevent similar accident.

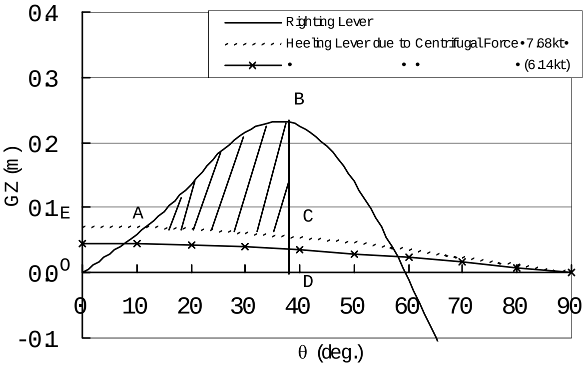


Fig. 7 Residual Dynamical Stability Under Action of the Outward Heeling Moment

5. CONCLUSIONS

Outline of the investigation into the capsizing accident of offshore trawler “Ryuho Maru No.5” is presented. In the investigation the sequence and mechanism of capsizing were clarified and the factors related to the accident were analysed and evaluated.

Main conclusions in the investigation are summarised as follows.

1. The accident is considered to be caused by the combination of 4 factors, namely,
(1) hauling much amount of fish on the upper deck,
(2) rough manoeuvring,
(3) shift of unlashed items on board, and
(4) shift of the cod end with fish over the inner bulwark.

2. The analysis shows that hauling much amount of fish on the upper deck causes not only considerable reduction of the stability, but also the excess heeling moment if it moves, and moreover it increases the outward heeling moment lever. Therefore it is essential for prevention of similar accidents that in case of a big catch, the cod end should not be hauled up at once.

3. The outward heeling moment by tuning of the vessel is smaller than the heeling moment due to shift of the cod end, but it keeps working along the capsizing motion. So its effect becomes very large. Therefore taking turn with slow speed is important as a preventing measure for similar accident.

Based on these results Ministry of Transport made an official notice about preventing measures for similar accident and have notified it to the organizations concerned.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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