# Experimental Investigations into Accidents of Two Japanese Fishing Vessels

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**ABSTRACT**

This paper outlines the experimental investigations into serious accidents of a purse seiner, which capsized and foundered during lying to with a sea anchor in the North Pacific Ocean on 23 June 2008, and a stern trawler of pair trawling, which foundered on the way to a fishing ground in the East China Sea on 12 January 2010. In order to clarify the sequence and mechanism of each accident, model experiments in waves were carried out individually and further consideration with stability calculation so on were made.

**KEYWORDS**

Accident investigation; purse seiner; capsizing; shipping water; stern trawler; foundering; free water

## INTRODUCTION

In one and half years from June 2008, three serious accidents of relatively large fishing vessels, which related to their stabilities, successively happened in Japan and total 39 lives of crews on board were lost. The Japan Transport Safety Board (JTSB) had investigated these accidents and identified the probable causes of each accident. The results of the investigations were compiled into investigation reports and submitted to the Minister of Land, Infrastructure, Transport and Tourism and publicized.

For two of these three accidents, namely "Purse seiner Suwa-maru No.58 accident"(JTSB (2011a)) and "Stern trawler Yamada-maru No.2 accident"(JTSB (2011b)), as parts of the investigations model experiments along with stability calculation were carried out in NMRI and NRIFE respectively. Based on the experimental results and so on the JTSB concluded the probable causes of the accidents and issued remarks to parties relevant to the causes in order to prevent similar accidents.

In this paper the main points of experimental investigations are presented.

## 135GT PURSE SEINER ACCIDENT

### *Outline of the Accident*

A 135GT purse seiner "Suwa-maru No.58" (L=48.28m, B=8.10m and D=3.35m) capsized and foundered during lying to with a sea anchor in the North Pacific Ocean on 23 June 2008. The accident claimed 17 lives out of 20 crews on board. According to survivors, who stayed in the crew space inside the hull at the initial stage of the accident, the vessel had impact twice on the starboard bow section and it started to heel to starboard side then capsized in about one minute after the second impact.

The supposed wind and sea conditions at the time of the accident are summarised in Table 1. Furthermore the impacts on the bow section were presumed to be caused by isolated big waves, which might hit the side of the vessel.

Table 2 summarises the estimated conditions of the vessel at the accident. In this condition the vessels complied with the requirements of the Japanese stability criteria for fishing vessels. In addition the vessels is presumed to be inclined to starboard side due to unintentional unbalanced loading of the fishing net and the fishing gears before the accident.

Table 1: Wind and Sea Conditions at the Accident.

| | |
|---|---|
| Average wind speed | 14 m/s ~ 16 m/s |
| Wind direction | SW ~ S |
| Significant wave height | 2.5 m ~ 3.6 m |
| Average wave period | 6.8 s ~ 8.4 s |
| Wave direction | SW ~ S |

Table 2: Hull Conditions at the Accident.

| | |
|---|---|
| Displacement: W | 430.70 t |
| Mean draft: dm | 2.68 m |
| Freeboard: Fb | 0.68 m |
| Height of C.G.: KG | 3.16 m |
| Metacentric height: GM | 1.81 m |

### *Model Experiment*

As all survivors stayed in the crew space inside the hull at the initial stage of the accident, the sequence and mechanism of the accident were not clear. In order to ascertain the capsizing process and factors related to the accident, a model experiment aiming to reproduce the situation at the accident was carried out in a wave tank (50 m in length, 8 m in width and 4.5 m in depth) at NMRI.

In the experiment a 1/23.9 scaled model ship was moored to the carriage with weak springs to simulate the situation of lying to with a sea anchor and keep intended encounter angle in waves and ship motions were measured in starboard bow to beam waves (Fig. 1). In the experiment wave conditions (properties and encounter angle) and ship conditions (position of centre of gravity and function of freeing ports) were varied and their effects on capsizing were investigated.

Fig. 1: Model Ship in Waves.

Waves used in the experiment were regular waves with superimposition of a concentrating wave intending to simulate the isolated big waves, which were presumed to be a cause of the impact at bow section at the accident. The height and period of regular waves were varied with referring to the supposed sea condition at the accident (Table 2). And the height of concentrating wave was set 1.6 times of superimposed regular wave. Encounter angle were varied from 165 degrees (starboard bow wave) to 90 degrees (starboard beam wave).

With following possible situations at the accident considered, ship conditions were also varied in the experiment and the measured conditions were set in appropriate combination of parameters listed in Table 3.

(1) Actual height of the loaded fishing net and fishing gear, ropes and other items loaded on the canopy of wheelhouse might increase the height of the centre of gravity than that in Table 2 which is estimated without above things considered.

(2) Unintentional loading the fishing net and the fishing gears in unbalanced condition might lead lateral deviation of the centre of gravity and the vessel might exhibit steady heel or be in initial heel condition before the accident.

(3) Inherent structure of the freeing ports and fittings around them might disturb shipped water drainage and reduce their function.

Table 3: Ship Conditions in the Experiment.

| | |
|---|---|
| Height of C.G. | KGo, 1.05KGo or 1.10KGo; KGo means the estimated value at the accident shown in Table.2. |
| Lateral deviation of C.G. | 0 m (on C.L.) or 1 m to starboard side in ship scale; 1 m deviation leads 3 degrees heel of the vessel. |
| Function of freeing ports | Opened or Closed |

***Experimental Results***

In the experiment capsizing occurred in 30 cases out of all 133 measured cases. Table 4 summaries the experimental results.

Table 4: Occurrence of Capsizing in the Experiment.

| (a) Height of C.G. KG = KGo | | Function of freeing ports | |
|---|---|---|---|
| | | Opened | Closed |
| Lateral deviation of C.G. | 0 m; w/o initial heel | | No |
| | 1 m; with initial heel | | No |
| (b) Height of C.G. KG = 1.05KGo | | Function of freeing ports | |
| | | Opened | Closed |
| Lateral deviation of C.G. | 0 m; w/o initial heel | No | Yes |
| | 1 m; with initial heel | Yes | Yes |
| (c) Height of C.G. KG = 1.10KGo | | Function of freeing ports | |
| | | Opened | Closed |
| Lateral deviation of C.G. | 0 m; w/o initial heel | No | Yes |
| | 1 m; with initial heel) | Yes | Yes |

As shown in Table 4, capsizing occurred under the conditions with the increased height of C.G. (KG = 1.05KGo or 1.10KGo) and initial heel and/or closed freeing ports. No capsizing occurred in the originally estimated C.G. (KG=KGo) even with initial heel and closed freeing ports. And even in the increased height of C.G., hull conditions with no initial heel and opened freeing ports did not lead the model ship to capsize. In the experiment it was confirmed that as the height of C.G. is increased, the range of encounter angle leading to capsizing is extend, but capsizing with the encounter angle of 150 degrees occurred only in the highest C.G. condition(KG = 1.10KGo).

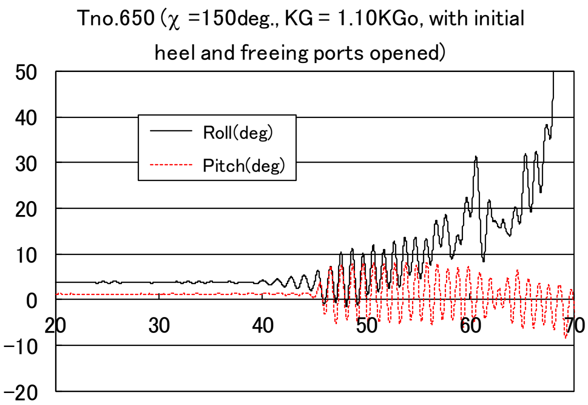


Fig. 2: Measured roll angle and pitch angle in regular wave of □ = 1.6m and Hw = 0.13m with a superimposed concentrating wave. □ = 150 deg., KG = 1.10KGo and with initial heel and all freeing ports opened.

Fig. 2 shows typical time histories of roll angle and pitch angle in capsized case. From the measured ship motion and the observation during the experiment the capsizing sequence in bow waves could be summarised as follows (refer to Fig. 2). At first shipping water around midship part occurs and water floods the fore deck. This increases the bow trim and the starboard heel and the resultant freeboard around the starboard bow section decreases. This change in the mean position of the ship stimulates further shipping water. At last successive shipping water occurs and the increased flooded water reduces the stability of the ship, then the wave action turns over the ship. In short, the mechanism of the capsizing in bow waves is that the increased flooded water on the fore deck reduces the freeboard of bow part and the reduced freeboard accelerates shipping water then with the increased flooded water stability of the ship reduces drastically and capsizing occurs.

***Consideration on Factors Related to the Accident***

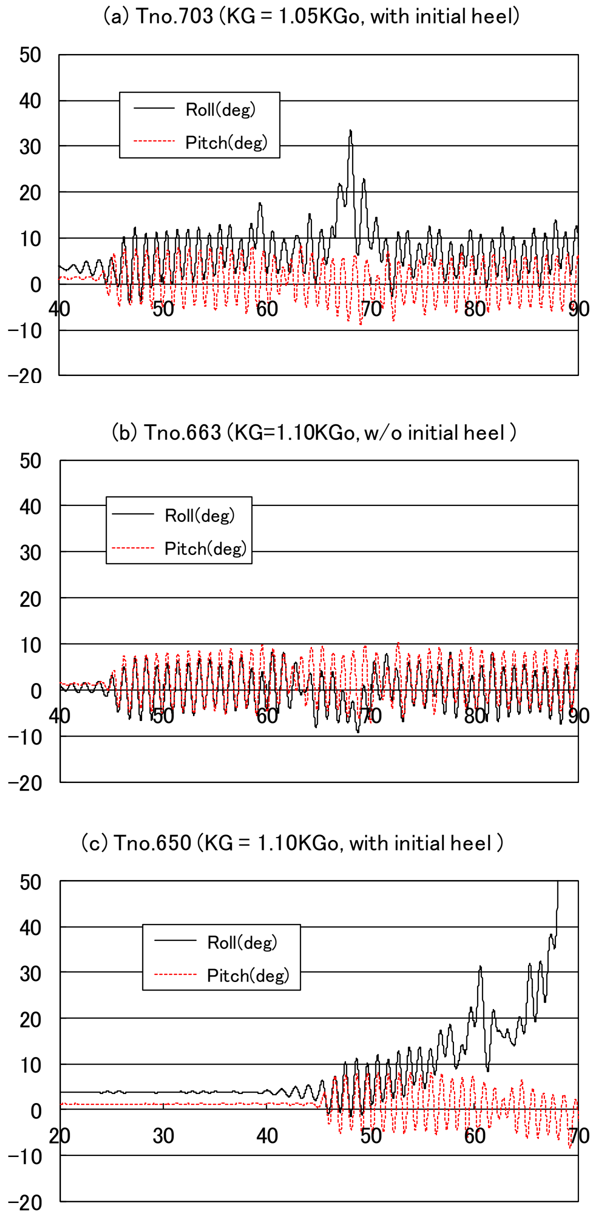


Fig. 3: Effects of height and lateral deviation of C.G. on measured roll angle and pitch angle in regular wave of □ = 1.6m and Hw = 0.13m with a superimposed concentrating wave. □ = 150 deg. and with all freeing ports opened.

Based on the conditions leading to capsizing and the capsizing sequence in bow waves, which have been clarified in the experiment, it is presumed that following factors, increased height and lateral deviation of C.G., poor function of freeing ports and improper encounter angle to waves played key roll to the capsizing of the purse seiner.

On the other hand the experimental result shows that no capsizing occurred with the encounter angle of 165 degrees and even in the highest C.G. condition capsizing did not occur with no lateral deviation of C.G. and all freeing ports opened (Table 4 and Fig. 3).

These experimental results imply that careful operation and sufficient maintenance of vessels with the above things into consideration might prevent similar accident.

***Conclusions for Experimental Investigation into the Purse Seiner Accident***

With the model experiment the situation, which could lead a vessel during lying to in bow waves to capsizing was confirmed, and the key factors related to the purse seiner accident, namely increased height and lateral deviation of C.G., poor function of freeing ports and improper encounter angle to waves, were clarified. Moreover it is pointed out that experimental results imply that as safety measure careful operation, e.g. restraining increase in the height of C.G., is important to prevent similar accident.

## 113GT STERN TRAWLER ACCIDENT

***Outline of the Accidents***

A 113GT stern trawler "Yamada-maru No.2" of pair trawling foundered on the way to a fishing ground in the East China Sea on 12 January 2010. All 10 crews died at the accident.

The stern trawler was sailing with heading angle of 310 degrees. At that time, the wind speed was 13.0 m/sec, the mean wave height was 1.94 m and the mean wave period was 6.0 sec. The wave and wind direction was 338 degrees. The captain called to the captain of the consort trawler that “we cannot recover from heeling with water on deck!” And a few minutes later, she was lost from the radar of the consort trawler. The foundered trawler was salvaged to investigate conditions and damages. There was no serious damage of hull and some water tight doors were opened.

For the investigation of the accident, firstly we did free running model experiments in head seas. Secondly, we calculated for stability with flooded water in the engine room.

### *Free Running Model Experiments*

The subject ship model used in this research is the 1/16 scaled. The principal particulars are shown in Table 5. According to the investigation of salvaged trawler, two watertight doors were opened. Opened doors are shown in Fig. 4. For recording shipping water and flowing point, the model ship was installed with 5 video cameras and 360 degrees video camera. The positions of cameras are shown in Fig. 5. The 360 degrees camera recorded situation in the working room as shown in Fig. 6.

Table 5: Principal particulars of the stern trawler

| | Ship | Model |
|---|---|---|
| Length between perpendiculars: $L_{pp}$ | 26.50m | 1.656m |
| Breadth : $B$ | 6.85m | 0.428m |
| Depth : $D$ | 3.10m | 0.194m |
| Displacement : W | 350.17t | 0.0835t |
| KG | 2.61m | 0.056m |
| Scale | | 1/16 |

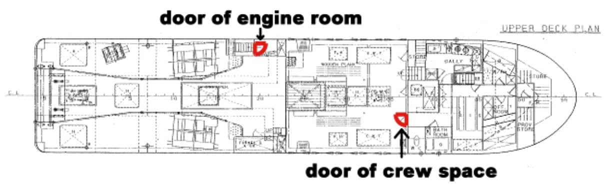


Fig. 4: Opened watertight doors.

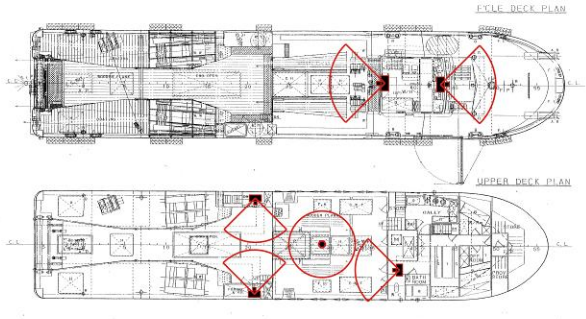


Fig. 5: Positions of video cameras.

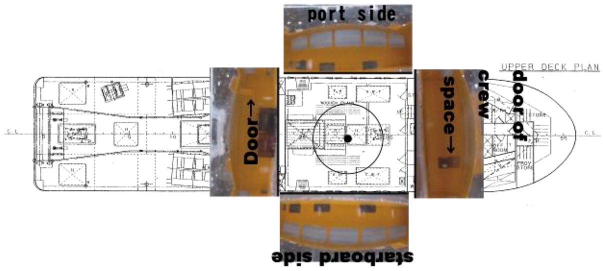


Fig. 6: The recording area by 360 degrees camera

In this accident, the ship speed was 9 knots and the encounter angle between wave and ship was 5 degrees or 28 degrees in head seas to starboard. So, experimental conditions were set as shown in Table 6.

Table 6: Conditions of experiments

| | Conditions |
|---|---|
| Heading angle | 5 degrees, 28 degrees, 45degrees, 60 degrees |
| Ship speed | 9 knots |
| Wave period | 4.5 sec, 5.0 sec, 5.5 sec, 6.0 sec |
| Wave heights | 1.94 m, 2.91 m, 3.88 m, 4.85 m, 5.82 m |

The results of shipping and flooded water are shown in Tables 7 and 8. In these tables, the results are shown with following abbreviations, "No": no shipping water occurred, "Yes": shipping water occurred, "FW": flooded water on deck occurred, and "HFW": huge flooded water on deck occurred. Shipping water occurred in the waves of more than 2.91 m height. And flooded water on deck occurred in waves of more than 3.88 m height.

Table 7: Results of experiments (heading angle: 5 degrees)

| | | Wave period | | | |
|---|---|---|---|---|---|
| | | 4.5 s | 5.0 s | 5.5 s | 6.0 s |
| Wave height | 5.82 m | | | | HFW |
| | 4.85 m | | HFW | FW | FW |
| | 3.88 m | Yes | FW | FW | Yes |
| | 2.91 m | No | Yes | Yes | No |
| | 1.94 m | No | No | No | No |

Table 8: Results of experiments (heading angle: 28 degrees)

| | | Wave period | | | |
|---|---|---|---|---|---|
| | | 4.5s | 5.0s | 5.5s | 6.0s |
| Wave height | 5.82 m | | | | HFW |
| | 4.85 m | | HFW | FW | FW |
| | 3.88 m | Yes | FW | FW | No |
| | 2.91 m | Yes | Yes | No | No |
| | 1.94 m | No | No | No | No |

Fig. 7: Flooding water in the working room (red circle) observed with wave period = 6 sec, wave height = 5.88m, $\chi$ = 28 degrees. (interval = 0.8sec; time goes on from top to bottom)

An example of flooded water in the working room at "huge flooded water on deck" case is shown in Fig. 7 and the time series of ship motion and rudder angle in the same condition are shown in Fig. 8. The average heel angle of water on deck was -7 degrees in this case. But Fig. 8 shows that the flooded water in the working room had never reached to the door of crew space.

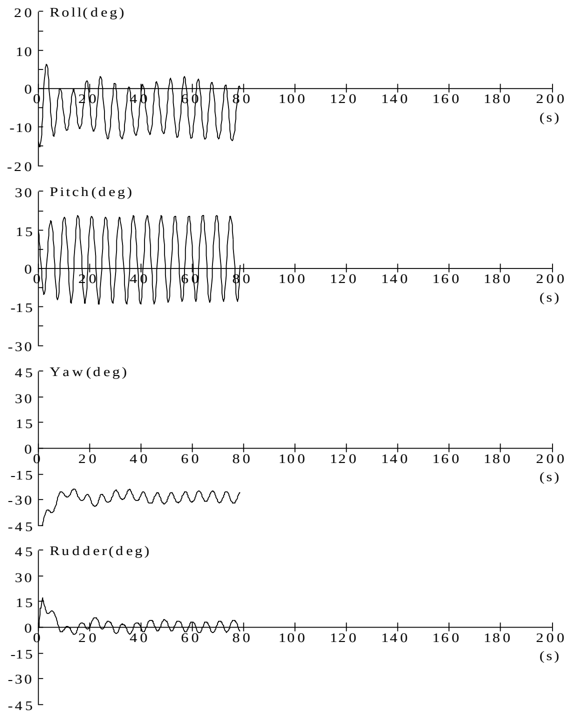


Fig. 8: Time series. (wave period = 6 sec, wave height = 5.88m, $\chi$ = 28 degrees)

Fig. 9: Shipping water on upper deck

Fig. 9 shows the shipping water on upper deck. It shows that the shipping water from bow went straight to the opening entrance of engine room.

***Flooded Water***

According to the experiments, shipping water continues to flow into the entrance of engine room for 1 sec per one time in model scale.

Flowing water volume $Q_1$ can be calculated using equation (1) (Katayama et al. (2005)).

$$Q_1 = C_1 \frac{2}{3} \sqrt{2gb} (h^{\frac{3}{2}} - h'^{\frac{3}{2}}) \quad (1)$$

Here $C_1$: flow coefficient, $g$: gravitational acceleration, $b$: width of opening, $h$: depth of bottom of opening, $h'$: depth of top of opening. Flooding water to the engine room was estimated about 2.56 t to 7.24 t one time.

### *Model Experiments with Flooding Water*

Fig. 10: Model with hanging weight

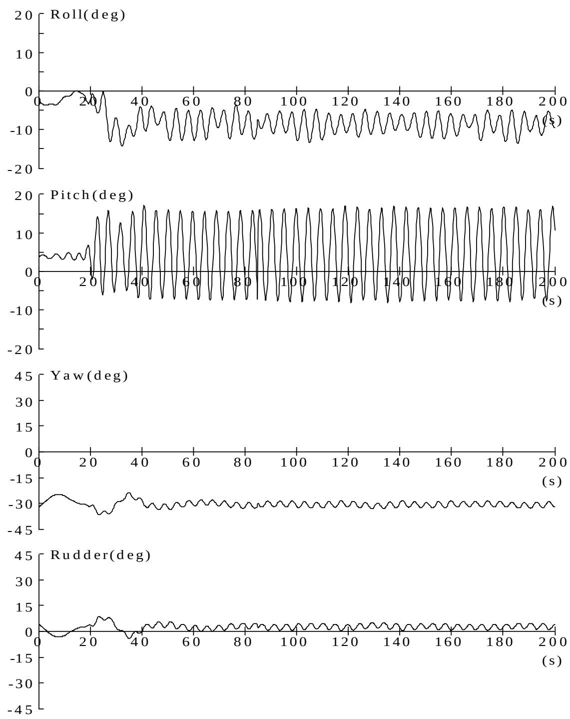


Fig. 11: Time series. (wave period = 5.5 sec, wave height = 1.94 m, $\chi$ = 28 degrees)

Free running model experiments were implemented with hanging weight for simulating of flooded water. The model is shown in Fig. 10.

Time series with 12 t of flooded water is shown in Fig. 11. 1.94 m wave height is enough to make initial roll angle to the situation of water on deck.

### *Stability Calculations*

Stability curve with flooding water in engine room is shown in Figures 12 and 13. It shows that maximum GZ is reduced by 30% with 12 t of flooded water and by 50% with 16 t of flooded water. And, there is no stability left with 70 t of flooded water.

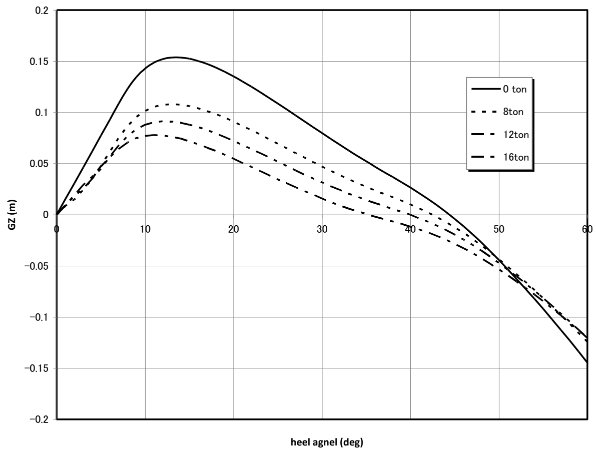


Fig. 12: GZ curve with flooded water.

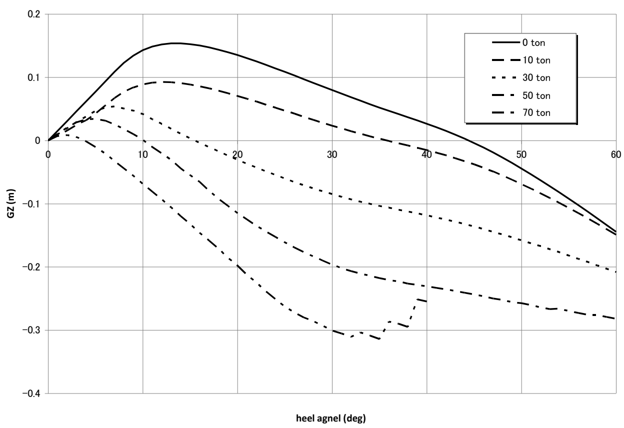


Fig. 13: GZ curve with flooded water.

Stability calculations show that more than 70 t of flooded water in the engine room makes total loss of stability. Based on the estimated flowing rate of water into the engine room, 2 minutes is enough time for flowing water of 70 t into the engine room. Reserve buoyancy of this trawler is about 202.7t. Less than 5 minutes is enough to sink it.

***Conclusions for Experimental Investigation along with Stability Calculation into the Stern Trawler Accident***

The accident causation of stern trawler is inferred from this research.

1) The stern trawler met more than 2 times higher wave of average.
2) Shipping water flowed into the engine room from the opened watertight door.
3) Maximum of GZ was decreased by flooded water.
4) With the reduced stability the opening of engine room was easy to under the water level.
5) In less than 5 minutes, the trawler sank.

## CONCLUSIONS

Model experiments and stability calculation were carried out as parts of the investigations into two serious accidents of Japanese fishing vessels. As a result sequences and mechanisms of the accidents were inferred and supposed factors related to the accidents were also clarified.

Based on the results of these experimental investigations so on, the JTSB has concluded the probable causes of the accidents and issued remarks on safety measures to parties relevant to the causes in order to prevent similar accidents (JTSB (2011a, 2011b)). Main points of remarks are as follows and some details are also available in "Japan Transport Safety Board Annual Report 2012"(JTSB (2012)).

For "Purse seiner Suwa-maru No.58 accident", the remarks require that during lying to with a sea anchor a seaman, such as the master, with plenty of navigation knowledge and experience, should stand on bridge to look out situation around and keep the main engine in its stand-by state so that prompt attitude adjustment is possible so as to prevent water from flooding in. And for "Stern trawler Yamada-maru No.2 accident", the remarks require that during navigation, exit doors etc. on the deck should always be closed and whenever they are opened for access, they should be closed promptly.

## ACKNOWLEDMENTS

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